TECHNICAL SESSION PROCEEDINGS

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Subsurface Drip Irrigation and Plastic Mulch Effects on Yield and Brix Levels of Kabocha Squash,

Cucurbita moschata

Mahbub Alam[1] and Rick Zimmerman[2]

ABSTRACT:

Kabocha squash, *Cucurbita moschata,* is an important cash crop for western Colorado. A combination of different colored plastic mulches with subsurface drip irrigation (SDI) was compared to non-mulched furrow irrigated Kabocha squash. An average of 18 inches of water was applied through SDI, which was one-fourth the amount applied by furrow irrigation. Subsurface drip in combination with plastic mulch produced consistently higher total yield averaging 26,940 lbs. per acre compared to furrow irrigated squash without mulch, which produced 6,080 lbs. per acre. Transplanted squash produced higher yields compared to direct seeded plots, which produced average 21,127 lbs. per acre. Average marketable yield from two years of data was 19,761 lbs. per acre for SDI with mulch treatments for transplanted squash. Furrow irrigated transplanted squash with no mulch averaged at 5,018 lbs. per acre. Soluble solids (measured as Brix) ranged from 11.29 to 15.2 and were consistently higher for subsurface drip irrigated squash compared to furrow irrigated squash.

INTRODUCTION:

Virtually all of the Kabocha squash produced in Western Colorado is exported to Japan. Rich in beta-carotene, it is prized for its delicious smooth textured flesh. This winter squash has a beautiful jade green rind with celadon green streaks (Fig.2). Its pale orange flesh is tender smooth and sweet when cooked. Colorado Kabocha producers receive a premium price for squash due to its high quality. However, to remain competitive, growers need to utilize methods, which can increase production, while maintaining quality and economic viability.

The use of plastic mulch and subsurface drip irrigation has been recognized as two methods that might increase squash yields and maintain and/or increase quality. Feibert et al (1992) observed improvement in quality from use of plastic mulch in eastern Oregon. At the Rocky Ford Research Station in Southeastern Colorado, Bartolo (1996) found a significant increase in yield of cantaloupes when grown with plastic mulch and subsurface drip irrigation. There are several colored plastic mulches available for horticultural crop production. The effect of plastic mulch color on yield of squash has not been reported. A combination of subsurface drip irrigation and plastic mulch can lead to a significant water savings.

Fiebert et al (1992) reported a 50% water savings from use of drip irrigation when compared to furrow irrigation. Water conservation is an important issue in Western Colorado, which depends on limited water

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supplies for use in both urban and agricultural areas. Subsurface drip irrigation also gives growers the flexibility to inject liquid fertilizer at the time when plants need it and according to the amount needed.

Applying fertilizer according to growth stage and plant needs will increase the efficiency in terms of uptake and reduction of losses. Growers could also decrease the amount of fertilizer by applying fertilizer directly to the root zone. Lamm et al (1997) reported saving nitrogen applications for corn (*Zea mays*) using subsurface drip system.

Objectives of the study were to see the effect of different colored plastic mulch in combination with subsurface drip irrigation on (1) Kabocha squash yield, (2) sugar content as Brix level, and (3) water saving compared to producers practice of surface irrigating without mulch. The study also included evaluating of planting method, transplanting versus direct seeding, on squash yield.

METHODS:

This study was conducted for three years, 1998-2000, at the Western Colorado Research Center at Rogers Mesa, located 20 miles east of Delta, Colorado (latitude:38^{o} $47^{'}$ and longitude:107^{o} $47^{'}$). The elevation is 5,640 feet above mean sea level. The growing season is approximately 150 days. Weather data were collected from the weather station at the research center. The field was prepared by disking followed by roto-tilling. Plastic mulch and drip tape was laid with a Buckeye combination mulch layer drip tape applicator and bed shaper.

The beds were 42 inches wide and 8 feet between centers. The drip tube used for irrigation was T-Tape™ TSX-51030-340 (T-Systems International, San Diego, California)[3]. The T-Tape was laid 2-3 inches below the surface of the soil in the center of the bed. The beds were prepared in mid-May in 1998, 1999 and 2000.

Planting methods used were direct seeding and transplanting. Three different colored plastic mulches were used: 1) clear, 2) black and 3) green. The treatments were (a) drip irrigation with clear, green, or black plastic mulch, (b) drip irrigation with no-mulch, and (c) furrow irrigation with no-mulch on both transplanted and direct seeded squash. Furrow irrigation for a mulched squash bed by furrow irrigation is slow, consequently inefficient, and was not included.

Irrigation water was delivered through a series of ditches. Irrigation water from the ditch was first filtered through 2 Spin-Klin™ 140-mesh filters followed by 4 Amiad™ 120-mesh filters to achieve adequate filtration.

The amount of water used was measured with inline flow meters for 1999. Flow meters were not available for 1998. Water usage for 1998 was estimated from emitter flow rate at operating pressure of 9 psi.

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[3] Mention of a trademark, proprietary product, or a vendor does not constitute a guarantee or warranty of the product by authors or institutes they represent.

Water pressure for the drip system was maintained at 9 psi for 1998,1999, and 2000. Soil water status was monitored using tensiometers and soil water potential was maintained between 15 to 45 centibars, which was in agreement with recommendation made by Top and Ashcroft (2000).

Fertilizers were injected using a Chem Feed™ C600P pump. In 1998, 1999 and 2000 approximately 15 gallons of Uran (32% nitrogen) and 21 gallons of 5-5-5 (5% nitrogen, 5% phosphate and 5% potash) was applied during the growing season. Transplanted seedlings were 4-week-old. The second half of the plots was direct seeded. Seeds and transplants were planted on May 28 –29 in 1998, June 15-16 in 1999, and June 12-13 in 2000. Figure 1, gives a view of a young squash plant in mulch.

Figure 1: Kabocha squash plant in black plastic mulch 16 days after seed was planted.

Plots were 40 feet long with 2 feet in-row plant spacing with 4 replications in a randomized complete block design. Row orientation was north to south. Squash were harvested in the first week of September in 1998 and the second week of September for 1999. Harvest was not possible in 2000 due to the loss of irrigation water at the end of August.

Squash were individually weighed and evaluated as marketable or non-marketable. Squash were considered non-marketable, based on the following criteria: 1) sunburn, 2) excessive scarring (scarring would include raised warts and ridges on squash surface), 3) too small (<2lbs), and 3) immature (immaturity was based on the greenness of the stalk (Figure 2). The Brix level (percentage of soluble solids which consist mostly of sugars) was taken from three squash randomly selected from each plot. The Brix levels were taken with a hand held refractometer (Atago Co., LTD., Tokyo, Japan).

Figure 2: Kabocha squash on the left is mature (the stalk is shriveled and dry). The squash on the right is immature and would be considered non-marketable. The peduncle is still green.

The major weed pests in 1998 and 1999 were common mallow (*Malva neglecta* Wallr.), lambsquarter (*Chenopodium berlandieri* Moq.), red root pigweed (*Amaranthus palmeri* S. Wats.) and bindweed (*Convolvulus arvensis* L.). A combination of the herbicides, 2-4-D (Dow AgriSciences, Indianapolis, IN) and Roundup

(Monsanto Co., St. Louis, MO) were used on the furrow irrigated and non-mulched plots until the plants were too large to safely spray around. Henceforth all weeding for non-mulched plots were done by hand on a weekly basis. Herbicide 2-4-D and Roundup were used to control weeds in the open space between the mulched beds until the vines covered the ground. After the vines filled in between the mulched beds, weeds were pulled when they broached the leaf canopy of the squash plant. These weeds were not competing with the squash plants. Squash bug populations were treated with Diazinon AG (Novartis Crop Protection Inc., Greensboro, NC)) twice per season.

RESULTS:

In 1998 there was a significant difference in the amount of irrigation water applied between the furrow-irrigated plots and the subsurface drip irrigated plots. The water applied in subsurface drip irrigated plots was equivalent to average 19 inches per acre. An equivalent of 76 inches per acre on average were applied to furrow irrigated plots. Water application by subsurface drip irrigation 1999 slightly improved and an equivalent of 18 inches per acre was applied, whereas an equivalent of 82 inches per acre was applied by furrow irrigation. Water usage decreased for subsurface drip irrigated plots whereas furrow irrigation amount increased. This may be due to better control of subsurface drip irrigation compared to furrow flood irrigation where efficiency is dependent on available flow from the ditch system at the time of irrigation.

Irrigation interval for subsurface drip irrigated plots was three days and the furrow irrigated plots were watered weekly. Soil water level in subsurface drip irrigated plots reached to field capacity (10-30 centibar) level in a short time and the distribution was uniform. In furrow irrigation it took longer time since water running down the furrow took time to seep down the rows and across the bed to the squash plants. Also, while the upper part of the squash beds might be adequately wet, the lower parts of the furrow may not have reached the proper soil water levels. Thus in order to attain proper soil moisture levels at the bottom of the field; the upper parts of the field became over saturated.

Kabocha squash yield results of 1998 and 1999 were combined for statistical analysis and are presented in Table 1. The weather of 1999 was somewhat cooler in September, Table 2, but had no significant influence on yield. There was significant difference in squash production between subsurface drip irrigated plots with mulch compared to non-mulched furrow irrigated plots (Table 1). Overall yields were lower for furrow-irrigated plots. Transplanted squash tended to produce higher yields compared to direct seeded, except for furrow-irrigated plots with direct seeding. Soil water contact with seed and subsequent root development were probably favorable for direct seeded furrow irrigated treatment. Direct seeded non-mulched drip irrigated plots performed poorly.

Black plastic mulch performed better for direct seeded squash, probably by increasing the necessary heat units. However, the color of plastic mulch showed no significant influence on total yield of squash. Mulch in combination with drip irrigation showed significant yield improvement. There was no significant difference in average fruit size across all treatments (average fruit weight ranged from 2.88 to 3.54 lbs). Brix readings were significantly lower for furrow irrigated direct seeded non-mulched squash. Brix reading was 11.6 for furrow-irrigated plots as compared to 15.2 for subsurface drip irrigated plots.

Table 1: Results of Kabocha squash trial (1998 and 1999 combined) investigating the influence of subsurface drip irrigation and plastic mulches at Rogers Mesa Research Center, Hotchkiss, Colorado.

Planting Method	Mulch Type	Irrigation Treatment	Fruit size (lbs.)[a]	Brix[b]	Yield	
					Total lbs/acre[c]	Marketable lbs/acre[d]
Transplant	Clear	Drip[e]	2.96a	13.81a	27,796a	20,173a
	Green	Drip	3.16a	15.04a	29,695a	23,522a
	Black	Drip	3.04a	14.92a	23,331a	15,590a
	No Mulch	Drip	3.03a	13.66a	24,389a	21,603a
	No Mulch	Furrow	2.71a	11.6c	6,080b	5,018b
Direct Seeding	Clear	Drip	3.39a	14.58a	20,744a	15,679ab
	Green	Drip	3.27a	15.19a	18,188a	12,383bc
	Black	Drip	3.49a	14.92a	24,451a	19,972a
	No Mulch	Drip	2.73a	13.23b	7,721b	5,767d
	No Mulch	Furrow	3.24a	11.62c	12,285b	7,814cd

[a]F=1.4, n=38, P<0.26. [b]F=2.31, n=118, P<0.06. [c]F=6.27, n =38, P<0.0008. [d]F=3.36, n=38, P<0.02, [e]Subsurface drip irrigation.

Treatments within the same column followed by the same letter are not significantly different.

Table 2: Weekly average weather data of Rogers Mesa Research Center at Hotchkiss, Colorado for 1998 and 1999.

Month	Weekly Av.[1]	Max. T °F		Min. T °F		Lngly[2]		Rainfall[3] inches		GDU[4]		Ref ET[5] inches	
		98	99	98	99	98	99	98	99	98	99	98	99
June	1	77.1	76.7	44.4	41.7	637	595	0.2	0.2	108	107	2.58	2.39
	2	74.3	81.9	45.8	46.8	629	584	0.1	0.0	197	220	2.03	2.16
	3	78.8	83.7	48.0	51.2	588	468	0.2	0.5	301	343	2.08	1.83
	4	90.8	89.3	51.0	53.4	754	511	0.0	0.0	452	500	3.30	2.72
July	1	90.7	90.7	57.3	59.9	618	482	0.4	0.2	623	681	2.70	2.50
	2	92.4	86.2	57.5	55.8	626	512	0.0	0.6	795	841	2.72	2.12
	3	94.6	85.5	61.8	56.4	635	487	0.1	0.3	984	1,003	2.78	1.96
	4	84.6	84.9	60.2	58.6	551	534	1.4	0.4	1,139	1,153	1.77	1.72
Aug	1	88.3	83.0	54.3	56.9	621	512	0.0	0.1	1,297	1,310	2.43	1.84
	2	88.9	83.0	56.1	52.9	564	491	0.0	0.5	1,462	1,454	2.30	1.83
	3	88.9	84.2	57.6	56.6	514	516	0.1	0.5	1,634	1,614	2.07	1.80
	4	89.9	83.8	55.7	56.6	529	438	0.1	0.2	1,780	1,755	1.85	1.41
Sept	1	88.8	79.3	57.1	48.6	515	482	0.1	0.7	1,948	1,878	1.97	1.69
	2	80.0	78.8	54.3	47.8	431	468	0.9	0.1	2,072	1,982	1.35	1.47
	3	82.4	73.2	47.13	44.3	488	467	0.0	0.5	2,186	2,063	1.48	1.21
	4	80.0	72.5	47.0	39.9	449	482	0.1	0.0	2,306	2,154	1.44	1.50

[1] Weekly average (of either 7 or 8 days), [2] Average Solar radiation in Langleys, [3] Total weekly rainfall, [4] Cumulative growing degree units starting from June 1 and based on equation {(Max. Temperature in ° F + Min. Temp in °F)/2 – 50°F}, where 86° F is maximum threshold and 50° F is the minimum threshold, [5] Weekly total reference evapotranspiration estimates in inches calculated using modified Penman equation for alfalfa as a reference crop.

DISCUSSION:

There was a significant decrease in the amount of water used between the subsurface drip and furrow irrigated plots. Lamm et al (1995) comments that a 25 percent net water savings are possible by using SDI compared to sprinkler irrigated corn and a 50 percent saving compared to furrow-flood irrigation. Feibert et al (1992) reported a fifty percent of water savings from drip irrigation compared to surface irrigation. Excessive run-off contributed to the higher diversion of water to furrow irrigated plots in this study, hence a higher difference was observed between drip and furrow irrigation, compared to what has been reported in literature. Measuring run-off would have helped.

Transplanted squash produced higher total yields compared to direct seeded plants. This is in contrast to findings of Feibert et al (1992) who found no advantage over direct seeding. The increase in yield observed in this study may be in part due to lengthening of the growing season by starting seedlings at a nursery. Transplanted squash started flowering approximately 20 days before the direct seeded squash plants. However, there is a cost of seedling and transplanting that need to be considered for evaluating an economic benefit from transplanting compared to direct seeding for commercial production.

The skin of Kabocha squash is very sensitive to sunburn. A reason for culls was sunburn. A good canopy cover is necessary to protect the squash from sunburn. In this study, the rows were farther apart than would be found in a commercial setting and may have contributed to more culls.

The major pest problems were common mallow, lamb's-quarter, red root pigweed, and bindweed. Squash bug, *Anasa tristis,* was the only insect pest of any concern. Powdery mildew, *Erysiphe polygoni,* was spotty throughout the field but weather conditions never attained optimum conditions to create an outbreak serious enough to affect the squash plants. Weed competition may have depressed yields in the furrow-irrigated plots. Squash bug populations started building at the outside of the plots and moved in towards the middle of the squash plots. In 1998, squash bugs may have had an effect on the outermost row of drip irrigated and black-mulched plots. Scouting for early infestations is difficult because the squash bugs is secretive and tend to stay near the base of the squash plant. The plastic mulch may have exacerbated the problem by providing a hiding place for the squash bugs at the point where the plant is growing through the mulch.

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Sensitivity of Center Pivot Sprinkler and SDI Economic Comparisons

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Introduction

In much of the Great Plains, the rate of new irrigation development is slow or zero. However, as the farming populace and irrigation systems age, there has been a continued momentum for conversion of existing furrow-irrigated systems to modern pressurized irrigation systems. These systems, including center pivot sprinkler irrigation (CP) and subsurface drip irrigation (SDI), can potentially have higher irrigation efficiency and irrigation uniformity while at the same time reducing irrigation labor. SDI is a relatively new irrigation system alternative for corn production on the Great Plains. Producers converting from furrow-irrigated systems to a pressurized system are faced with economic uncertainty about whether to convert to center pivot sprinklers (CP) or SDI. This paper presents economic comparisons of CP and SDI and the sensitivity of these comparisons to key factors. A Microsoft Excel[1] spreadsheet template also will be introduced for making these comparisons.

Analyses Methods and Economic Assumptions

Field & irrigation system estimates

An existing furrow-irrigated field with a working well and pumping plant is being converted to either center pivot sprinkler irrigation or SDI. The pumping plant is located at the center of one of the field edges and is at a suitable location for the initial SDI distribution point (i.e. upslope of the field to be irrigated). Any necessary pump modifications (flow and pressure) for the CP or SDI systems are assumed to be of equal cost and thus are not considered in the analysis.

Land costs are assumed to be equal across systems for the overall field size with no differential values in real estate taxes or in any government farm payments. Thus these factors "fall out" or do not economically affect the analyses.

An overall field size of 160 acres (square quarter section) was assumed for the base analysis. This overall field size will accommodate a 125 acre CP system and a 155 acre SDI system. It was assumed that there would be 5 noncropped acres consumed by field roads and access areas. The remaining 30 acres under the CP system are available for dryland cropping systems.

Irrigation system costs were obtained from KSU estimates (O'Brien et al., 2001). The 125 acre CP system was assumed to cost \$45,113.75 or \$360.91/irrigated acre, while the 155 acre SDI system was assumed to cost \$122,016.00 or \$787.20/irrigated acre. In the base analyses, the system life for the two systems are assumed to be 25 and 15 years for the CP and SDI systems, respectively. No salvage value was assumed for either system. This assumption of no salvage value may be inaccurate, as both systems might have a few components that may be reusable or available for resale at the end of the system life. However, relatively long depreciation periods of 15 and 25 years makes the zero salvage value a minor issue in the analysis.

When the overall field size decreases, thus decreasing system size, there are large changes in cost per irrigated acre between systems. SDI costs are nearly proportional to field size, while CP costs are not proportional to field size (Figure 1). Quadratic equations were developed to calculate system costs when less than full size 160 acre fields were used in the analysis:

$$CPcost\% = 44.4 + (0.837 \times CPsize\%) - (0.00282 \times CPsize\%^2) \quad \text{(Eq. 1)}$$

$$SDIcost\% = 2.9 + (1.034 \times SDIsize\%) - (0.0006 \times SDIsize\%^2) \quad \text{(Eq. 2)}$$

where CPcost% and CPsize%, and SDIcost% and SDIsize% are the respective cost and size % in relation to the full costs and sizes of irrigation systems fitting within a square 160 acre block.

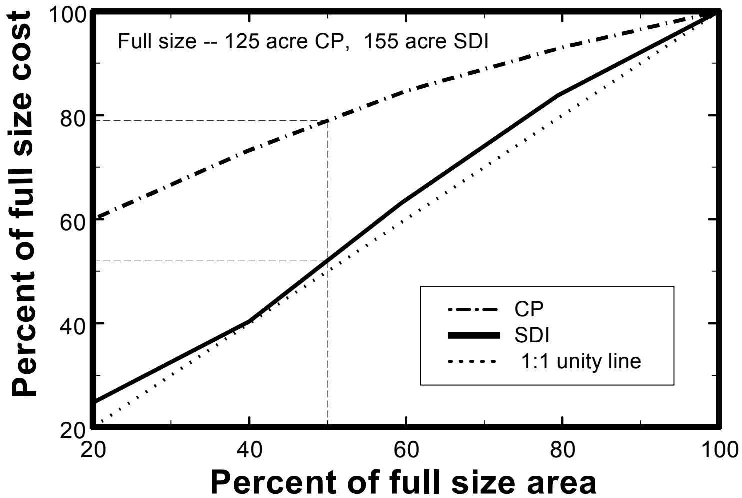

Figure 1. CP and SDI system costs as related to field size. (O'Brien et al., 1997)

Investment interest costs were assumed to be 8% and total interest costs were converted to an average annual interest cost for this analysis. Annual insurance costs were assumed to be 0.25% of each total system cost. It is unclear whether insurance can be obtained for SDI systems and if SDI insurance rates would be lower or higher than CP systems. Many of the SDI components are not subject to the climatic conditions that are typically insured hazards for CP systems. However, system failure risk is probably higher with SDI systems which might influence any obtainable insurance rate.

A summary of field and system estimates is provided in Table 1.

Table 1. Field description and irrigation system estimates

	Total	CP	SDI
Field area, acres	160	125	155
Non-cropped field area (roads and access areas), acres	5	-	-
Cropped dryland area, acres		30	0
Irrigation system investment cost, total $		$45,113.75	$122,016.00
Irrigation system investment cost, $/irrigated acre		$360.91	$787.20
Irrigation system life, years		25	15
Interest rate for investment, %	8		
Annual Insurance rate, % of total system cost		0.25	0.25

Production cost estimates

The following economic analysis expresses the results as an advantage or disadvantage of CP systems over SDI in net returns to land and management. Thus, many fixed costs do not affect the analysis and can be ignored. Additionally, the analysis does not indicate if either system is ultimately profitable for corn production under the assumed current economic conditions.

Production costs are adapted from KSU estimates (Dumler, et al., 2001). CP variable costs are estimated to be $342.91/acre in the baseline analysis while SDI variable costs are slightly lower at $326.06/acre. The reduction in variable costs for SDI is attributable to an assumed 25% net water savings that is consistent with research findings by Lamm et al., 1995. This translates into a 17 and 13 inch gross application amount for CP and SDI, respectively, for this analysis. The estimated production costs (Table 2.) are somewhat high considering the gross revenues are only $400/irrigated acre. This may be reflecting the overall profitability issue during these economic conditions, but producers might also try to reduce these variable costs somewhat to cope with low crop prices. This fact is pointed out because a lowering of overall variable costs favors SDI, since more irrigated cropped acres are involved, while higher overall variable costs favors CP production. The variable costs for both irrigation systems represent typical practices for western Kansas.

Table 2. Variable costs factors for corn using CP and SDI.

Factor	CP	SDI
Corn seeding rate, seeds/acre	30000	30000
Corn seed costs at $1.16/1000 seeds, $/acre	$34.80	$34.80
Herbicide, $/acre	$31.23	$31.23
Insecticide, $/acre	$37.89	$37.89
Nitrogen fertilizer, lb/acre	225	225
Nitrogen fertilizer at $0.16/lb, $/acre	$36.00	$36.00
Phosphorus fertilizer, lb/acre	45	45
Phosphorus fertilizer at $0.21/lb, $/acre	$9.45	$9.45
Crop consulting, $/acre	$6.50	$6.50
Custom hire/machinery expenses, $/acre	$100.00	$100.00
Irrigation labor, $/acre	$5.00	$5.00
Irrigation amounts, inches	17	13
Fuel and oil for pumping, $/inch	$3.72	$3.72
Fuel and oil for pumping, $/acre	$63.24	$48.36
Irrigation maintenance and repairs, $/inch	$0.33	$0.33
Irrigation maintenance and repairs, $/acre	$5.61	$4.29
1/2 year interest on variable costs with 8% rate	$13.19	$12.54
Total Variable Costs	**$342.91**	**$326.06**

Yield and revenue stream estimates

Corn grain yield was estimated at 200 bushels/acre in the base analysis and a corn selling price of $2.28/bushel. Net returns for the 30 cropped dryland acres for the CP system (corners of field) were assumed to be $32.50/acre which is essentially the current dryland crop cash rent estimate for Northwest Kansas. Government payments related to irrigated crop production are assumed to be spread across the overall field size and thus do not affect the economic comparison of systems.

Sensitivity analyses

In any economic analyses the results depend greatly on the initial economic assumptions. In this analyses, changes in the economic assumptions can affect which system is most profitable and by how much. Thus, a major effort of this paper as indicated in the title was to examine the economic sensitivity of the baseline results to key economic factors. The factors examined were:

- Size of CP irrigation system
- Shape of field (full vs. partial circle CP system)
- Life of SDI system
- SDI system cost
- Any additional production cost savings with SDI
- Corn yield
- Corn price
- Yield/price combinations
- Yield advantage for SDI

Microsoft Excel spreadsheet template

A Microsoft Excel[2] spreadsheet template was created to perform the economic analyses. Additionally, this template can serve as an easy tool for users to perform their own comparisons using their own estimates. The template has five worksheets, the Main, CF, Field size & SDI life, SDI cost & life, Yield & price tabs. Most of the calculations and the result are shown on the Main tab (Figure 2.). The Main tab requires 18 user inputs to perform the comparison. However, current KSU suggestions are indicated for all 18 inputs in case the user does not have a better estimate. The user is responsible for entering and checking the values in the unprotected input cells. All other cells are protected on the Main tab. Some error checking exists on overall field size and some items (e.g. overall results and cost savings) are highlighted differently when different results are indicated. The CF tab represents the costs of production and is provided to the user for informational purposes. It is suggested to the user that rather than changing the baseline assumptions on the CF tab, the user should just input differential production costs between the systems on the Main tab. This will help maintain integrity of the baseline production cost assumptions. KSU plans to maintain the CF tab and update it at least annually. The essence of the CF tab is represented by Table 2. The last three tabs are sensitivity analyses for selected key factors. Figures 3, 4, and 5 restate most of the results of these three additional tabs in graphical form. These sensitivity analysis tabs automatically update when different assumptions are made on the Main tab.

This template determines the economics of converting existing furrow-irrigated fields to center pivot sprinkler irrigation (CP) or subsurface drip irrigation (SDI) for corn production.

Version 2, modified by F.R. Lamm, 4-9-02

Field description and irrigation system estimates	**Total**	**Suggested**	**CP**	**Suggested**	**SDI**	**Suggested**
Field area, acres	160	← 160	125	← 125	155	← 155
Non-cropped field area (roads and access areas), acres	5	← 5				
Cropped dryland area, acres (= Field area - Non-cropped field area - Irrigated area)			30		0	
Irrigation system investment cost, total $			$45,113.75	← $45,114	$122,016.00	← $122,016
Irrigation system investment cost, $/irrigated acre			$360.91		$787.20	
Irrigation system life, years			25	← 25	15	← 15
Interest rate for system investment, %	8%	← 8%				
Annual insurance rate, % of total system cost			0.25%	← 0.25%	0.25%	← 0.25%
Production cost estimates			**CP**	**Suggested**	**SDI**	**Suggested**
Total variable costs, $/acre **(See CF Tab for details on suggested values)**			$342.91	← $342.91	$326.06	← $326.06
Additional SDI variable costs (+) or savings (-), $/acre			**Additional Costs**	→	$0.00	← $0.00
Yield and revenue stream estimates			**CP**	**Suggested**	**SDI**	**Suggested**
Corn grain yield, bushels/acre		**Suggested**	200	← 200	200	← 200
Corn selling price, $/bushel	$2.28	← $2.28				
Net return to cropped dryland area of field ($/acre)	$32.50	← $32.50				

Advantage* of CP over SDI, $/total field each year **$4,568.75**

$/acres each year **$28.55** * Advantage in *Net returns to land and management*

You may examine sensitivity to Main worksheet (tab) assumptions on three of the tabs listed below.

Figure 2. ***Main*** **worksheet (tab) of CP_SDI Excel template used to compare CP and SDI for corn production. Available for free at http://www.oznet.ksu.edu/sdi/.**

Results and Discussion of the Economic Analyses

Baseline analysis

Using the baseline assumptions (Table 1 and Table 2), the CP system has a $4,568.75/year ($28.55/acre-year) advantage over the SDI system (Figure 2.) These results match the general conclusions of O'Brien et al., 1998 indicating that CP systems generally have an advantage for large field sizes. Although, SDI systems can generate more gross revenue by having a higher percentage of irrigated acres in a given field, the much lower cost and longer assumed system life for full sized 125 acre CP systems offsets the higher SDI revenue advantage.

Sensitivity to field and irrigation system assumptions

The economic comparison is very sensitive to the size of the CP system and to the shape of the field (full vs. partial circle CP system). Smaller CP systems and systems which only complete part of the circle are less competitive with SDI than full size 125 acre CP systems (Figure 3). This is primarily because the CP investment costs ($/ irrigated acre) increase dramatically as field size decreases (Figure 1) or when the CP system cannot complete a full circle.

The economic comparison is also very sensitive to life of the SDI system and to the SDI system cost (Figures 3 and 4). Increased longevity for SDI systems is probably the most important factor for SDI to gain economic competitiveness with CP systems. Conversely a short SDI system life that might be caused by early failure due to plugging, indicates a huge economic disadvantage that must be avoided. The sensitivity of CP system life and cost is much less (data not shown) because of the much lower initial CP cost and the much longer assumed life. In areas where CP life might be much less than 25 years due to corrosive waters, a sensitivity analysis with shorter CP life is warranted.

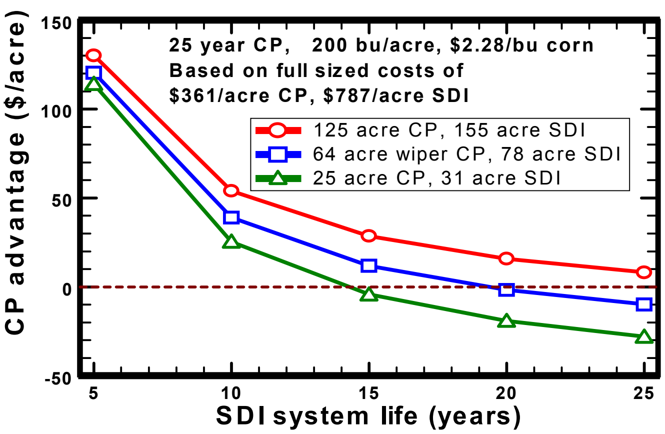

Figure 3. CP economic advantage as affected by field size, shape, and SDI system life.

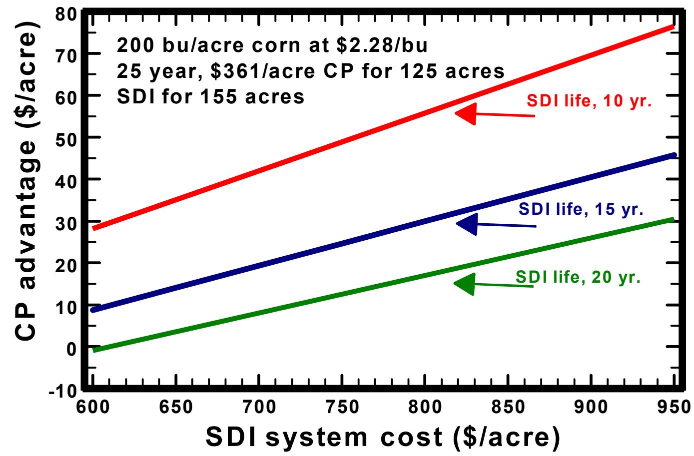

Figure 4. CP economic advantage as affected by SDI system life and cost.

Sensitivity to production cost estimates

The economic comparison is very sensitive to any additional cost savings with SDI (Figure 5). It should be noted that the present baseline analysis already assumes a 25% water savings with SDI. There are potentially some other production cost savings such as fertilizer and herbicides that have been reported for some crops and some locales. Small changes in the assumptions can make a sizable difference.

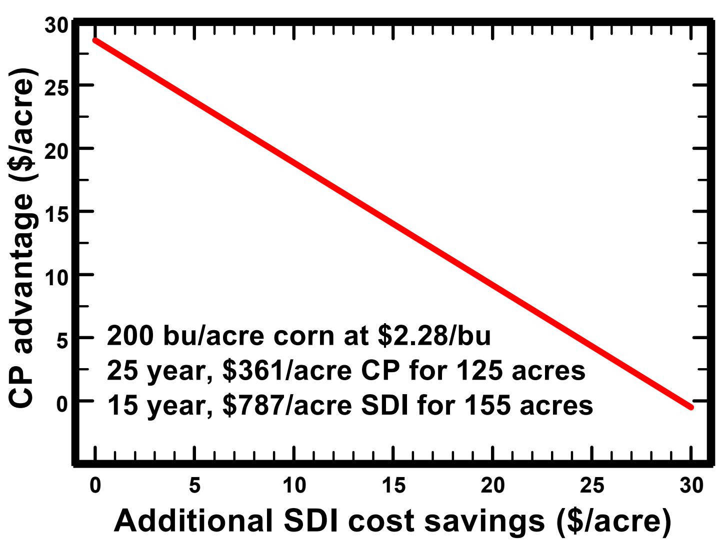

Figure 5. CP economic advantage as affected by additional SDI production cost savings.

Sensitivity to yield and revenue stream estimates

The economic comparison is moderately sensitive to corn yield and price and yield/price combinations and is very sensitive to any yield advantage for SDI. Higher yields and higher corn prices allow SDI to become more economically competitive with CP systems (Figure 6.). Combining a higher overall yield potential with an additional small yield advantage for SDI can allow SDI to be very competitive with CP systems (Figure 7.).

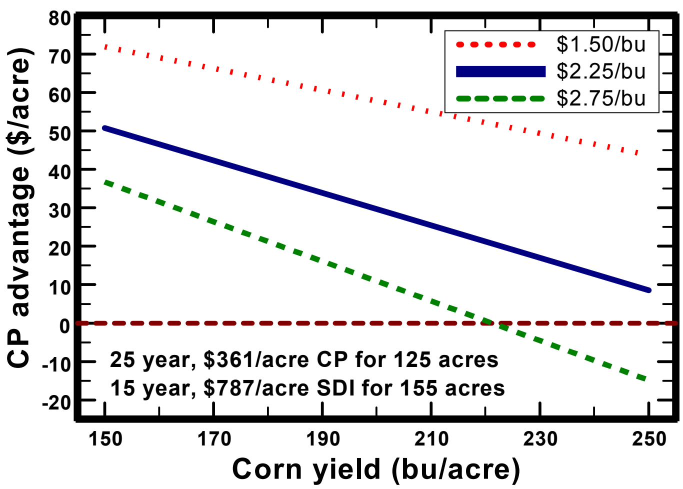

Figure 6. CP economic advantage as affected by corn yield and price.

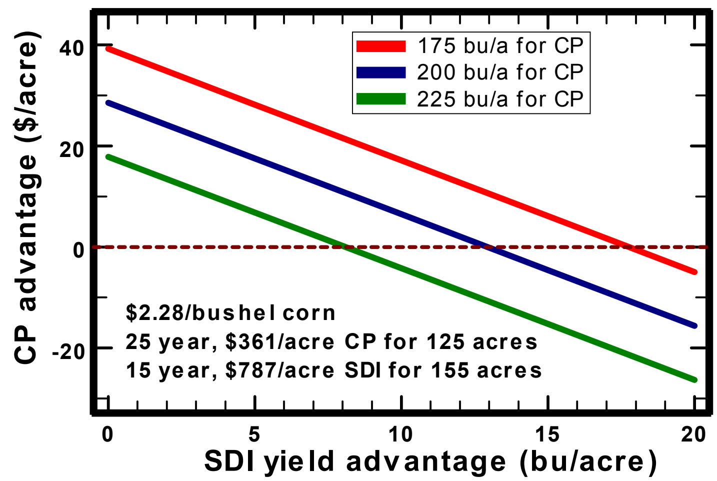

Figure 7. CP economic advantage as affected by overall corn yield potential and SDI yield .

Conclusions

Economic comparisons of CP and SDI systems are sensitive to the underlying assumptions used in the analysis. These results show that these comparisons are very sensitive to

- Size of CP irrigation system
- Shape of field (full vs. partial circle CP system)
- Life of SDI system
- SDI system cost

with advantages favoring larger CP systems and cheaper, longer life SDI systems.

The results are very sensitive to

- any additional production cost savings with SDI

The results are moderately sensitive to

- corn yield
- corn price
- yield/price combinations

and very sensitive to

- higher potential yields with SDI

with advantages favoring SDI as corn yields and price increase.

The results obtained here might differ drastically from those obtained from using your own assumptions. A Microsoft Excel spreadsheet template has been developed to allow producers to make their own comparisons. It is available on the SDI software page of the KSU SDI website at http://www.oznet.ksu.edu/sdi/.

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[2] *Mention of tradename is for informational purposes and does not constitute endorsement by Kansas State University.*

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Deficit Irrigation and Partial Rootzone Drying Compared in Figi Apples

Brian Leib, Horst Caspari, Preston Andrews, and Cristoti Redulla

Abstract

Many agricultural/horticultural industries depend on a large and inexpensive supply of water for irrigation. However, increasing demands from cities, recreational users and environmental groups are competing for the same supply of water causing new approaches to irrigation management to be required to meet this challenge.

In this research, Figi apple trees were irrigated in three treatments: 1) a control where micro-sprinklers on both sides of a tree were operated to maintain soil moisture at field capacity, 2) deficit irrigation (DI) where both micro-sprinklers were operated at half the time as the control, and 3) Partial Rootzone Drying (PRD) where only one micro sprinkler alternately wetted half the rootzone with half the water as the control.

In 2001, the Figi apple trees received 22 inches of water in the control treatments and 12 inches of water in the DI and PRD treatments without any significant difference in yield or quality. In this deep silt loam soil, more than an additional inch of soil water was depleted from the DI treatments as compared to the PRD treatments.

Introduction

The success and survival of many agricultural/horticultural industries depends on the continued supply of large volumes of water for irrigation. However, good quality water is a scarce resource and competition between resource users will continue to increase. With increasing water demands from cities, recreational users and environmental groups, less of this finite resource will be available for agriculture/horticulture. Clearly, new approaches to irrigation management are required that will reduce both water consumption and the detrimental environmental effects of current practices. While irrigation strategies such as Regulated Deficit Irrigation (RDI) (Chalmers et al., 1981) can significantly reduce water use in crops such as peaches, pears and grapes, they have not been successful with apples due to a negative impact on fruit size and yield. In fact, many studies have shown that water deficits reduce final fruit size in apples, irrespective of timing (Ebel et al., 1993; 1995; Landsberg and Jones, 1981; Lötter et al., 1985; Mpelasoka et al., 2000). Partial Rootzone Drying (PRD) is a new deficit irrigation strategy that offers the potential to use deficit irrigation on crops where other deficit strategies such as RDI lead to negative outcomes.

Partial Rootzone Drying is a new deficit irrigation strategy that has been developed recently for grapevines (*Vitis vinifera* L.) in Australia (Dry et al., 1996; Dry and Loveys, 1998; Dry et al., 2000a; 2000b). With PRD, irrigation is withheld from a part of a plant's rootzone while the remaining part is kept well watered. Briefly, the proposed physiological mechanism of PRD is that roots in drying soil synthesize a hormonal signal (abscisic acid, ABA) which is transported to the shoots, indicating a developing soil-water deficit. In the leaves, ABA induces partial stomatal closure which increases water-use efficiency. However, as the remaining part of the rootzone is kept well watered, the effect on plant water potential is minimal. In order to maintain the ABA signal, irrigation is alternately applied to each side of the rootzone, allowing the wet side to dry while the dry side is rewetted. Such application of PRD to grapevines has resulted in water savings of up to 50% with significant reductions in vegetative vigor and improved fruit quality, but without loss of yield (Dry et al., 1996; Loveys et al., 1998).

In the last four years, trials were conducted with PRD on apples in the Marlborough region of New Zealand, and one preliminary trial in Washington State. In the New Zealand experiments with Royal Gala, Fuji and Braeburn apples, seasonal irrigation input was reduced by 30-50 % without loss in fruit size or yield (Caspari and Neal, unpublished). Similarly, PRD applied for the final seven weeks prior to harvest did not reduce fruit size and yield of 'Golden Delicious' apple growing near Prosser, WA while conserving 50 % of irrigation water over this same period (Caspari and Lang, 2000).

Many studies have compared one form or another of deficit irrigation to a well-watered control, but only few studies have included more than one type of deficit irrigation. During the 1999/2000 growing season, three different forms of deficit irrigation of Braeburn apples were compared to a well-watered control in the Marlborough region of New Zealand (Caspari and Neal, unpublished). All deficit treatments were irrigated at 50% of the control. Fruit size and yield was reduced by omitting every other irrigation and by applying 50% of the water to the entire planting area as compared to the control, but fruit size and yield were not affected by PRD. There was no significant treatment effect on soluble solids, firmness, color, starch pattern index, and the development of fruit disorders.

Objective

Determine the impact of Partial Rootzone Drying on apple size, yield and quality, including the occurrence of sunburn, fruit cracking and post-harvest disorders as compared to Deficit Irrigation and a well-watered control group.

Method

At the beginning of the 2001 growing season, a block of 6 year old Figi apples containing 120 trees on a 9 foot by 16 foot spacing was converted from furrow to micro sprinkler irrigation at Washington State University's Irrigated Agricultural Research & Extension Center in Prosser, WA. The micro sprinklers were placed in the tree rows in the middle of the space between trees such that a micro sprinkler's wetting pattern only reached the trees on each side. This configuration isolated the irrigation to each side of a tree to allow for partial rootzone drying. Water supply pipe was installed to create three treatments, Control, Deficit Irrigation, and Partial Rootzone Drying, in a completely randomized block design of four replications (see Table 1).

The control plot was maintained at field capacity by applying 60 to 70% of the Public Agricultural Weather System (PAWS) estimated evapotranspiration rate. For the partial rootzone drying (PRD) blocks, one side of the sprinkler system (half of the tree's roots) was operated for the same length of time as the control. After 3 to 4 weeks, the sides were switched to irrigate the other half of the root system. In the deficit irrigation (DI), sprinklers on both sides of the tree were operated for half of the amount of time as the control, with a total quantity of about half of the total water applied to the whole root zone. Immediately following bloom, the moisture in all three plots was raised to field capacity. The plots were then irrigated as described above once a week until early October when all plots were returned to field capacity for winter dormancy. The total amount of water applied prior to refilling the rootzone was 22.1 inches in the control and 11.5 inches in both PRD and DI.

Soil water and apple size were monitored on a weekly basis throughout the 2001 growing season. Neutron Probe access tubes were located mid way between the micro sprinklers and the trees. One access tube was installed in each experimental unit with the exception of the PRD treatments in which case two access tubes were installed to measure soil water on each side of a tree's rootzone. The access tubes were inserted to a 3 to 4 foot depth depending on the soil depth encountered, and measurements were taken at a six-inch interval approximately 2 days after each weekly irrigation. The soil is classified as a very fine sandy loam to silt loam with a water holding capacity of nearly 2 inches per foot. Apple size was also measured on a weekly basis using a Cranston diameter gauge. The same ten fruit were measured in each experimental unit throughout the growing season.

Fruit was harvested from designated trees in each experimental unit on October 3, 2001. The fruit was sorted by size and each size group was counted and weighed. A sub sample of similar size fruit were evaluated for sunburn and then taken to the lab for further analyzed. Maturity indexes were measured at harvest and after 14 days of ripening in respiration chambers held at room temperature. Measurements of fruit firmness using the Fruit Texture Analyzer (Güss), soluble solid concentration (SSC) using a digital refractometer (Atago), starch index (0-6 scale for Fuji), density, titratable acidity, percentage of red color and internal ethylene using a gas chromatograph (Hewlett-Packard GC 5830 with a PLOT column). Ten fruit were used for each measurement. Six apples stored for 14 days in the respiration chambers had carbon dioxide (CO_2) and ethylene (C_2H_4) evolution recorded.

Results

Figure 1 shows the soil water trends for the three treatments; Control Irrigation (CI), Deficit Irrigation (DI), and Partial Rootzone Drying (PRD). It should be noted that the PRD soil-water content is an average of the wet and dry sides of the treatment. All treatments show a drop in soil water at the end of May because water deliveries were stopped during this time period to conserve reservoir water for use later in the growing season due to the drought conditions of 2001. Also, the drought caused water deliveries to be turned off earlier than normal at the end of the growing season and soil water profiles reveal a large increase in soil water to prepare for the dormant season. With the exception of these drought induced changes in soil water, the CI treatment was kept consistently at field capacity (3 in/ft) during the 2001 growing season. Both the DI and PRD treatments show a consistent decrease in soil-water content and significant use of water from the soil profile. However, DI soil water-content dropped at a faster rate than PRD. This could be the result of PRD creating a longer lasting ABA signal and thus reducing tree transpiration as discovered in earlier research, but it should be noted that PRD wets half of the surface area of the other treatments. PRD could be creating less soil surface evaporation and thus be increasing the application efficiency of this irrigation method.

Figure 2 shows the apple growth trends for the three treatments. Apple size is very similar early in the growing season for all the treatments. DI caused apple size to start decreasing around the end of July and the decreasing rate continued until the end of the growing season. PRD apple size also started to decrease at the beginning of September as compared with CI. The decrease in apple size for both the DI and PRD seemed to correspond to the time when soil water content dropped to around 2.1 in/ft (averaged for the entire rootzone) or around 50% depletion.

Table 2 shows that there was no statistical difference between treatments for any of the yield and quality parameters. It should be noted that these apples were harvested in a single picking about two weeks prior to their optimum maturity. The fact that no statistical difference was found seemed to contradict the growth response found in Figure 2 that seemed to indicate a noticeable difference in apple size. Figures 3 and 4 reveal some reasons for this discrepancy by showing the individual yield data in relationship to the crop load (number of apples per tree). The crop load varied from 50 to 350 apples per tree and this caused noticeable differences in fruit size and yield. Figure 3 shows decreasing average apple size with increasing crop load, and Figure 4 shows increasing yield per tree with increasing crop load until 300 fruit per tree were reached, then yield stayed the same as crop load increased to 350 apples per tree. A covariant analysis will reduce the variation caused by crop load and help identify treatment differences. In Figures 3 & 4, DI data points are lower in apple size and yield and may separate from the other treatments. Figures 3 & 4 also provide a possible reason for the apple size reductions observed in Figure 2. The DI treatments have greater crop load than both CI & PRD, and PRD has greater crop load than CI.

Conclusions

Figi apples grown in deep soils with high water-holding capacity were able to produce the same apple yield and quality when half the water was applied by either DI or PRD. However, soil-water monitoring revealed that more water was preserved in the soil profile under PRD than DI. In shallower and lower water-holding soils, the ability of PRD to conserve soil water may have a greater impact on fruit yield and quality. Also, crop load created a noticeable difference in yield and quality. Therefore, a covariant analysis would help identify treatment differences and greater care was taken in the 2002 growing season to created similar crop loads in each experimental unit. Also, the 2002 growing season may reveal a carryover effect in the deficit irrigation treatments.

Acknowledgements

Recognition is given to the Washington Tree Fruit Research Commission and Washington State University Irrigated Agriculture Research and Extension Center (IAREC) for supporting this research effort.

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Table 1: Irrigation Amounts in 2001, Figi PRD Trial, Prosser, WA

PAWS ET Apples no cover crop	Control Treatments	Deficit Irrigation Treatments	Partial Rootzone Drying Treatments
29.8 inches	22.1 inches	11.5 inches	11.5 inches

Table 2: Apple Yield and Quality Statistics, Figi PRD Trial, Prosser, WA

Fruit Yield	Fruit Size	Soluble solids	Acids	Starch	Firmness	Sunburn Incidence	Sunburn Severity
CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns	CI, DI, PRD ns

CI - Control Irrigation
DI - Deficit Irrigtion
PRD - Partial Rootzone Drying

ns – no significant difference

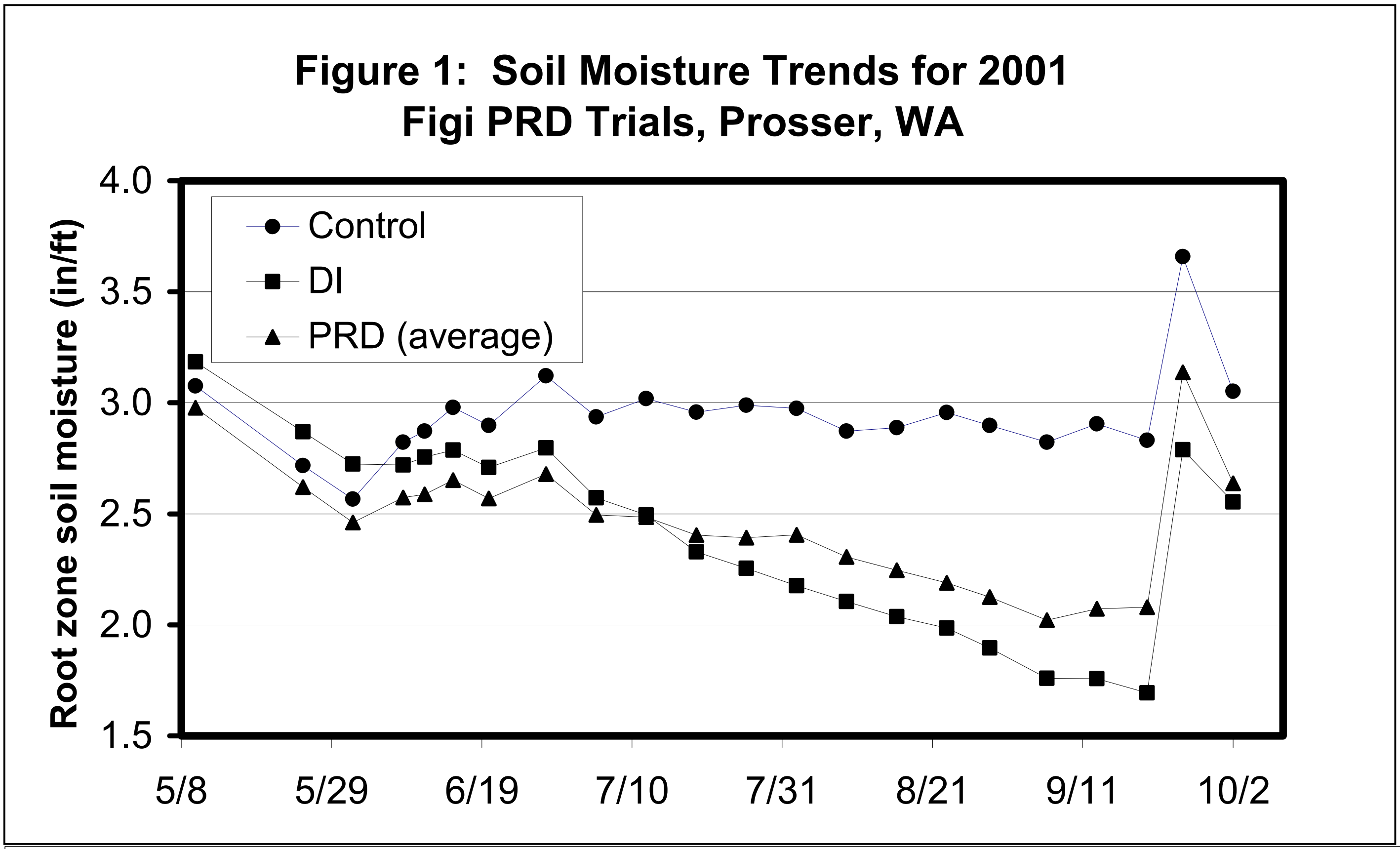


Figure 1: Soil Moisture Trends for 2001
Figi PRD Trials, Prosser, WA
Root zone soil moisture (in/ft)
Control
DI
PRD (average)
4.0
3.5
3.0
2.5
2.0
1.5
5/8
5/29
6/19
7/10
7/31
8/21
9/11
10/2

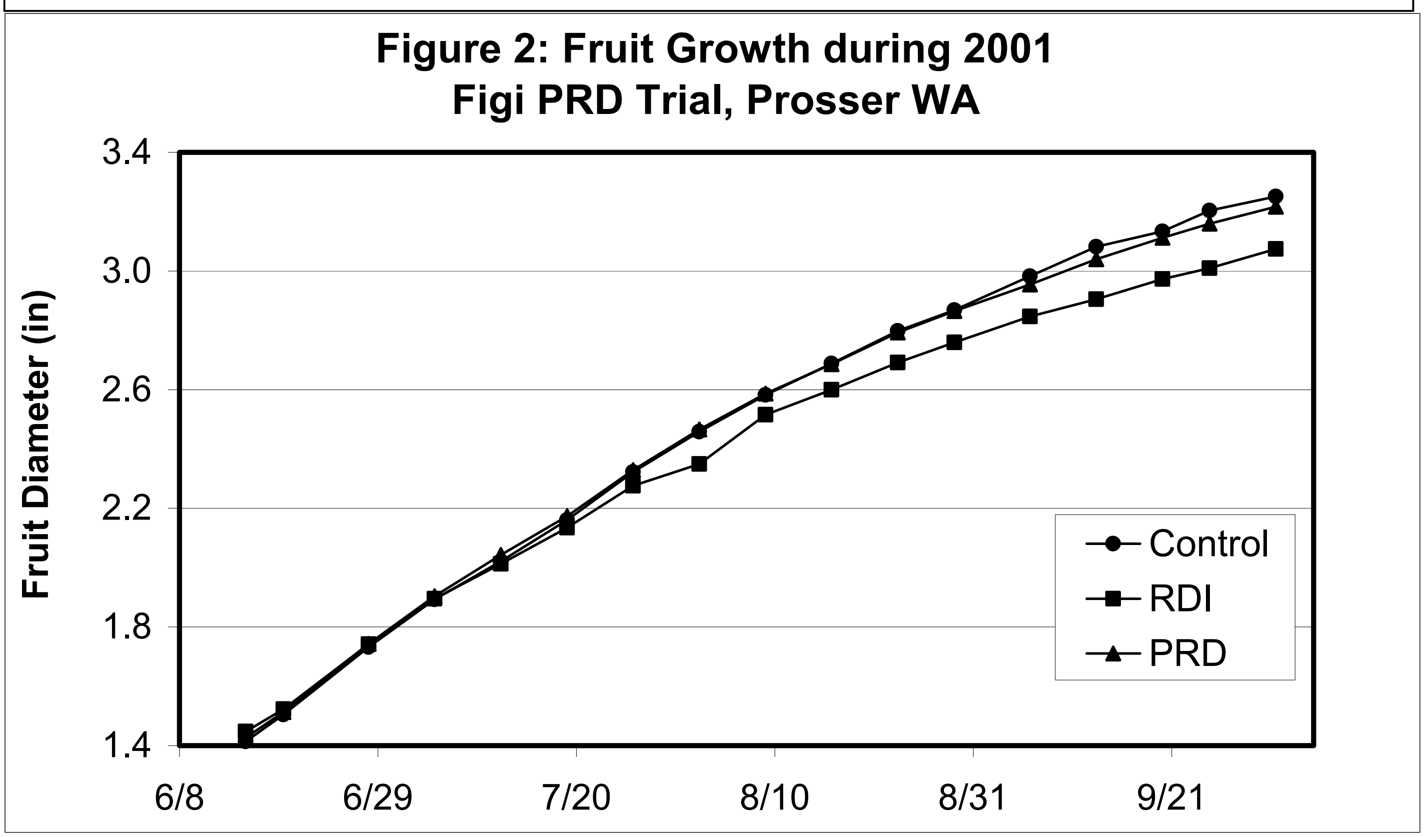


Figure 2: Fruit Growth during 2001
Figi PRD Trial, Prosser WA
Fruit Diameter (in)
Control
RDI
PRD
3.4
3.0
2.6
2.2
1.8
1.4
6/8
6/29
7/20
8/10
8/31
9/21

Figure 3: Apple Size at Harvest 2001
Figi PRD Trial, Prosser, WA

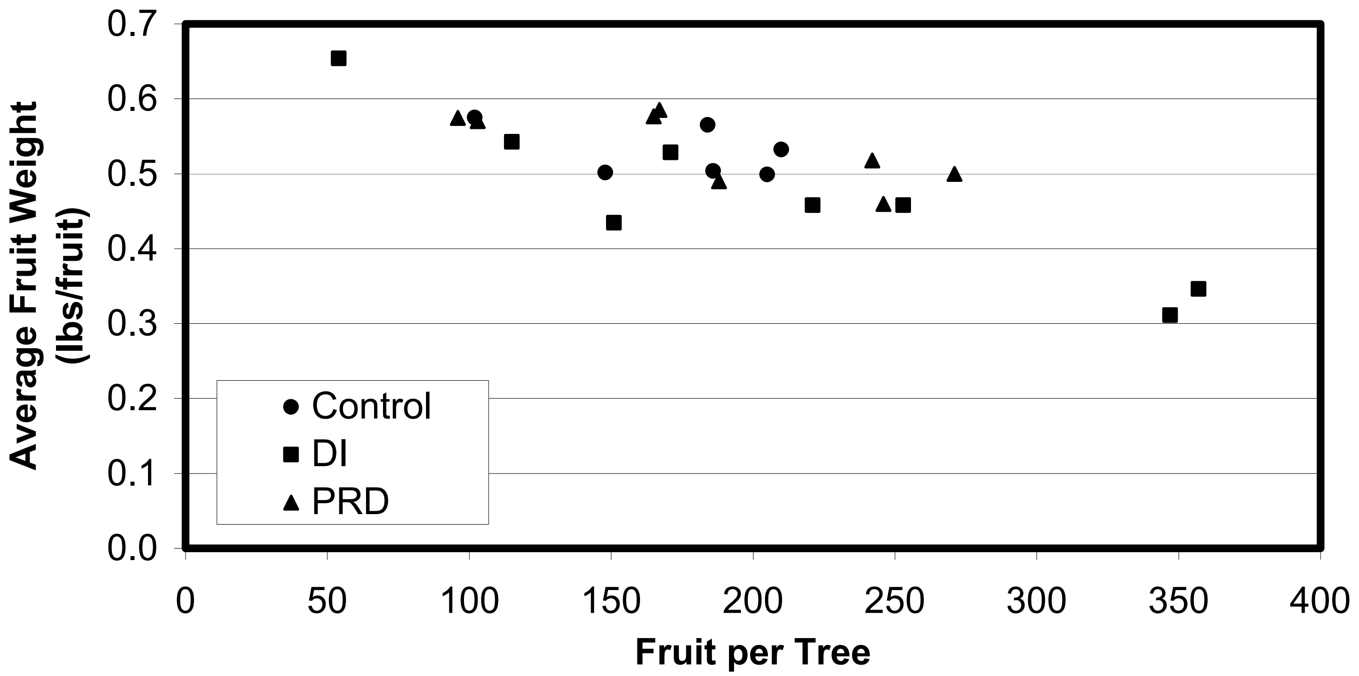
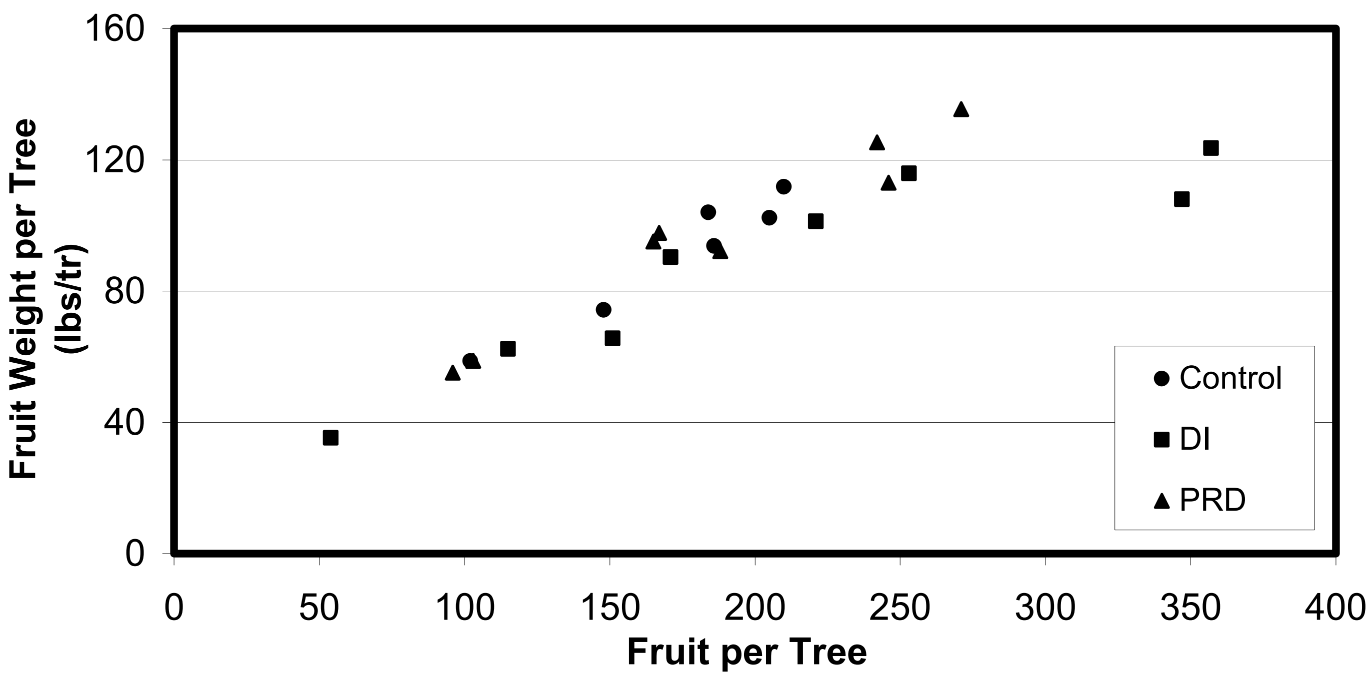


Figure 4: Apple Yield 2001
Figi PRD Trial, Prosser, WA



Yield and Irrigation Water Use of Fruit Vegetables Grown with Plastic and Straw Mulch in the U.S. Virgin Islands

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Abstract

A major factor limiting increased vegetable production in the U.S. Virgin Islands (USVI) is water availability. The climate of the USVI is semi-arid with moderate rainfall (1100 mm/yr) and high evapotranspiration (ET) of about 1500 mm/yr. The University of the Virgin Islands Agricultural Experiment Station has been conducting studies to increase water use efficiency of vegetable crops under limited water availability. Field experiments were conducted from 1995 to 2000 to determine yield and irrigation water use of fruits vegetables including bell peppers (*Capsicum annuum* L.), cucumber (*Cucumis sativus* L.), and tomato (*Lycopersicon esculentum* L.). Except for tomato all crops were drip-irrigated at three soil moisture regimes (-20, -40, -60 kPa) based on soil tensiometers. Irrigation regime for tomato was based on U.S. Weather Service Class A pan evaporation rates equivalent to 40, 60 and 80%. Crops were planted in plots with polyethylene mulch, straw mulch and no mulch (bare). For each crop, trials were conducted over two seasons. Data on marketable yield, total water use and efficiency were collected from each trial. Results in general indicate no significant yield differences ($P>0.05$) between irrigation regimes. Water use was highest at -20 kPa or 80% ET and lowest at -60 kPa or 40% ET. Since water use efficiency was highest at the lowest irrigation rate, fruit vegetables can be grown with minimum irrigation water without sacrificing yield. Furthermore, the use of mulch conserves water and increases yield of vegetables.

Introduction

A major factor limiting increased vegetable production in the U.S. Virgin Islands (USVI) is water availability. The climate of the USVI is semi-arid with moderate rainfall (1100 mm/yr) and high evapotranspiration (ET) of about 1500 mm/yr. Continuous wind movement associated with high temperatures (24-29^{o}C) results in ET exceeding precipitation most of the year. The University of the Virgin Islands Agricultural Experiment Station (UVI/AES) has been conducting studies on drip irrigation and mulching with vegetables and culinary herbs to conserve soil moisture, thus reducing irrigation water cost. The combination of drip irrigation and mulching can increase yields and economic returns from vegetable production in areas where water is a limiting resource. In the USVI, drip irrigation has benefitted vegetable production by reducing water use, improving quality and yield of vegetables as well as increasing economic returns (Navarro and Newman, 1989; Palada et al., 1995; Palada et al., 2001).

The benefits of drip irrigation combined with mulching have been demonstrated in several vegetables including melons, squash, cucumbers and tomatoes (Bhella and Kwolek, 1984; Briones et al., 1995; Locascio and Smajstrla , 1993; Schales and Sheldrake, 1966). In Puerto Rico yield of sweet pepper was higher with plastic mulch under drip irrigation compared with no mulch (Crespo-Ruiz et al., 1988). Similarly, the combination of black plastic mulch and irrigation produced maximum yields, but frequency of irrigation had little effect on yield when peppers were mulched (VanDerwerken and Wilcox-Lee, 1988). Smittle et al. (1994) reported that yields and water use by bell pepper were maximized when irrigation was applied at soil moisture maintained at -25 kPa.

Several studies in the USVI have shown the benefits of using mulch with drip irrigation on culinary herbs (Palada et al., 1999). No studies have been conducted on the effects of mulching and drip irrigation on fruit vegetables in the Virgin Islands. These studies were conducted to determine yield and water use of fruit vegetables including cucumber (*Cucumis sativus* L.), bell pepper (*Capsicum annuum* L.), and tomato (*Lycopersicon esculentum* Mill.) grown in plastic and grass straw mulch.

Materials and Methods

The series of studies were conducted from 1995 to 2001 at the Agricultural Experiment Station, University of the Virgin Islands in St. Croix, USVI (lat. 17°42'N and long. 64°48'). The soil is Fredensborg clay (loamy, fine carbonatic isohypethermic, shallow calciustolls). Trials were conducted over two seasons for all crops.

<u>Cucumber</u>. The field experiments were conducted from March 17 to June 5, 1995 and March 26 to June 21, 1996 to compare the influence of black plastic and grass straw mulch on cucumber production in terms of total and marketable yield, fruit size and water use efficiency under three levels of drip irrigation. Plots were established measuring 4.6 m wide and 4.1 m long. Each plot contained 3 rows spaced at 1.5 m. Cucumber cv 'Calypso' (1995) and 'Dasher II' (1996) were direct seeded on March 17 using 2-3 seeds per hole at a spacing of 40.6 cm within the row. After germination seedlings were later thinned to 2 plants per hole. Treatments consisted of black plastic mulch (1.2 m wide) and straw mulch, composed of dried guinea grass (*Panicum maximum* L.). The black plastic mulch (1.25 mil) was installed in plots after the final land preparation, whereas the straw mulch was applied at 5.0-6.5 cm thick over the entire area of the plot on 11 April (1995) and April 16 (1996) about 3 weeks after seeding. The late application of the straw mulch was to prevent the newly germinated seedlings from becoming smothered by the mulch. Plots were arranged in a randomized complete block design with 4 replications.

For each mulch treatment, plots were drip irrigated at three regimes corresponding to soil water tensions of -20, -40 and -60 kPa. A higher number reading on the tensiometer means that the soil is drier, when compared to a lower number. The irrigation system consisted of main and sub-main lines made of 15 mm black polyethylene hose. The laterals were made of 15 mm New Hardie Tape (Hardie Irrigation, CA) with laser-drilled orifice 40.6 cm (16 inch) apart. Soil tensiometers (Irrometer Co., Riverside, CA) were installed at 15 cm depth adjacent to plant in the center row of each treatment, for 2 replications, to monitor the soil water tension. The tensiometers were read daily and readings were used to initiate an irrigation cycle when soil moisture tension exceeded the specified regime. A flow meter and a timer were installed in the irrigation system for each treatment. Water use was determined from weekly flow meter readings. Total irrigation water use was calculated over a period of 10 weeks (1995) and 11 weeks (1996).

In 1995 all plots were fertilized with 12-12-12 NPK fertilizer at the rate of 200 $kg.ha^{-1}$ each of N, P_2O_5, and K_2O. The fertilizer was banded and split-applied on 11 April and 16 May. In 1996, all plots were fertilized on April 18 with triple super phosphate and sulphate of potash to supply 120 and 60 kg/ha of P_2O_5 and K_2O, respectively. Nitrogen was applied in 5 equal fertigations using Ammonium Sulfate for a total rate of 100 kg/ha. Weeds were controlled by hand-weeding and insect pests by the application of various pesticides, when necessary during both years.

Cucumbers were harvested starting on May 3 and ending on 5 June for a total of 11 harvests during 1995 and from May 29 to June 21 for a total of 10 harvests in 1996. Fruits were harvested from all 3 rows per plot. For each harvest, fruits were counted, weighed and sorted into marketable and non-marketable size. Fruits with insect and/or disease damage were classified as non-marketable.

Bell Pepper. The field experiments were conducted from 7 May 1997 to 10 Sept 1997 and from 6 Nov 1997 to 5 Mar 1998 to compare the influence of white on black plastic and grass straw mulch on bell pepper production in terms of yield, water use, efficiency, and economic returns. Plots were established measuring 2.73 m wide and 5.52 m long. Each plot contained three rows spaced at 0.91 m. Seedlings of bell pepper cv. Calwonder were transplanted on 7 May 1997 (first season) and 6 November 1997 (second season) at a spacing of 0.46 m within rows. Treatments consisted of synthetic (white on black plastic) mulch and organic (grass straw) mulch. A bare (no mulch) treatment was also included. The plastic mulch (1.25 mil) was installed in plots after the final land preparation, whereas the straw mulch was applied at 5.0-6.5 cm thick three weeks after planting. Plots were arranged in a randomized complete block design with four replications. For each treatment, plots were drip-irrigated at three regimes corresponding to soil moisture tensions of -20, -40 and -60 kPa. The irrigation and monitoring system was similar to that used in the cucumber trial except that emitter spacing was 46 cm (18 inch) apart. All plots were fertilized with 150N, 100P and 100K in $kg.ha^{-1}$. Nitrogen was applied in five equal fertigation rates during the first season and three equal split applications in the second season. Bell peppers were harvested 12 times during the first season and eight times during the second season. Fruits were harvested from middle rows, counted, weighed and sorted into marketable and non-marketable size. Fruits with insect and/or disease damage were classified as non-marketable.

Tomato. Field experiments were conducted during the 1998-99 and 2000 winter-spring seasons to compare the yield and water use of tomato (*Lycopersicon esculentum* L. cv. 'Celebrity') grown with grass straw and white on black plastic mulch under three levels of drip irrigation. Tomato was grown in replicated plots arranged in randomized complete block design and mulched with either grass straw at 5.0-6.5 cm thick or white on black plastic mulch (1.25 mil). A no-mulch (bare) plot was included as a treatment. All plots consisted of 3 rows 7.3 m long. Plants were spaced 1.22 m between rows and 0.46 m within rows. Plots were drip-irrigated based upon a percentage of the amount of water evaporated from the free surface of a U.S. Weather Service Class A pan, located at the crop production site. The drip system was similar to that used in the cucumber and bell pepper trials. Drip irrigation was applied at rates equivalent to 40, 60 and 80 percent of pan evaporation (PE). All plots were fertilized with 50N-100P-100K in $kg\ ha^{-1}$. Nitrogen was applied in five fertigation schedules. Data were collected on total number of fruits, total weight of fruits, total number and weight of marketable fruits and fruit size for each of the twelve harvests during the first season and four harvests in the second season. Plant height was measured during the first harvest in each season.

Data from all trials were analyzed using the General Linear Models (GLM) procedures by Statistical Analysis System (SAS).

Results and Discussion

Cucumber: 1995 Trial cultivar 'Calypso'. The effect of mulch on marketable fruit yield was highly significant (Table 1). Marketable fruit yield from plots with black plastic mulch was significantly greater (*P<0.005*) than those obtained from grass straw mulch. Black plastic mulch resulted in a 25% higher yield than straw mulch (Table 1). These results agree with those from other studies where cucumber overall yields were much improved under black plastic mulch.

The incidence of fusarium wilt (*Fusarium sp.*) became apparent in plots with straw mulch during the latter part of the 1995 season. More plants under straw mulch were affected by this soil-borne fungal disease resulting in poor quality fruits and reduced yields. The disease is believed to spread rapidly after a heavy rainfall and plants under straw mulch might have been more susceptible. The black plastic mulch may have prevented the spread of the fungus by acting as a better barrier between the soil and the plants. The edible product from a mulched crop is cleaner and less subject to rots, because the soil is not splashed on the plants or fruits.

Cucumber: 1996 Trial cultivar 'Dasher II'. The grass straw mulch treatment produced significantly more marketable cucumber fruits and higher yields than the black plastic for the first three harvests (Table 1). The number of marketable fruits harvested and the yield from both treatments were similar for all other harvests except the tenth harvest, when significantly more fruits and a higher yield were produced by the black plastic mulch treatment. The pattern of the grass mulch treatment producing more marketable cucumber fruits during the early harvests is similar to the results obtained for the 'Calypso' cultivar in 1995. The production of 'Dasher II' cucumbers was not significantly influenced by either the type of mulch or the soil moisture level under which the crop was grown

The 1996 study utilizing cultivar 'Dasher II', indicates that cucumber production from this cultivar is not affected by any of the two mulches or the irrigation regimes. These findings are important since production is not significantly affected by a reduction in the amount of applied irrigation. This can result in savings to growers regarding water and energy costs. Despite an infestation of thrips (*Thrips palmi*) this cultivar continued to be very productive (52.7 t/ha mean marketable yield) compared to the yield for 'Calypso' 1995 (marketable yields of 15.9 and 11.9 t/ha for plastic and grass, respectively). Further studies are needed to evaluate the performance of other mulches (organic and synthetic) in cucumber production. Even though 'Dasher II' has been demonstrated to be more productive than 'Calypso', local consumer preferences dictate that farmers grow 'Calypso'.

Bell Pepper: During the first season (summer, 1997) there were no significant differences in marketable yield due to mulch or irrigation regimes (Table 1). The interaction between mulch and irrigation regime also was not significant. Although there were no significant differences among mulch treatments, marketable fruit yield in plots with plastic mulch was higher than plots with grass mulch and bare (Table 1). The higher marketable yield from plots with plastic mulch was attributed to a consistently higher number of marketable fruits in almost all harvests (data not shown) compared to plots with grass mulch and bare. Similar results were obtained in the second season (fall-winter, 1997-98). The effects of mulch and irrigation regime were not significant (Table 1).

In general, the first season trial resulted in higher number of fruits (total and marketable) than the second season trial (data not shown). However, fruits produced from the first season were smaller than those in the second season. Therefore, differences in total fruit weight and marketable yield were small between two growing seasons.

Results of this study support the findings of previous work by Crespo-Ruiz et al. (1988) where they reported higher sweet pepper yield with plastic mulch under drip irrigation than with no mulch. Results are also in agreement with the findings of VanDerwerken and Wilcox-Lee (1988) where they reported maximum yields when peppers were grown with polyethylene mulch and irrigation, but frequency of irrigation had little effect on yield when peppers were mulched.

Tomato: During the first season (1999), the effects of mulch and irrigation regime on marketable yield not ($P>0.05$) significant (Table 1). There was also no significant ($P>0.05$) interaction between mulch and irrigation. . The insignificant effects of mulch and drip irrigation can be attributed to relatively high rainfall in 1999. Plots drip irrigated at 40% PE produced similar or even higher yield than those irrigated at 60 or 80% PE. Although not significant, marketable fruit yield in plots with no mulch increased at higher irrigation level (80% PE), whereas, yields in plots with mulch did not increase with increasing levels of irrigation. This would indicate that water use by tomato is reduced under mulch compared to bare plots. Results of the second season (winter-spring, 2000) trial indicated no significant effect of mulch on marketable fruit yield, however, the main effect of irrigation regime was significant ($P>0.05$) on weight of marketable fruits (Table 1).

Results of this study did not show any benefits of either plastic or grass straw mulch on tomato yield during the first season. However, during the second season there is an indication that the use of grass straw mulch with increasing levels of drip irrigation improved fruit size. Increased drip irrigation level also improved tomato marketable fruit yield. Growers would benefit by using both straw mulch and drip irrigation for increased tomato production.

Water Use Efficiency

For each crop total water use varied among irrigation regimes (Table 2). In general, water use decreased as soil moisture tension increased. Tomato used the greatest amount of irrigation water compared to cucumber and bell pepper. Water use by cucumbers and bell peppers grown under grass straw was lower than those under black plastic mulch. Tomato grown under plastic and grass straw had similar total water use, but slightly higher than grown without mulch. Water use efficiency (WUE) was generally better under low irrigation level than at high level. Between mulch, WUE was better for bell pepper grown with straw mulch than plastic and bare, but not for cucumber and tomato where plastic mulch was better than straw.

Conclusion

These studies have demonstrated the benefits of drip irrigation and mulching on cucumber and bell pepper. Mulching resulted in 33 to 52% more efficient use of irrigation water in bell pepper compared to bare soil. Although tomato did not benefit from mulching, drip irrigation improved marketable yield and fruit quality.

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Table 1. Marketable yield of cucumber, bell pepper and tomato grown with grass straw and plastic mulch under three levels of drip irrigation, St. Croix, Virgin Islands.

Mulch	Irrigation regime[1] (kPa)	Cucumber cv 'Calypso 1995	Cucumber cv 'Dasher' 1996	Bell Pepper cv 'Calwonder' 1997	Bell Pepper cv 'Calwonder' 1998	Tomato cv 'Celebrity' 1999	Tomato cv 'Celebrity' 2000
Plastic	-20	14.4	54.9	9.88	11.85	82	29
	-40	15.9	51.2	7.81	9.80	81	33
	-60	16.9	51.8	12.60	7.42	79	43
	Mean	**15.9**	**52.6**	**10.09**	**9.69**	**81**	**35**
Grass straw	-20	13.7	57.6	9.69	7.94	85	35
	-40	11.4	50.9	8.24	11.55	87	35
	-60	10.5	49.8	6.88	10.67	87	34
	Mean	**11.9**	**52.8**	**8.27**	**10.05**	**86**	**35**
Bare	-20	x	x	9.83	7.42	86	28
	-40	x	x	7.10	9.17	88	41
	-60	x	x	4.53	5.71	98	35
	Mean	x	x	**7.15**	**7.43**	**91**	**35**
Significance							
Mulch (M)		**	NS	NS	NS	NS	NS
Irrigation Regime (IR)		NS	NS	NS	NS	NS	*
M X IR		NS	NS	NS	NS	NS	NS

[1]For tomato, irrigation regimes were based upon the percentage of water evaporated from U.S. Weather Service Class A Pan (40, 60 and 80% PE).
*Significant at P<0.05; **Significant at P<0.01; NS=not significant.
x= no control or bare treatment for cucumber trial.

Table 2. Estimated irrigation water use and efficiency of cucumber, bell pepper and tomato grown under plastic and grass mulch at three drip irrigation regimes, St. Croix, Virgin Islands. (Data average of two seasons).

Crop	Mulch	Irrigation regime (kPa or %PE)	Irrigation water use ($m^3\ ha^{-1}$)	Water use efficiency (liters/kg)
Cucumber	Plastic	-20	785	32
		-40	712	31
		-60	671	26
		Mean	**723**	**30**
	Grass straw	-20	802	36
		-40	664	36
		-60	603	34
		Mean	**690**	**35**
Bell Pepper	Plastic	-20	665	41
		-40	407	34
		-60	315	20
		Mean	**462**	**32**
	Grass straw	-20	288	26
		-40	265	23
		-60	161	20
		Mean	**238**	**23**
	Bare	-20	679	57
		-40	539	49
		-60	377	39
		Mean	**532**	**48**

Tomato	Plastic	-20	1948	25
		-40	1455	21
		-60	1012	15
		Mean	**1472**	**20**
	Grass straw	-20	1900	25
		-40	1471	19
		-60	1044	14
		Mean	**1472**	**19**
	Bare	-20	1830	22
		-40	1462	19
		-60	1010	14
		Mean	**1434**	**18**

IRRIGATION CRITERIA AND DRIP TAPE PLACEMENT FOR 'UMATILLA RUSSET' POTATO PRODUCTION

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Water quality and water scarcity issues may lead growers to adopt drip irrigation for potato (*Solanum tuberosum* L.). The ideal soil water potential irrigation criterion for drip-irrigated potato is unknown. A drip system will cost less if one drip tape irrigates two potato rows instead of a tape for every row. The tuber yield and quality response of 'Umatilla Russet' potato was examined with variable drip tape placement and irrigation criteria. The first factor was either one drip tape between two potato rows, or two tapes (one tape over each row). The second factor was automated irrigation at -15, -30, -45 or -60 kPa soil water potential. The factorial trial was replicated five times in 2000 and again in 2001. Tubers were evaluated for yield, grade, physical defects, specific gravity, and fry color. The tape placement factor (one tape per row or one tape for two rows) had a significant effect on every variable except total marketable yield and tuber bud-end fry color for which interaction effects with soil water potential were significant. Irrigation with one tape at -15 or -30 kPa produced more total yield and as much or more marketable yield as any other treatment. Maximum marketable yield was estimated to have occurred at irrigation plus precipitation slightly above Et_c both years.

Introduction

Water quality and water scarcity issues may lead some growers to adopt drip irrigation for potato production. The objectives of this study were to investigate and document the performance of 'Umatilla Russet' under drip irrigation, and to explore the interaction of drip tape placement and irrigation criteria for potato crop production. It would be desirable to reduce the amount of drip tape used and to conserve water. This was the second year of testing 'Umatilla Russet' potatoes grown with variable irrigation criteria and drip tape placement.

Materials and Methods

The 2001 trial was conducted on Owyhee silt loam where winter wheat was the previous crop. The wheat stubble was flailed, the field was furrow irrigated and disked, then 50 lb N/acre and 44 lb P/acre were broadcast. In the fall, the field was ripped with Telone II injected at 22 gal/acre. The field was fall-bedded on 36-inch row spacing. A soil test taken on April 17, 2001 showed available nitrate plus ammonia totaled 68 lb N/acre in the top 2 ft of soil, 20 ppm extractable P, 272 ppm K, 1 percent organic matter, and pH 7.8.

Certified seed was hand cut into 2-oz seed pieces and treated with Tops-MZ-Gaucho dust. Potato seed was planted on April 19, 2001 using a Parma two-row cup planter (Parma Corp., Parma, ID) with the center furrowing shovel removed. Seed piece spacing was 9 inches in the row, with rows 36 inches apart.

Prowl at 1 lb ai/acre plus Dual at 2 lb ai/acre, in 30 gal/acre spray mix, was applied on May 1 for weed control. The herbicides were incorporated with a spike-tooth bed harrow that formed a broad, flat-topped bed over the two potato rows. The toolbar at the back of the bed harrow had two wide shovels to lift soil out of the furrows, a spool of drip tape, and shanks to inject a single drip tape on the first pass, 2-3 inches deep in the center of the bed. A 16-ft length of 5/8-inch chain dragged in a “vee” from the shovel shanks pulled soil into the center of the bed. On the second pass with the bed harrow, in the opposite direction from the first pass, two drip tubes were injected 2-3 inches deep, directly over the two potato rows. The drip tape was 1000 Path (Nelson Irrigation, Walla Walla, WA), 8 mil thick, with 12-inch emitter spacing, and 0.22 gal/min/100 ft flow rate. In plots where one tape was to remain between the two potato rows, the outside two tapes were removed manually during the drip system installation. In the plots where a tape was over each row of potato plants, the center tape was removed manually during the drip system installation. Water was supplied to the drip tapes through 1/2-inch PVC pipe, with the five plots of each treatment fed by one valve. Matrix herbicide was applied preemergence at 1.2 oz/acre on May 7.

A complete factorial set of treatments was arranged in a randomized complete block design. Plots were two rows (6 ft) wide by 50 ft long. The first factor was either one drip tape between two potato rows, or two tapes (one tape over each row). The second factor was automated irrigation at -15, -30, -45 or -60 kPa soil water potential in the root zone measured with granular matrix sensors (GMS, Watermark Soil Moisture Sensors, Model 200SS, Irrometer Corp, Riverside, CA).

The four soil water potential levels and two tape placements were tested in all eight combinations in a randomized complete block design with five replicates. The GMS were installed between plants in the potato row, with three GMS per plot. Two GMS with the center of the sensor at 8-inch depth measured soil water potential for the irrigation criteria, and a third GMS, installed at 16-inch depth, monitored infiltration below the root zone.

The automated irrigation system (Shock et al. 2002) read the soil moisture sensors in each plot every 6 hours, using multiplexers connected to a data logger (model CR10, Campbell Scientific, Logan, UT). If the average of the sensor readings from all five replicates of a treatment was less (drier) than that treatment's irrigation criterion, the irrigation valve to that treatment was opened. Plots with two tapes received a 1.5-hour irrigation, and plots with one tape received 3 hours of irrigation, so that each irrigation applied 0.1 inch regardless of the number of tapes. If the 0.1-inch irrigation did not sufficiently wet the soil to bring the sensor readings back above the criterion for a treatment, at the next 6-hour interval another irrigation would be applied. Water meters measured the volume of water applied to each treatment, and the meter readings were recorded daily.

All of the nitrogen fertilizer was injected through the drip tape. A 120-gal tank was used to hold a solution of 150 lb calcium nitrate dissolved in 111 gal of water by stirring with a paddle on an electric drill. The solution was metered into the irrigation water using a model A30-2.5 Dosmatic metering pump (Dosmatic USA International, Inc., Carrolltown, TX) at a rate of 1 gal of fertilizer solution to 500 gal of irrigation water. Fertilizer was injected to supply 50 ppm NO_3 in the drip irrigation water, beginning with the first irrigation on May 26.

Leaf petioles were monitored regularly to assure that plant nitrogen status remained in the ideal range for all treatments. On June 17 and 18, 11 lb N/acre, 8 lb S/acre, 0.17 lb Cu/A, and 0.21 lb Mn/acre were injected to correct deficiencies shown in the first petiole test, which was taken on June 11. From June 18 to July 16, dissolved calcium nitrate fertilizer was injected to maintain 50 ppm NO_3 in the drip system. On July 17 to 18, 10 lb S/acre, 5 lb Mg/acre, 0.25 lb Zn/acre, and 0.25 lb Mn/acre were injected to correct deficiencies shown in the third petiole test, taken on July 12. From July 18 to July 31, calcium nitrate solution was again injected at 50 ppm NO_3. Fertilizer was injected to supply 50 ppm NO_3 in the drip system from June 2 to July 10. On July 10 additional calcium nitrate was injected to bring the total applied N on all treatments to 140 lb N/acre. From July 11 to August 2 fertilizer solution was injected to maintain 50 ppm NO_3 in the drip system. From August 3 through the final irrigation on September 19, no fertilizer was injected.

Fungicide applications to prevent late blight infection consisted of an aerial application of Ridomil Gold and Bravo at 2 lb/acre on June 14, and then Dithane at 4 pint/acre on June 22. Powdered sulfur was applied at 30 lb/acre by aerial application on July 14 and again on July 28 to control powdery mildew.

The vines were flailed on September 19. Potatoes were lifted on October 1 with a two-row digger (John Deere, Moline, IL) that laid the tubers back onto the soil in each row. The drip tape was dug along with the potatoes. It fed over the two-row primary chain digger and was gathered by hand and tied in bundles for disposal. At harvest, the potatoes in each plot were visually evaluated for defects such as growth cracks, knobs, curved or irregularly shaped tubers, pointed ends, or stem end decay. A 5-ft alley was measured at the ends of each plot. All tubers from the interior 45 ft of each plot were placed into burlap sacks and stored in a barn under tarps until grading.

Tubers were graded October 24 and a 20-tuber sample from each plot was placed into storage. The storage was kept near 90 percent relative humidity and the temperature was gradually reduced to 45°F. Samples were removed from storage December 5-6, specific gravity was measured using the weight-in-air, weight-in-water method for 20 tubers. To determine stem end fry color, 20 tubers/plot were cut lengthwise and center slices were fried for 3.5 min in 375°F soybean oil. Percent light reflectance was measured on the stem and bud ends of each fried slice using a model 577 Photovolt Reflectance Meter (Seradyn, Inc., Indianapolis, IN), with a green tristimulus filter, calibrated to read 0 percent light reflectance on the black standard cup and 73.6 percent light reflectance on the white porcelain standard plate (Shock et al. 1994).

Results and Discussion

Potatoes planted on April 19 did not fully emerge until May 20 due to cool-to-hot temperature fluctuations in April and May. Dry weather prevented late blight from developing in 2001. Precipitation for April through September was 2.13 inches.

2000 Drip Irrigation Management Factors Trial

Data for the 2000 trial have been presented previously (Shock et al. 2001. Yields in 2001 were generally higher than in 2000. In 2000 tuber specific gravity was influenced by the irrigation criteria and tape placement. There were more sugar ends in 2000, and lower percent of U.S. No. 1 tubers in

2000. The automated drip system applied more water than the AgriMet estimate of evapotranspiration (Et_c) to the treatments irrigated at -15 kPa with either one tape per row or one tape per two rows (data not shown).

2001 Tape Placement

The average total yield of all eight treatments was 582 cwt/acre, with a significantly higher total yield, 634 cwt/acre, with one tape for two rows (Table 1). Total US No. 1 grade tubers were significantly higher with one tape per row. The yield of under 4-oz-tubers was significantly higher with a drip tape on every row. Treatments with a drip tape for every row of potato plants produced more tubers in the 6- to 12-oz grade, averaging 271 cwt/acre, compared to 168 cwt/acre with one tape for two rows. Conversely, the treatments with one tape for two rows produced 217 cwt/acre over 12 oz, compared to 129 cwt/acre for one tape for each row. A tape for each row also produced significantly fewer US No.2 grade tubers, with a significant interaction between the irrigation criterion and the drip tape.

2001 Soil Water Potential

Treatments with irrigation automated at -45 and -60 kPa yielded less than the -15 and -30 kPa treatments (Table 2). Yield of U.S. No. 1 grade tubers was significantly higher with the two wetter irrigation criteria. The -15 kPa treatments with 458 cwt/acre U.S. No. 1, and the -30 kPa treatments with 468 cwt/acre, produced more U.S. No. 1 than the -45 and -60 kPa treatments, 398 and 339 cwt/acre, respectively. Marketable yield for processing, which included the U.S. No. 1 and U.S. No. 2 grades, averaged 548 cwt/acre overall, with the -45 and -60 kPa treatments producing progressively less marketable yield.

2001 Tuber Quality

Stem end fry color was the only tuber quality variable affected by irrigation levels and tape placement (Table 2). A high percentage (7 percent) of sugar ends resulted from the use of one tape for two rows and irrigation at -45 kPa. Average tuber fry color was not affected by tape placement or soil water potential irrigation level. Tuber specific gravity was not affected by irrigation level and tape placement.

2001 Water Use

The automated irrigation system applied substantially more water than Et_c of 25.7 inches to the -15 kPa treatment with one tape per two rows, which received 32.9 inches of water. The –30 kPa treatment with one tape per two rows received 27.7 inches, slightly more than Et_c. One tape per row at -15 kPa resulted in 18.0 inches of water applied. The -30 kPa treatment with one tape per row applied 18.0 inches, the -45 kPa treatment with one tape per two rows applied 22.9 inches, and the -45 kPa with one tape per row applied 15.5 inches. The -60 kPa treatment with one tape per two rows applied 21.3 inches, and the -60 kPa with one tape per row applied 11.0 inches.

The automated, sensor-driven irrigation was a feedback control system, and soil water potential oscillated around the average treatment criteria (data not shown). This oscillation was more pronounced in the drier treatments, which had a pattern of irrigating four times a day for 3 or 4 days then not irrigating for 3 days. The two -15 kPa treatments irrigated every day, but not always all four times every day. The treatments with one tape per row received less water for a given soil water potential criterion because the sensors were closer to the tape, which increased the efficiency in wetting the GMS and reduced lag time in the feedback oscillation of irrigation frequency.

During the 2001 season, average potato yields were 402 cwt/acre in Malheur County. Yields in the current trial were higher, possibly in part because the field had not grown a potato crop in 10 years. Many growers have a shorter rotation between potato crops, which usually leads to increased pathogens in the soil. Typically, 43.2 inches of water are applied using furrow irrigation, and 36 inches are applied using sprinkler irrigation. From the county yield and water use figures, sprinkler and furrow irrigation result in 1,116 and 931 lb of potatoes for each acre-inch/acre of water applied. Using drip irrigation with a tape for every row and irrigating at -30 kPa, yield was 3,217 lb/acre for each acre-inch/acre of applied water, with adequate tuber grade and quality. The -45 and -60 kPa treatments with one tape per row had water use efficiency of 2,707 and 2,854 lb/acre for each acre-inch/acre of applied water, but tuber quality was adversely affected at these drier irrigation criteria.

Combined 2000 and 2001

When the data for both years were analyzed together, the tape placement factor (one tape per row or one tape for two rows) had a significant effect on every variable except total marketable yield and tuber bud-end fry color for which interaction effects with tape number were significant (Table 2). Irrigation with one tape for two rows at -15 or -30 kPa produced more total yield than drier treatments. Marketable yield, which includes tubers with defects that cause them to be graded U.S. No. 2, was highest with one drip tape for two rows of potatoes, and the -15 and -30 kPa irrigation levels. One tape for two rows produced more tubers over 12 oz, which can be undesirable for processing if the tubers are too large to fit through the French fry cutting machinery. One tape per row produced more tubers in the 6- to 12-oz category, but also produced more tubers under 4 oz, which could cause volunteer potato problems as they may remain in the soil after harvest. With one tape per row, specific gravity was higher, stem-end fry color was lighter, and there were fewer sugar ends. With one tape per two rows, the highest incidence of sugar ends, 8 percent, was at the -15 kPa irrigation level. If the contract allowed a tolerance for sugar ends, one drip tape for two rows could be more economical. There were more cull potatoes with the -15 kPa irrigation with either one tape per row or one tape for two rows.

The irrigation criterion considered alone only influenced the total U.S. No. 1 and over-12-oz size categories, producing more U.S. No. 1 tubers and fewer oversized tubers over 12 oz, with a tape on each row. Tuber defects that graded U.S. No. 2 were highest with the -15 and -30 kPa irrigation levels.

Tape placement and irrigation criterion interacted to influence total yield, total marketable potatoes, and U.S. No. 2 yield, due to higher yield with one tape per two rows but more U.S. No. 2 tubers. The year variable showed a difference in stem-end fry color and sugar ends, with more in 2000. The tape-by-year interaction was significant for percent U.S. No. 1, total yield, with more U.S. No. 1 tubers at the wetter irrigation criteria in 2001, and also significant effects on 6- to 12-oz, under 4 oz, percent U.S. No. 2, culls, and bud-end fry color. The irrigation criteria by year interaction was significant only for culls. The three-way interaction of tape, kPa, and year was significant for percent U.S. No. 1, marketable, total U.S. No. 1, U.S. No. 2, stem-end fry color, and sugar ends.

Future Opportunities with Drip Irrigation

The drier treatments in this study were based on soil water potential that would be in the acceptable range of dryness for furrow or sprinkler irrigated potatoes. With this soil moisture sensor-driven automated drip irrigation system the drier treatments often had several days between irrigations, as shown by the flat regions of the lines in the graphs of applied water (Fig. 1 and 2). If the objective had been to grow a potato crop with a limited water supply, the tuber grade and quality might be harmed less with a daily irrigation with a fraction of Et_c.

Other research has shown that application of irrigation that closely matches the water needs of the crop results in better nitrogen use efficiency and reduced leaching potential. Less N fertilizer was required in the current trials than is routinely used by growers.

Drip irrigation might be used to deliver systemic fungicides or insecticides in small doses directly to the root system of the crop, possibly reducing production costs and chemical use. Hypothetically, these smaller doses might be able to substitute for high rates of soil fumigants used to prepare the soil for a potato crop. A systemic fungicide might replace aerial spraying on a scheduled basis to protect the foliage from late blight. Systemic fungicide could also potentially improve yields by preventing early vine death, thus prolonging the growing season.

Acknowledgments

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Table 1. 'Umatilla Russet' 2001 yield, grade, and processing quality when grown with automated drip irrigation using either one tape for two rows or a tape for every row, at four levels of soil water potential. Malheur Experiment Station, Oregon State University, Ontario, OR, 2002.

				Yield by grade									Fry color			
Number of drip tapes		U.S. No. 1	Total yield	Total marketable	Total U.S. No. 1	Over 12 oz	6 to 12 oz	4 to 6 oz	Under 4 oz	U.S. No. 2	Cull	Specific gravity	Stem end	Bud end	Average	Sugar ends
	kPa	%	----------	----------	----------	----------	cwt/acre	----------	----------	----------	----------	$g\ cm^{-3}$	--------	% Reflectance	--------	%
one per two rows	-15	69	651	619	451	285	158	8	11	167	17	1.0884	39	48	43	4.0
	-30	70	658	623	460	274	175	11	11	163	19	1.0906	40	46	43	2.0
	-45	60	620	580	370	178	182	11	14	210	20	1.0892	39	46	43	7.4
	-60	49	608	566	297	131	158	8	14	269	28	1.0886	41	47	44	3.0
	Mean	62	634	597	394	217	168	9	12	202	21	1.0892	40	47	43	4.1
one per row	kPa															
	-15	82	563	535	464	165	265	34	18	71	10	1.0915	41	47	44	3.0
	-30	82	579	547	477	140	304	34	18	70	10	1.0920	41	47	44	3.0
	-45	83	515	481	425	141	241	42	20	56	12	1.0922	43	46	45	0.0
	-60	82	467	431	381	71	274	37	25	50	7	1.0900	41	46	44	0.0
	Mean	82	531	499	437	129	271	37	20	62	10	1.0914	42	46	44	1.5
Average	kPa															
	-15	76	607	577	458	225	212	21	15	119	13	1.0900	40	47	44	3.5
	-30	76	618	585	468	207	239	22	14	117	14	1.0913	41	46	44	2.5
	-45	71	567	531	398	160	212	27	17	133	16	1.0907	41	46	44	3.7
	-60	65	537	498	339	101	216	22	19	159	18	1.0893	41	46	44	1.5
Overall	Mean	72	582	548	416	173	220	23	16	132	15	1.0903	41	47	44	2.8
LSD(0.05)	Tapes	4	12	13	35	53	61	8	4	24	7	NS	2	NS	NS	NS
	kPa	NS	NS	18	49	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Tapes x kPa	8	NS	NS	NS	NS	NS	NS	NS	48	NS	NS	NS	NS	NS	5.4

Table 2. 'Umatilla Russet' average of 2000 and 2001 yield, grade, and processing quality when grown with automated drip irrigation using either one tape for two rows or a tape for every row, at four levels of soil water potential. Malheur Experiment Station, Oregon State University, Ontario, OR, 2002.

				Yield by grade									Fry color			
Number of drip tapes		U.S. No. 1	Total yield	Total marketable	Total U.S. No. 1	Over 12 oz	6 to 12 oz	4 to 6 oz	Under 4 oz	U.S. No. 2	Cull	Specific gravity	Stem end	Bud end	Average	Sugar ends
	kPa	%	cwt/acre									$g\ cm^{-3}$	% Reflectance			%
one per two rows	-15	68	578	532	355	226	154	14	26	138	21	1.0883	37	45	41	7.5
	-30	70	557	510	350	209	160	20	31	121	8	1.0917	36	44	40	7.0
	-45	64	542	496	307	157	167	19	28	154	10	1.0882	37	45	41	6.0
	-60	57	524	474	279	116	156	21	32	181	7	1.0878	37	45	41	5.3
	Mean	65	550	503	354	177	159	18	29	149	18	1.0890	37	45	41	6.4
one per row	-15	78	535	474	458	133	245	41	45	56	15	1.0924	40	46	43	3.0
	-30	78	547	488	469	109	274	47	48	59	8	1.0939	39	45	42	3.0
	-45	75	481	414	398	93	215	55	56	51	10	1.0912	38	44	41	5.8
	-60	73	440	375	339	59	216	50	56	49	7	1.0909	39	45	42	4.3
	Mean	76	501	438	384	98	237	48	51	53	12	1.0921	39	45	42	4.0
Average	-15	73	557	503	407	180	199	28	36	97	18	1.0904	38	46	42	5.3
	-30	74	552	499	409	159	217	33	40	90	14	1.0928	38	45	41	5.0
	-45	69	512	455	353	125	191	37	42	103	15	1.0897	38	44	41	5.9
	-60	65	482	424	309	87	186	36	44	115	13	1.0894	38	45	41	4.8
Overall	Mean	70	526	470	369	138	198	33	40	101	15	1.0906	38	45	41	5.2
LSD(0.05)	Tapes	2	12	NS	16	19	20	4	4	10	4	0.0019	1	NS	1	2.1
	kPa	NS	NS	NS	23	27	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Tapes x kPa	NS	24	28	NS	NS	NS	NS	NS	20	NS	NS	NS	NS	NS	NS
	Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	2	NS	NS	2.9
	Tape x Year	3	17	NS	NS	NS	28	NS	6	14	7	NS	NS	1	NS	NS
	kPa x Year	NS	NS	NS	NS	NS	NS	NS	NS	NS	7	NS	NS	NS	NS	NS
Tape x kPa x Year		6	NS	20	32	NS	NS	NS	NS	28	NS	NS	3	NS	NS	5.9

Drip-Irrigated Onion More Responsive to Plant Population Than to Fertilizer Nitrogen

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Onion (*Allium cepa* L.) is usually fertilized with 300 lb/acre or more of N in furrow or sprinkler-irrigated fields in the Pacific Northwest. The use of drip irrigation is expanding for onion production and allows irrigation uniformity without leaching. Long day onion 'Vision' was subjected to a combination of seven nitrogen fertilizer rates (0 to 300 lb/acre in 50 lb increments) and four plant populations (75,000, 100,000, 125,000, and 150,000 plants per hectare) using drip irrigation in 1999, 2000, and 2001. Onions were grown on 44-in beds with two double rows centered 22 in apart with a drip tape buried 4 in deep in the bed center. Soil water potential was maintained nearly constant at -20 kPa by automated, high frequency irrigations based on soil water potential measurements at 8-in depth. Onions were evaluated for yield and grade after 70 days of storage. Onion yield and grade were not very responsive to the N fertilizer. Pre-plant soil available N, N mineralization, and N in irrigation water all contributed N to the crop. Onion yield and grade were highly responsive to plant population. Onion marketable yield increased with increasing plant population. Onion bulb diameter decreased with increasing plant population.

Introduction

Onion production with subsurface drip irrigation has been tested at the Malheur Experiment Station since 1992. While good guidelines have been developed for irrigation scheduling (Shock et al. 2000a), the optimum N fertilization practices for subsurface drip-irrigated onions are unknown. The plant population that optimizes yield and size of onions could be different under drip irrigation and could interact with the N fertilizer rate.

Residual soil N and fertilizer N have the potential to be used more efficiently in the context of carefully managed drip irrigation. Nitrogen fertilizer applied broadcast, sidedressed, or water run in a furrow irrigated field may be less efficient. Nitrogen applications with drip irrigation might be reduced compared to furrow irrigation as a result of the lower N leaching and potentially higher N use efficiency.

The objective of these trials was to determine the optimum combination of N rate and plant population for drip-irrigated onions to maximize yield, quality, and economic return.

Materials and Methods

Three trials were conducted at the Malheur Experiment Station, Ontario, Oregon on Owyhee silt loam in 1999, 2000, and 2001, each year following wheat. The fields had records of moderate productivity. In the fall 200 lb per acre of P_2O_5 plus other nutrients as required in the specific field (less N) were broadcast and the field was plowed and groundhogged twice. The field was fumigated in the fall prior to onions with Telone C-17 at 24 gal/acre and bedded on 22-inch centers. Onions (cv. 'Vision', Petoseed, Payette, ID) were planted in two double rows, spaced 22 inches apart in 44-inch beds in late March. Onions were planted at 210,000 seeds/acre. Nelson Pathfinder tape (Nelson Irrigation Corp., Walla Walla, WA) was laid simultaneously with planting at 4-inch depth between the two double onion rows. The drip tape had emitters spaced 12 inches apart and a flow rate of 0.22 gal/min/100 ft. Immediately after planting the onion rows received 3.7 oz of Lorsban 15G per 1,000 ft of row (0.82 lb ai/acre), and the soil surface was rolled. The trial was irrigated initially with a minisprinkler system (R10 Turbo Rotator, Nelson Irrigation Corp., Walla Walla, WA) for even stand establishment. Risers were spaced 25 ft apart along the flexible polyethylene hose laterals that were spaced 30 ft apart. Onions started emerging in April.

The seven N rates ranged from 0 to 300 lb N/acre (0, 50, 100, 150, 200, 250, 300 lb N/acre). The nitrogen for each treatment was split into five equal amounts and was applied as urea-ammonium nitrate (Uran) from late May through early July. Fertilizer solutions were applied through the drip lines with venturi injector units (Mazzei injector Model 287) installed in each plot. Nitrogen treatments were the main plots and were replicated three times each year. Nitrogen treatments were arranged in a randomized complete block design. Plant populations were split plots within each N plot. The plant populations (75,000, 100,000, 125,000, and 150,000 plants per acre) were achieved by hand thinning in May. Individual population plots were two beds wide and 50 ft long.

The soil water potential at 8-inch depth was designed to be maintained nearly constant at -20 kPa by applying 0.06 acre-in/acre of water up to eight times a day as needed based on automated soil water potential readings every 3 hours (Shock et al. 2000a, 2002). The automated drip irrigation system was started in May.

Soil water potential (SWP) was measured with one granular matrix sensor (GMS, Watermark Soil Moisture Sensors Model 200SS, Irrometer Co. Inc., Riverside, CA) at 8-inch depth, below an onion row in each split plot. In addition each main plot had a GMS installed at 18-inch depth below an onion row in the 125,000 plants/acre split plot. Sensors were calibrated to SWP (Shock et al. 1998). The GMS were connected to a datalogger (CR 10 datalogger, Campbell Scientific, Logan, UT) via five multiplexers (AM 410 multiplexer, Campbell Scientific, Logan, UT). The datalogger was programmed to read the GMS every 3 hours and, if the average of the sensors at 8-inch depth was less than -20 kPa, irrigate the field. The irrigations were controlled by the datalogger using a solenoid valve. The pressure in the drip lines was maintained at 10 psi by pressure regulators in each main plot. The amount of water applied to the field was recorded daily at 8:00 a.m. from a water meter installed downstream of the solenoid valve.

Onion evapotranspiration (Et_c) was calculated with a modified Penman equation using data collected at the Malheur Experiment Station by an AgriMet weather station (Wright 1982). Onion Et_c was estimated and recorded from onion emergence until the final irrigation and compared with onion evapotranspiration.

In late August, ten onion plants from the border rows in each subplot were taken for total N content determination. The tops were weighed, dried, weighed and ground. The bulbs were weighed and shredded. A shredded bulb subsample was weighed, dried, weighed, and ground. The ground top and bulb samples were analyzed for total N content. Nitrogen contribution from organic matter mineralization was estimated by anaerobic incubation at 104°F for 7 days (Waring and Bremner, 1964). The well water used for irrigation was analyzed for NO_3-N and NH_4-N. The well water used for irrigation had an average NO_3 and NH_4 concentration of 10.4 ppm and 1 ppm, respectively in 2001. Nitrogen contribution from irrigation was calculated to be 2.58 lb N/acre per acre-in of water in 2001, and lesser amounts in 1999 and 2000. The soil was sampled in 1-ft increments down to 2 ft in each replicate before planting and in each 125,000 plants/acre subplot after harvest and analyzed for nitrate and ammonium.

In mid September the onions were lifted to field cure. A week later, onions in the central 40 ft of the middle two double rows in each subplot were topped and bagged. The bags were placed into storage. The storage shed was managed to slowly lower the temperature and then maintain an air temperature of approximately 34°F. The onions were graded out of storage in mid-December. Bulbs were graded according to their diameters: small (<2¼ inches), medium (2¼ -3 inches), jumbo (3-4 inches), colossal, (4-4¼ inches), and supercolossal (>4¼ inches). Bulb counts of supercolossal onions were made during grading. Split bulbs were graded as No. 2s regardless of diameter. Marketable onions were considered perfect bulbs in the medium, jumbo, colossal and supercolossal size classes. Bulbs from all subplots were counted during grading in order to determine the actual plant population at harvest.

Gross economic returns were calculated by crediting the onion size classes with the average of prices paid to the grower (F.O.B. prices minus $3.13/50 lb for packing cost) from early August through January for the years 1992 through 2001.

Results and Discussion

Water applications over time closely followed onion Et_c. In 1999 and 2000, water applications plus rainfall were slightly less than onion Et_c (Shock et al. 2000b, 2001), while in 2001 water applications plus rainfall were slightly more than onion Et_c (Fig. 1). Onion Et_c for the 2001 season totaled 32 acre-inch/acre and irrigation water applied plus precipitation totaled 38 acre-inch/acre. Precipitation totaled 1.4 inches from onion emergence to the last irrigation. All three years, the soil water potential at 8-inch depth remained close to -20 kPa (Fig. 2), except for brief periods due to technical problems with the automated irrigation system. Soil water potential at 20-inch depth remained close to soil water potential at 8-inch depth.

Onion yield and grade did not respond to N rate. Each year, the unfertilized check treatment had a total N supply of over 300 lb/acre in the top two feet of soil during the season, counting the initial residual soil nitrate and ammonium, mineralized N, and nitrate and ammonium in the irrigation water (Table 1).

Whereas medium, jumbo, and total marketable onion yield increased with increasing plant population, colossal and supercolossal onion yield decreased (Figure 3). Only the onion yield and grade results from 2001 are reported here because the results from 1999 and 2000 were similar (Shock et al. 2000b, 2001). In 2000 and 2001 gross returns were not responsive to plant population. Within the range of plant populations tested, the decrease in gross returns, resulting from the decrease in marketable yield with decreasing plant population, was offset by the increase in supercolossal onions which give the highest returns.

Calculated gross returns increased with increasing plant population only in 1999, when we failed to consider the supercolossal onion yield and value separate from the colossal class. Consequently we consider this result as an artifact of our error of calculating value.

Acknowledgments

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Table 1. Nitrogen supply for the upper 2 ft of soil for drip-irrigated onions without considering any N fertilizer inputs. Malheur Experiment Station, Oregon State University, Ontario, OR.

Year	N supply			
	Pre-plant soil NO_3 + NH_4-N	N in irrigation water	Estimated N mineralization	Total N supply
	---------- lb/acre ----------			
1999	79	58	213	350
2000	120	58	228	406
2001	171	94	45	310

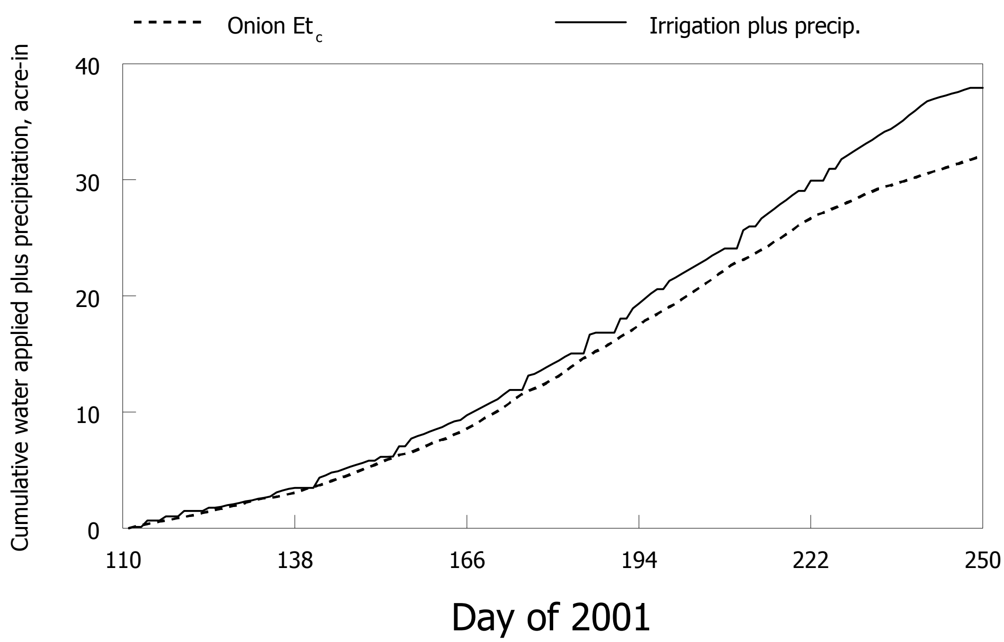

Figure 1. Cumulative water applied plus precipitation and Et$_c$ for onions drip-irrigated at a soil water potential of -20 kPa compared with estimated onion evapotranspiration in 2001. Malheur Experiment Station, Oregon State University, Ontario, OR.

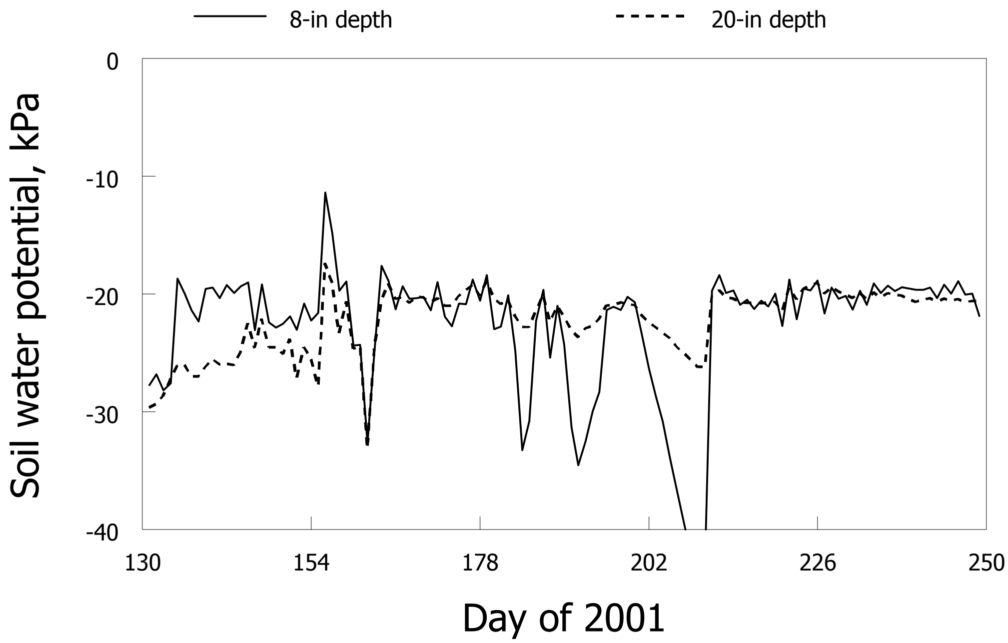

Figure 2. Soil water potential for drip-irrigated onions in 2001. Malheur Experiment Station, Oregon State University, Ontario, OR.

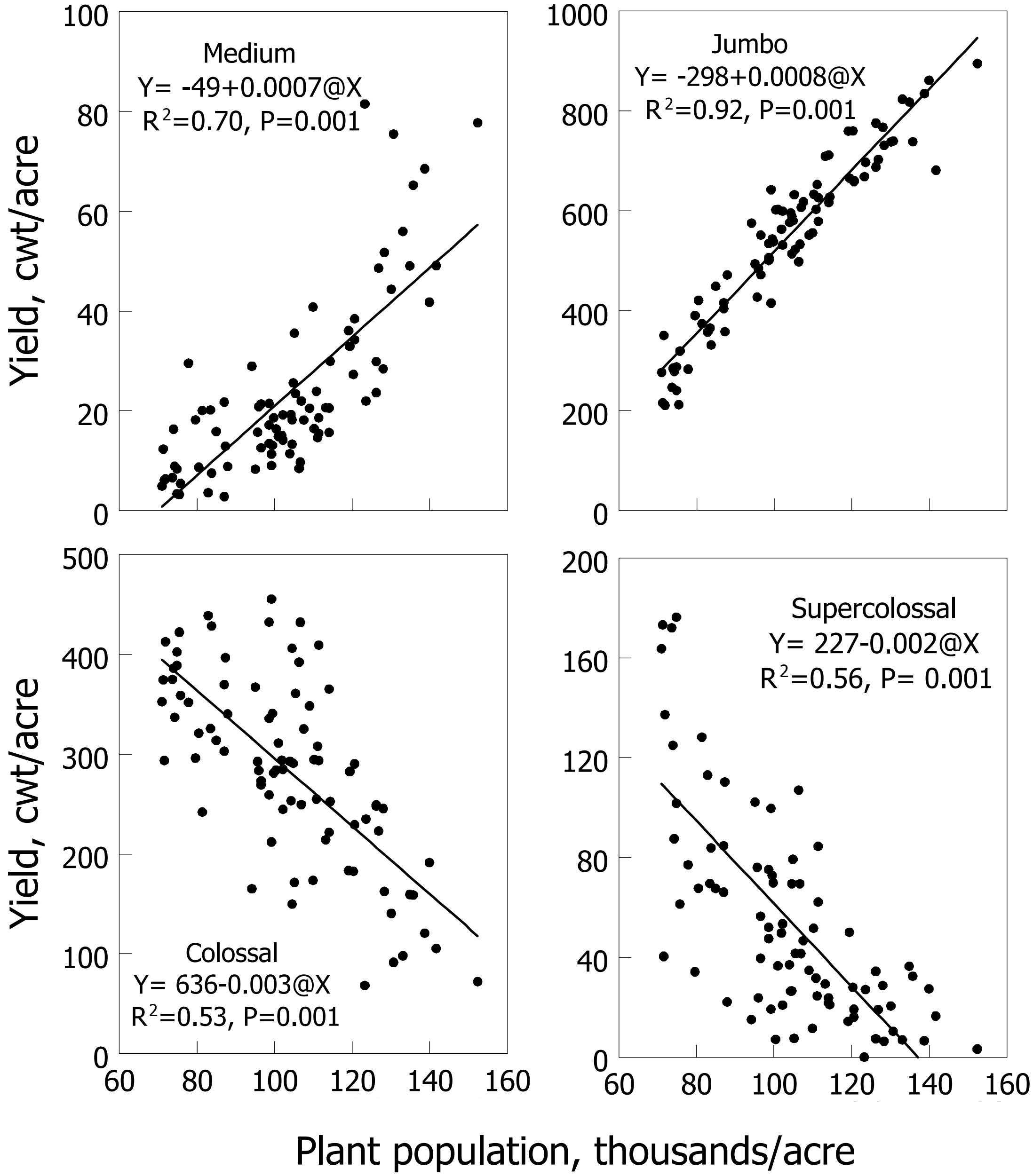

Figure 3. Onion yield response to plant population in 2001. Malheur Experiment Station, Oregon State University, Ontario, OR.

Effects of Irrigation and Pruning on 'Concord' Grape Productivity and Seasonal Root Development

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Abstract: A trial of heavy vs minimal pruning with and without supplemental irrigation was established in a mature Concord (Vitis labruscana Bailey) grape vineyard in a cool humid climate in Fredonia, New York in 1990. In the main trial minimal pruning gave significantly higher and more stable yields than with balance pruning, but fruit Brix levels were lower. Irrigation had its most positive effects in the minimal pruning treatment, but had few long-term effects on the severe pruning treatment. Clear butyrate minirhizotron tubes were installed in fall of 1996, and seasonal root production patterns were observed with remote video monitoring at 2 week intervals for the past 5 years. Patterns of root production varied from season to season. Root production was not apparently affected by pruning, but was strongly impacted by drought, or irrigation. In irrigated vines, total new root production varied from year to year; the variation in total numbers appeared to be best related to the amount of August root growth as influenced by crop level. Differences in new root production due to drought were primarily related to the lack of a pre-veraison August peak of root growth in the dry treatments. Computer simulations of carbon supply from the canopy and demands of the shoot and crop growth suggest that the pre-veraison period would provide the most available carbon for root growth. Irrigation maintained vine production so that there was carbon available for root growth. Irrigation did not consistently affect fine root lifespan.

Introduction

'Concord' (Vitis labruscana, Bailey) grapevines are grown in the cool, humid climate of Northeastern US primarily near the Great Lakes. The grapes are used mostly for fresh juice, and irrigation has been rare. Since the price paid per ton is relatively low and is the same as it was in 1972, to remain profitable growers have had to increase yields while also reducing production costs. The primary method to accomplish this is to leave more buds at winter pruning, so that the vines will produce more shoots with more crop. An extreme version of this is to essentially not prune the vines except trimming to keep the vines off the ground. This is called "minimal" pruning.

Compared to standard pruning, minimal pruning leads to much earlier canopy development on many more shoots, and heavier crops, typically 20-30% higher (Ralph, 1984; Clingeleffer and Krake, 1992; Pool, 1995). The early canopy development leads to more sunlight interception and thus higher productivity, but also uses more water early in the season. This combination of characteristics, while being very productive in low stress years, predisposes the vines to additional stresses such as drought due to the higher water use and the added stress of heavier crops. Irrigation studies in NY in the 1950's by Dr. Nelson Shaulis found no significant benefit of irrigation in normally-pruned vines with lower crop levels.

These factors led to the hypothesis that the effects of irrigation over time would be much greater on vines with minimal pruning than normally pruned vines. Consequently, studies were initiated in 1990 to examine the effects of supplemental irrigation on vine productivity in three levels of pruning severity over many years. This report covers 12 years of this study.

Additionally, in some vineyards and years, there are significant problems with poor crop development of Concord grapes in the Northeast leading to erratic bearing from year to year. The problems appear to be related to accumulated stresses such as heavy cropping from high node numbers over several years, drought years, etc. One consistent effect of heavy cropping on fruit crops is the reduction of growth of the root system. Yet, no measurements or observations on root systems of native American vines with or without these symptoms have been made. So we have monitored fine root production in this trial since 1997 to examine the effects of pruning, irrigation/drought, and the interactions on fine root production.

Materials and Methods

<u>Plant Materials</u> – The trial was established in a mature, 24-year-old, own-rooted 'Concord' (Vitis labruscana L.) vineyard at the Cornell University Vineyard Laboratory in Fredonia, NY near the shore of Lake Erie. The vines were planted at 2.44 m between vines and x 2.74 m between rows. The vineyard was located on a deep Chenango gravelly loam that was very well drained, had a relatively low water-holding capacity, but was at least 6 m deep.

<u>Vine Management</u> - The vines were trained as high wire cordons at about 1.8 m high. Until the late winter of 1990, all vines were pruned to approximately 80 buds per vine and averaged about 0.8 kg of cane pruning weight per vine after the 1989 season. The vineyard soil management consisted of a 1 m wide clean residual herbicide strip and row-middle glyphosate treatments at bloom (mid-June) each year. This led to a cover of primarily annual natural grasses. In this soil and with this management, vines in adjacent blocks have been found to have significant root numbers down to at least 2 m. Generally, this soil management system is considered to be quite water conservative.

<u>Treatments</u> – Six treatments in a split plot were applied in 1990; three pruning x two irrigation (main plots). The pruning treatments were:

- Balance pruned – 44 nodes per kg of cane pruning weight from the previous season
- 80 Node Constant – 80 nodes per vine (33 nodes/m) every year
- Minimally pruned – Only a low hedging cut at 1 m to eliminate low-hanging canes

The irrigation treatments were:

No irrigation – natural rainfall in the summer averages about 70 mm/month
Supplemental irrigation – applied as drip irrigation at weekly intervals when needed based on neutron probe monitoring and observations of vine appearance, shoot growth rates, leaf gas exchange, or vine stem water potentials.

<u>Root Growth Observations</u>. Fine root production was monitored since 1997 with remote microvideo camera (Bartz Technology, Santa Barbara, CA) photos through 5 cm diameter clear plastic tubes inserted in the soil under the vines in late 1996 (see Comas et al., 2000). This method is called the minirhizotron (McMichael and Taylor, 1987: Taylor, 1987). Observations were made at 14-day intervals from early April until December each year to determine when new fine roots were produced.

Results and Discussion

The rainfall in NY is generally adequate but is very erratic. For the May-September period the long-term total is 450 mm (monthly average rainfall of 90 mm), but can vary from 220 to 780 mm. In the 12 years of the trial the amounts of irrigation applied to the irrigated plots averaged 100 mm varied from 0 to 225 mm.

In the main trial minimal pruning gave significantly higher and more stable yields than with balance or 80 Node pruning, but fruit sugar levels were lower as expected with higher yield. As with the rainfall variation, yields and the effects of irrigation varied from year to year (Fig. 1). With balanced pruning the greatest benefit of irrigation was only about 2 t/ha and those increases only occurred in 3 years. With minimal pruning the increases exceeded 4 t/ha in 5 years and reached a maximum effect of 8 t/ha. Within the minimal pruning replicate plots there were even greater differences related to soil water holding capacity. One plot with better soil never showed a benefit of irrigation while a drier plot showed a long-term 20% increase in yields. There was very little variation amongst plots of the irrigated treatments.

Over the full 12 years of the study, several conclusions could be made. First, the minimal pruning gave 41 and 28% increases in yield over the balance and 80 Node pruning treatments. Additionally, irrigation gave no significant effect on yields of balance or 80 Node-pruned vines, but gave a 9% or 2.2 mT/ha increase in mean annual yields.

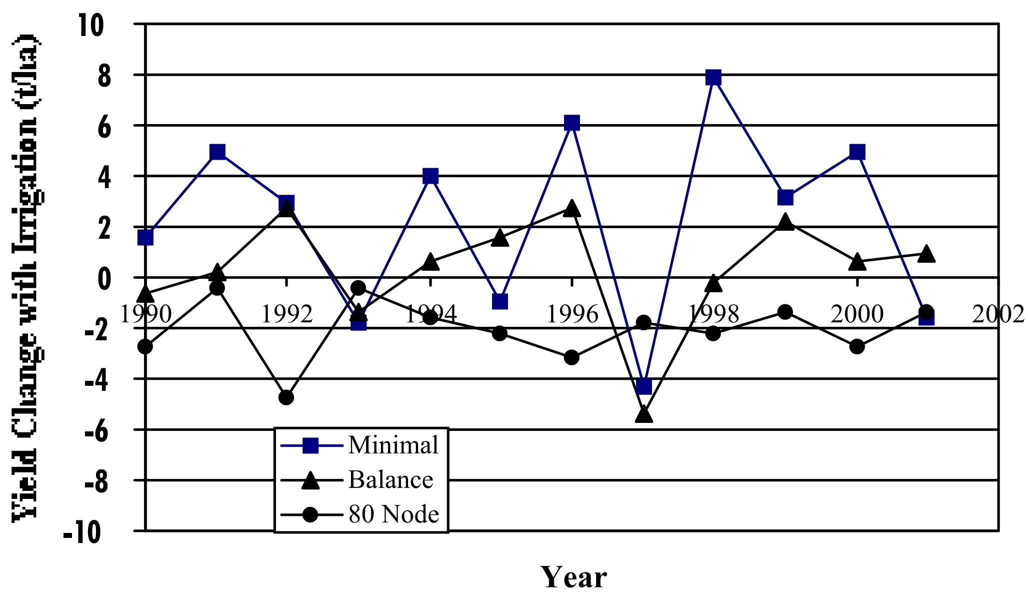

Figure 1. Yearly effects of irrigation vs the non-irrigated 'Concord' grapevines with balanced, 80 Node, and minimal pruning in Fredonia, NY.

Root observations indicated several led to several general conclusions:

• New roots could be produced at many times during the season between April and November, but generally peak root production occurred around bloom in June and again before veraison (the beginning of fruit ripening) in late-July and early-August.

• In dry years new root production was inhibited in dry soil, especially during July and August when droughts are typically the most severe in the Northeast.
• In wet years the numbers of new roots produced were similar, but in a very dry year, 1999, the non-irrigated vines produced only about 1/3 as many roots. McLean (McLean, 1993) also found a strong reduction in grape root growth with dry soil.
• There was no apparent effect of pruning regime on new root production.

From this study in the climate of New York, irrigation is not necessary for normally-pruned 'Concord' grapevines if a conservative soil management is used. With minimal pruning, however, irrigation may be of value, depending on the soil and soil/cover crop management. In this study over 12 years, 12 additional tons of yield/ha generated approximately $7400 of additional income/ha even though the prices per ton for 'Concord' grapes were quite low, averaging only about $275/ton. In a related experiment with mature 'Concord' at the same location, but on a somewhat drier site, irrigation gave 15 and 23 % increases for balance and minimally-pruned treatments, respectively, during a 5-year period when the irrigation in the study reported here gave no increase for balance pruning and an 11% increase with minimal pruning.

In conclusion, the need for irrigation of grapes in a cool humid climate is not assured. It depends not only on the rainfall patterns, but also on other factors, such as pruning and soil type that affect water requirements or soil reserves. To address the need for irrigation, a risk assessment approach for water balance is needed (Lakso, 1999).

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Performance of Line Source Emitters under Fertigation Using Leachate from an On-Farm Anaerobic Digester.

Dorota Z. Haman[1] David M. O'Keefe Anne W. Barkdoll

With appropriate treatment, it is possible to use the effluent from the anaerobic digester for injection directly into a drip system for fertigation. Three types of drip irrigation lines under seven treatments for clogging control were evaluated during two seasons on an organic farm that is currently receiving food waste and recycle it using anaerobic digestion and fertigation using the liquid fraction from the digestion process. Following treatments were used to prevent emitter clogging: T1: filtration, T2: filtration and chlorine, T3: filtration and acid, T4: filtration, acid and chlorine, T5: ozone, T6: well water (no effluent), T7: well water and chlorine. The change in uniformity and in flow rate with time was evaluated. Two of the drip tapes RoDrip and Chapin were used in both seasons, however TigerTape was substituted with Queen Gil in the second season. Sand media filtration without chemical injection was not sufficient to prevent clogging of all three types of drip line, especially during the first season. The quality of the effluent was much better in the second season resulting in less clogging problems in all treatments.

INTRODUCTION

There are very few liquid, organic fertilizers currently available. Most organic forms of fertilizer are not sufficiently soluble in water to be suitable for fertigation. An exception is fish emulsion, which however, is ten times more expensive than comparable forms of soluble fertilizer (Burt et al., 1995). The liquid fertilizer from anaerobic digestion should be less costly than fish emulsion which is imported into the region from as far away as Alaska (Full Circle Solutions, Inc., 1997).

Some of the characteristics of the digester liquid fertilizer may contribute to clogging of micro-irrigation emitters. Emitter clogging is still a major problem and is related to the quality of the irrigation water (Gilbert and Ford, 1986). Factors such as microbial activity, suspended solids, and chemical activity determine the type of water treatment required to prevent clogging (Gilbert and Ford, 1986). Suspended solids in the range of 50 – 100 ppm and bacterial populations of 10,000 – 50,000 per L can cause moderate clogging problems (Burt et al., 1995). Other than using high quality water sources, methods to prevent clogging include water filtration, flushing and chemical treatment. Chlorine, acids, and ozone are some of the chemical treatments used to prevent clogging (Burt et al., 1995; Burt and Styles, 1994).

Emitter clogging in micro systems can be the biggest problem with fertigation. Usually, sodium hypochlorite (chlorine) is used for periodic cleaning of irrigation lines and emitters. Currently, chlorine is still permitted for irrigation cleaning purposes on organic farms. Other methods, such as

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1 **Florida Agricultural Experiment Station Journal Series No. N-02278**. The mention of trade names or commercial products is solely for the information of the reader and does not constitute an endorsement or recommendation for use.
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ozone treatment, are more expensive but promising for organic production. Clogging problems can also be minimized through careful selection of irrigation and filtration equipment. Five types of treatment (filtration, chlorination with filtration, acid injection, acid combined with chlorine, and ozone treatment with filtration and flushing) were compared to control treatment of direct well water and chlorinated water. The systems were evaluated for clogging and changes in application uniformity by using a statistical uniformity coefficient (Bralts and Kesner 1983, Haman et al., 1997).

IRRIGATION AND FERTIGATION TREATMENTS

Effluent was injected into drip irrigation system during two vegetable seasons 2001 and 2002. Three types of drip irrigation lines under seven treatments for clogging control were evaluated in each season. Continuous fertigation using the liquid fraction from the digestion process was used during each growing season using peristaltic injection pump (Masterflex, Cole-Parmer Instrument Company, Vernon Hills, IL). The injection rate of the effluent was 1 gallon per minute (gpm). Approximately, 60 gallons of effluent were injected into 5 irrigation treatments during each irrigation cycle.

The test included seven treatments. Five included effluent injection and two were used as controls. One control included typical chlorine treatment of well water often used by the growers and one was well water without any treatment. The treatments are summarized in Table 1.

Table 1. Summary of treatments for emitter clogging prevention.

Treatment symbol	Treatment description
T1	Effluent + sand and screen filtration
T2	Effluent + sand and screen filtration + chlorine
T3	Effluent + sand and screen filtration + acid
T4	Effluent + sand and screen filtration + acid + chlorine
T5	Effluent + sand and screen filtration + ozone
T6	Well water
T7	Well water + chlorine

All filtration was accomplished using a sand media filter with a #20 media followed by 200-mesh screen filter and small, secondary 200–mesh screen filters in each treatment. Each manifold (one for each treatment) included a pressure regulator, a flowmeter, a pressure gauge and a secondary 200-mesh screen filter. The layout of the microirrigation system control head and chemigation treatments is presented in Figure 1. Injection of acid and chlorine were accomplished using peristaltic pumps with a flow rate of approximately 1 gal/ hour (gph). Acid (hydrochloric, 35%) and ozone were injected continuously during irrigations (treatments T3,T4,T5). Chlorine injection was performed once a week using 10% household bleach. Initially, it was attempted to inject chlorine continuously at a rate that would maintain the concentration of 2 ppm at the end of the farthest lateral line. However, due to varying quality of effluent and changing amount of organic matter in the lines it was decided to chlorinate at high concentration once a week. Full strength of chlorine was injected for one hour/week at approximately 1gph into treatments T2 and T4. The objective of acid injection was to lower the pH of water to inhibit bacterial growth and to increase the activity of chlorine in the treatment where chlorine was injected. Again, due to variation in effluent quality and very high buffering capacity of the effluent in the first season frequent adjustment was necessary.

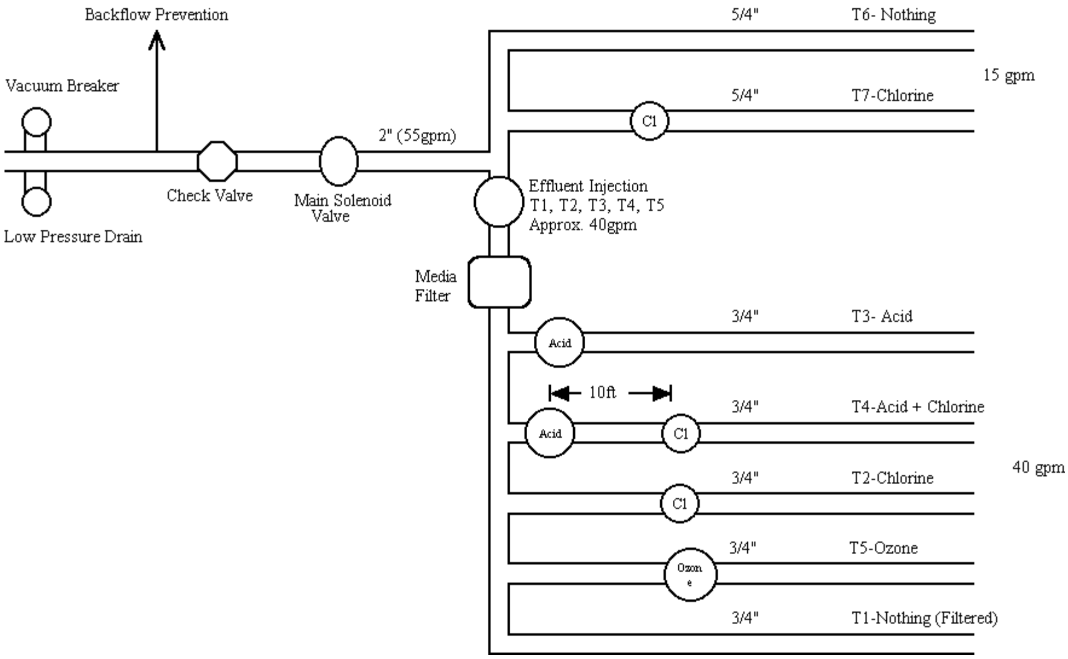

Figure 1. Control head and injection schematic for irrigation/fertigation treatment

Ozone was generated using model CS-4 ozone generator (Ozonology Inc. Northbrook, IL) and injected into the system using a venturi (Mazzei Injector Cooperation, Bakersfield, CA) injector. The rate of air intake into the ozone generator was approximately 2-3 cubic feet per hour. The average rate of ozone that could be detected at the end of the line was approximately 0.2 ppm. The water collected at the end of the lines was periodically tested for pH, free chlorine and ozone, depending on the treatment.

Three blocks with different drip tape were tested. Seven treatments were completely randomized throughout the block and replicated three times. Each replication consisted of two 50-ft long drip lines (100 ft per replication). The layout of the drip tape is presented in Figure 2. All three tapes were 8 mil thick with 8 inch spaced emitters and with very similar flow rates. In 2001 following tapes were evaluated: TigerTape (40 gph/100ft) RoDrip (40 gph/100 ft) Chapin (39 gph/100 ft). In 2002 season the Tigertape was substituted with Queen Gil, emitter spacing of 4” with (4 emitters per outlet) with approximately 40 gph flow rate due to its poor performance of TigerTape in the first season. Queen Gil was selected since it has a very different design and emitter flow and there is a lot of interest among vegetable growers in this new drip tape.

Water was applied daily for one hour. All treatments were watered at the same time. Effluent was injected into T1-T5 whenever the irrigation system was on. Water application to each treatment was recorded using a flow meter. The system was turned off after major rainfall and on some days during winter season (second season). This was controlled by the farm owner.

The uniformity of water application was tested twice during the first season and three times during the second season. In both seasons the tests were performed at the beginning and at the end of the season. Since the second season was much longer, an additional uniformity test was performed in the middle of the season. Water was collected into the trays from three emitters at 4 random locations along each lateral. Since each treatment consisted of two lines replicated 3 times, water was collected at 24 locations for each treatment. The uniformity of water application was calculated using the following equation: U = (1-V) 100% , where V is a statistical coefficient of variation.

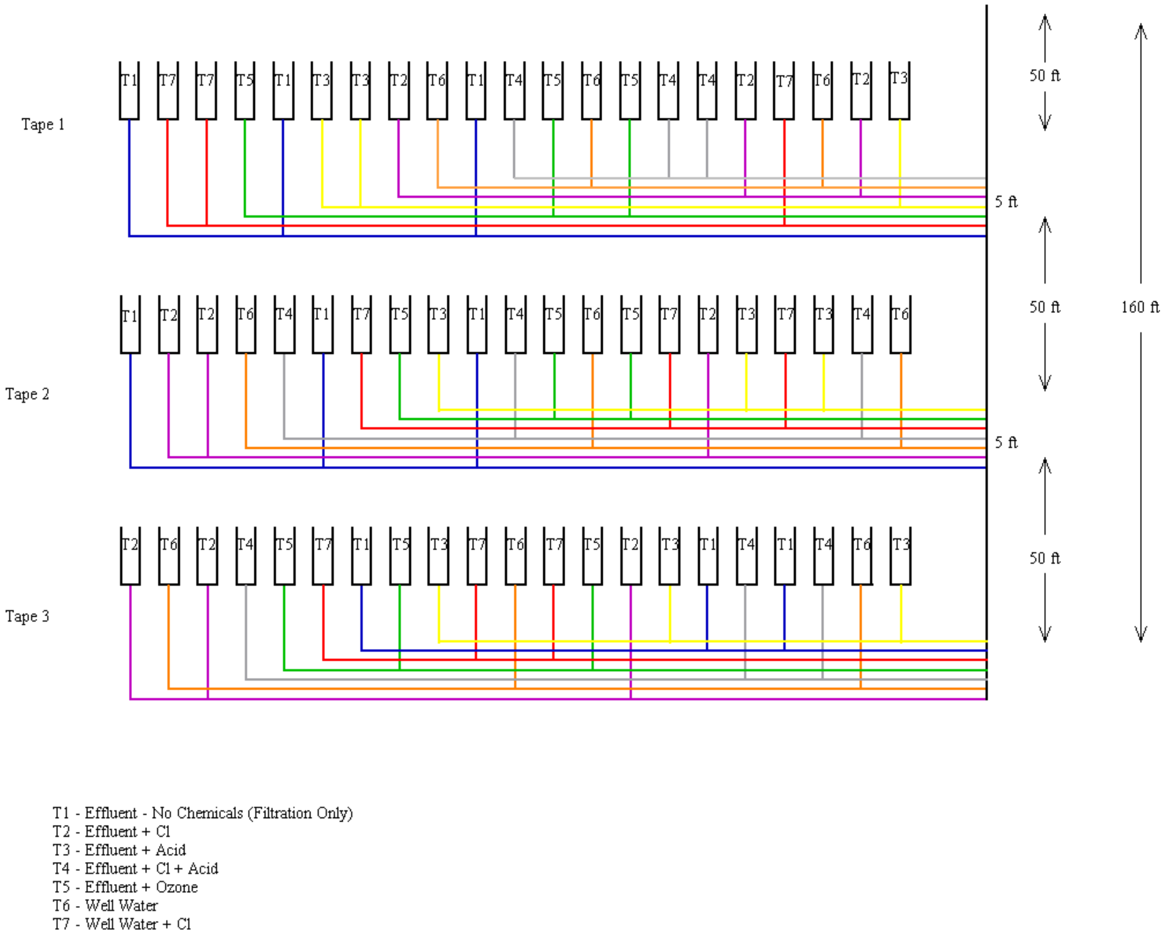

Figure 2. The layout of drip tape treatments in the field.

Irrigation System Performance

The change in uniformity and in flow rate with time was evaluated. Two tests were performed in 2001 season and three were performed in 2002. The number of uniformity tests was increased in 2002 since the tape was installed earlier (November 2001) and the fertigation trials started before plans were planted at the beginning of 2002. At this farm, plants are added gradually, so there is no specific day of planting.

The quality of the effluent was quite variable and there was a big difference in the quality of effluent used in the first season as compared to the second season. In 2001 all kind of food waste was used in the digester where in 2001 the waste used was mainly vegetable waste. This change may have contributed to the lower clogging problems in the second season (see tables 2-6).

Table 2. Statistical uniformity (%) of 3 drip tapes at the beginning of the 2001 season 02/13/01

	T1	T2	T3	T4	T5	T6	T7
TigerTape	89	87	94	87	91	81	87
RoDrip	94	91	90	91	95	91	88
Chapin	93	95	94	95	97	96	94

Table 3. Statistical uniformity (%) of three drip tapes at the end of 2001 season 04/24/01

	T1	T2	T3	T4	T5	T6	T7
TigerTape	**	5 6	43	78	61	64	67
RoDrip	**	86	56	81	54	71	86
Chapin	51	88	85	89	74	90	74

** too low uniformity to evaluate

Table 4. Statistical uniformity (%) of three drip tapes at the beginning of 2001/2002 season11/08/01

	T1	T2	T3	T4	T5	T6	T7
QueenGil	91	92	94	90	90	91	91
RoDrip	94	97	96	95	97	92	96
Chapin	92	97	92	97	97	96	95

Table 5. Statistical uniformity (%) of three drip tapes the middle of 2001/2002 season 03/07/02

	T1	T2	T3	T4	T5	T6	T7
QueenGil	83	89	66	71	81	82	71
RoDrip	96	88	94	97	86	91	90
Chapin	96	97	97	89	92	95	97

Table 6. Statistical uniformity (%) of three drip tapes at the end of 2001/2002 season 04/26/02

	T1	T2	T3	T4	T5	T6	T7
QueenGil	39	57	66	35	44	59	69
RoDrip	81	93	85	91	91	89	93
Chapin	83	83	86	90	78	91	87

The flow rate to each individual treatment was recorded using ¾" flowmeters every week or more often. The changes of low throughout the season are presented in Figures 3 and 4. In the first season the flow rates were reduced at the end of the season in all treatments where effluent was injected. Only two treatments without injection maintained approximately the same flow rate (300 gph). Treatment T1 (effluent injection without any chemical treatment) experienced the lowest flow rate at the end of the season. Media filtration followed by 200-mesh screen without chemical treatment of chlorine, acid or ozone was not sufficient to prevent significant clogging of emitters. Treatments T2,T3,T4, and T5 had the flow rates reduced by approximately 50% but the uniformity was still high at the end of the season (88%, 85%, 89%, and 74% respectively). This indicates “relatively uniform clogging” along the lines. To deliver the required amount of water to the plants, due to the flow rate reduction, the watering time would have to be double by the end of the season.

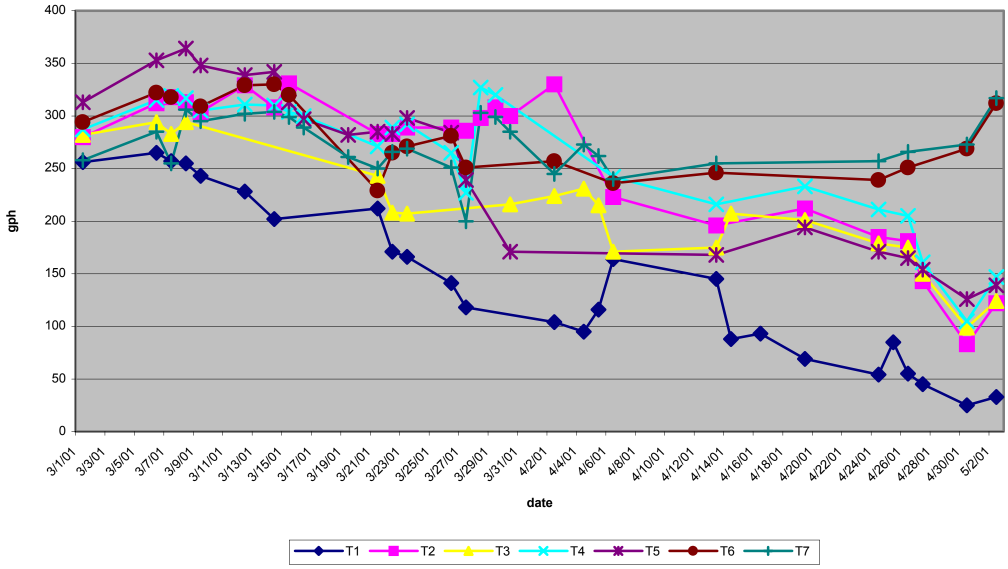

Figure 3. The changes of flow rates to the individual treatments during the first season.

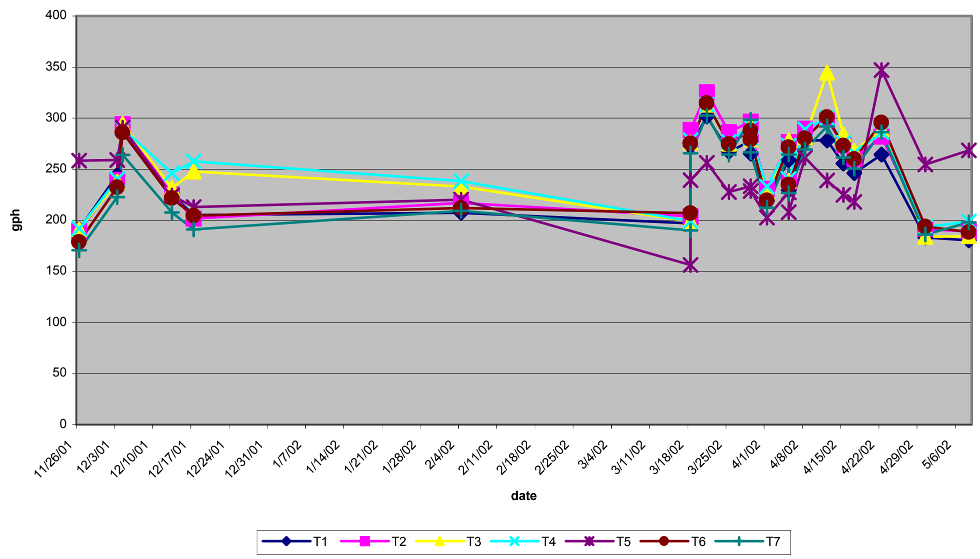

Figure 4. The changes of flow rates to the individual treatments during the second season.

In the second season there were no differences in the flow rates between the beginning and the end of the season (no measurable emitter clogging) and among the treatments. Based on the results, it can be concluded that with appropriate chemical treatment, it is possible to use the effluent from the anaerobic digester for injection directly into the drip system with minimal loss of uniformity throughout the growing season. Differences in the results between the first and second season are probably attributable to improved management and operation of the digester during the second season. Improved management and operation of the digester led to more consistent effluent properties and more thoroughly treated effluent. During the first season effluent was being drawn from the leach bed portion of the digester due to plumbing difficulties associated with the choice of high-rate centrifugal pumps for recirculating effluent. This problem was rectified by the second seasons trial by using low-rate peristaltic pumps. As a result we were able to use the effluent from the second stage (pack bed) that was lower in both total and volatile solids. Average total and volatile solids for effluent drawn from the leach bed portion of the digester were 1.3% and 56.6% respectively, while for effluent drawn from the packed bed portion of the digester they were 0.9% and 50.4%. As a result, effluent drawn from the leach bed portion of the digester had higher inert particulates and carbohydrates to encourage bacterial growth. Both of these factors can increase clogging of emitters. In addition, during the irrigation trials the first season the digesters were cleaned out and restarted using air potatoes. As a result the effluent was affected by both the change in digester feed stocks and effluent changes during the digester startup after the cleanout. During the second trial the digester had been running for over six months at "steady state" conditions treating only food waste. The change may have contributed to the lower clogging problems in the second season (Table 2-6). The first season's trial conditions should be considered close to a worst-case scenario for effluent quality and the second season conditions to be normal.

Irrigation Water Quality

Periodically the pH and Electrical Conductivity (EC) was measured at the plots. These results are presented in table 7.

Table 7. Electrical conductivity and pH of water in different irrigation treatments throughout the second season.

Date: 3/18/02

	T1	T2	T3	T4	T5	T6	T7	Effluent	Well Water
pH	6.84	6.91	6.95	2.24	7.0	6.54	6.67	8.21	6.42
EC (*100 umol/cm)	6.20	6.60	6.20	7.00	5.3	3.40	4.40	20	2.00
Ozone Detected					yes				

Date: 4/5/02

	T1	T2	T3	T4	T5	T6	T7	Effluent	Well Water
pH	7.03	7.02	6.49	2.61	6.94	6.70	6.75	8.5	6.54
EC (*100 umol/cm)	5.80	5.60	6.00	9.40	5.20	3.60	4.00	18.4	3.60
Ozone Detected					yes				

Date: 4/15/02

	T1	T2	T3	T4	T5	T6	T7	Effluent	Well Water
pH	7.13	7.06	5.89	5.72	7.01	6.75	6.90	8.3	6.51
EC (*100 umol/cm)	5.00	5.00	6.10	6.10	5.20	3.60	3.80	18.6	3.40
Ozone Detected					yes				

A sample of effluent was tested every time the tank was filled. The results of the tests are presented in table 8. There was a significant variation in nutrient content of the effluent throughout the season.

Table 8. Effluent analysis

Date	TS %	VS (% of TS)	Ammonia mg/l	TKN mg/l	Total P mg/l	K mg/l	COD mg/l
12/14/01	0.7	34.2	2515	2826	62	811	8120
12/10/01	0.6	54.4	2467	2861	59	807	7920
02/12/02	0.6	37.1	2454	2800	43	801	5192
03/21/02	Nd*	Nd	1770	3500	17	478	2226
03/27/02	Nd	Nd	1143	3290	16	454	2448
04/01/02	Nd	Nd	611	2250	7.6	202	1416
04/22/02	Nd	Nd	1361	2370	16.8	522	2680
05/01/02	Nd	Nd	1584	1991	24	570	3496

* Not determined

Conclusions

It can be concluded that effluent can be injected into the drip line if appropriate clogging prevention method is used to prevent the decrease of uniformity. The quality of effluent is very important in drip tape performance. Drip tape selection is an important factor in maintaining high application of uniformity throughout the season.

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USING BEEF LAGOON WASTEWATER WITH SDI

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ABSTRACT

Using subsurface drip irrigation (SDI) with lagoon wastewater has many potential advantages. The challenge is to design and manage the SDI system to prevent emitter clogging. A study was initiated in 1998 to test the performance of five types of driplines (with emitter flow rates of 0.15, 0.24, 0.40, 0.60, and 0.92 gal/hr-emitter) with beef lagoon wastewater. A disk filter (200 mesh, with openings of 0.003 inches) was used and shock treatments of chlorine and acid were injected periodically. Over the course of four seasons (1998-2001) a total of approximately 66 inches of irrigation water was applied through the SDI system. It is estimated that approximately 9300 lbs/acre of total suspended solids have passed through the driplines. The flow rates of the two smallest emitter sizes, 0.15 and 0.24 gal/hr-emitter decreased approximately 40% and 30%, respectively, during the four seasons, indicating considerable emitter clogging. The three driplines with the highest flow rate emitters (0.40, 0.60, and 0.92 gal/hr-emitters) have had approximately 7, 8, and 13% reductions in flow rate, respectively. Following an aggressive freshwater flushing, acid and chlorine injections in April of 2002, the flowrates of the lowest two emitter sizes (0.15 and 0.24 gal/hr-emitter) were restored to nearly 80 and 97% of their initial flowrates, respectively. Further laboratory tests on individual emitters from excavated driplines showed the lowest flow dripline experiencing partial clogging of most emitters with full clogging of about 4% of the emitters. These results indicate SDI can be used to successfully apply beef lagoon wastewater. However, the smaller emitter sizes normally used with groundwater sources in western Kansas may be risky for use with lagoon wastewater.

INTRODUCTION

In response to increasing nationwide concern with livestock wastewater generated by confined animal feeding operations, K-State Research and Extension initiated a project to address odor, seepage into groundwater and runoff into surface water supplies. Subsurface drip irrigation (SDI) is a potential tool that can alleviate all three problems, while still utilizing livestock wastewater as a valuable crop production resource. A study was begun in 1998 on a commercial beef feedlot to answer the engineering question, "***Can SDI be successfully used to apply livestock wastewater?***"

Approximately 8 million cattle are on feed in the central and southern Great Plains of the USA; more than 2 million are in Kansas alone. Using the Kansas design parameter of 250 ft^2 per animal, the land area of feedlots in the Great Plains is approximately 45,500 ac, and that in Kansas is approximately 11,400 ac. Perhaps 20 to 33% of average annual precipitation in the Great Plains could be collected as runoff from feedlots. Assuming 20% runoff and an average annual precipitation of 20 inches, approximately 3,700 to 15,000 ac-ft of runoff from feedlots might be available annually in Kansas and the Great Plains, respectively. This feedlot runoff, minus any evaporation from the lagoons, must be disposed of by land application.

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Using subsurface drip irrigation (SDI) with this livestock wastewater has many potential advantages:

- Saves fresh water for other uses
- Reduces groundwater withdrawals in areas of low recharge
- Rich in nutrients, such as N, P, and K, for crop growth
- Reduced human contact with wastewater
- Less odors and no sprinkler aerial pathogen drift
- No runoff of wastewater into surface waters
- Subsurface placement of phosphorus-rich water reduces hazards of P movement into streams by surface runoff and soil erosion
- Greater water application uniformity resulting in better control of the water, nutrients, and salts
- Reduced irrigation system corrosion
- Reduced weather-related water application constraints (especially high winds and freezing temperatures)
- Increased flexibility in matching field and irrigation system sizes
- Better environmental aesthetics

Worldwide, the leading cause of microirrigation system failure is clogging of the emitters. Therefore, it is easy to recognize that prevention of emitter clogging will be the primary design and management challenge of using SDI with this particle-rich, biologically active wastewater. Given that challenge, the objective of this project was to measure the performance of five different dripline types as affected by irrigation with filtered but untreated water from a beef feedlot runoff lagoon.

METHODS

This project was conducted adjacent to a beef cattle feedlot in Gray County, KS. The soil type is a Richfield silt loam. As is typical for beef feedlots in the region, precipitation runoff water from beef cattle pens was collected in a single-cell lagoon. Selected wastewater characteristics are shown in Table 1.

Table 1. Selected wastewater characteristics, Midwest Feeders, KS, 1998-2001.

Sampling Date	pH	EC mmho/cm	SAR	N ppm	P ppm	K ppm	TDS ppm	BOD ppm	TSS ppm
Mar. 6, 1998	8.00	2.93	1.8	118	35	336	1875	N/S	N/S
Jun. 5, 1998	7.81	2.56	1.9	92	30	341	1613	N/S	N/S
Jul. 17, 1998	7.84	2.54	2.0	67	30	349	1625	N/S	N/S
Jul. 31, 1998	7.64	2.70	2.0	89	30	383	1728	N/S	N/S
Aug. 21, 1998	7.60	2.90	2.2	51	33	428	1856	N/S	N/S
Sep. 1, 1998	7.90	3.60	2.3	84	32	467	2304	96	190
May 12, 1999	8.20	5.29	2.9	260	39	724	3386	1033	580
Aug. 13, 1999	7.60	4.30	2.9	160	39	672	2739	405	1320
Sep. 10, 1999	8.00	5.30	2.8	140	31	724	3379	255	440
Jun. 23, 2000	7.80	4.90	2.9	240	53	828	3136	998	533
Jul. 13, 2000	8.10	5.20	2.7	250	53	828	3328	834	740
Aug. 25, 2000	8.00	5.10	3.0	210	31	888	3290	228	940
Jul. 13, 2001	8.20	6.40	2.8	360	48	991	4109	154	1225
Aug. 24, 2001	8.20	5.00	2.5	160	26	784	3194	142	390

N/S: Not sampled.

Abbreviations: N: nitrogen, P: phosphorus, K: potassium, TDS: total dissolved solids, TSS: total suspended solids, BOD: biochemical oxygen demand.

In April 1998, driplines were installed 17 inches deep and on a lateral spacing of 60 inches. Each plot was 20 ft wide (4 driplines) and 450 ft long. Plots were arranged in a randomized complete block design with three replications. There was a border plot at the north and south ends for a total of 17 plots. The system installation and testing were completed on June 16. The first wastewater was used for irrigation on June 17. After completion and testing of the system, the lagoon wastewater was the only water that was applied with the SDI system; no fresh, clean water was used for irrigation, flushing, or dripline chemical treatment during the first three years of the study. On June 19-20, 2001, two fresh water events were conducted to examine the potential for cleaning the driplines and also to enhance chemical treatment (acid and chlorine are more effective with fresh water). Corn was the irrigated crop in all four seasons. On April 16, 2002, the system was flushed with fresh water and an aggressive acid and chlorination program was performed with fresh water. This was repeated the next day (April 17, 2002) and was followed with the final pressure and flow test. Eight driplines were excavated on April 18, 2002. Three lines were selected from the lowest flow treatment, three from the medium flow treatment and two from the highest flow treatment. These driplines were refrigerated until flowrates from individual emitters could be tested in the lab on August 8, 2002.

Five drip irrigation lateral line (dripline) types, each with a different emitter flow rate (and thus different emitter size), were tested (Table 2) to determine the optimum emitter size that would be less prone to clogging with the wastewater. Agricultural designs of SDI in the Great Plains with groundwater typically use lower flow rate emitters to allow for longer lateral run lengths. The emitter flow rates and flow path dimensions were obtained from the manufacturers.

Table 2. Selected emitter characteristics for the driplines used in the SDI study using livestock wastewater, Midwest Feeders, KS, 1998-2002.

Emitter flow rate, (gal/hr)	Flow path dimensions, width by height by length (inch)	Flow path area, ($inch^2$)	Operating inlet pressure (psi)
0.15	*	*	8
0.24	0.0212 by 0.0297 by *	0.000663 **	8
0.40	0.028 by 0.032 by 0.787	0.000896	10
0.60	0.034 by 0.037 by 0.713	0.001258	10
0.92	0.052 by 0.052 by 0.610	0.002704	***

* These dimensions were not available from the manufacturer.
** Flow path was not rectangular, so the area differs from the product of the width X height.
*** This product was a pressure-compensating emitter. Inlet pressure was greater than 30 psi.

The wastewater was filtered with a plastic grooved-disk filter with flow capacity about 25% greater than the filter manufacturer's recommendations for wastewater (1168 in^2 for our maximum flow rate of 120 gal/min). The disks were selected to provide 200-mesh equivalent (openings of 0.003 inches) filtration even though the manufacturers' recommendations for all driplines were filtration of 140 mesh or finer. A controller was used to automatically backflush the filter after every hour of operation or when the differential pressure across the filter reached 7 psi. To help keep bacteria and algae from growing and accumulating in the driplines and to clean lines of existing organic materials, acid and chlorine occasionally were injected simultaneously into the flow stream at injection points about 3 ft apart. Acid was added at a rate to reduce the pH to approximately 6.3. For the special freshwater events in June 2001 and April 2002, the pH was lowered to approximately 4.0. The acid used was N-pHuric 15/49, and the chlorine source was commercial chlorine bleach (2.5% Cl). Flushing (10 dripline volumes) to clean the lines and injections took place on the schedule shown in Table 3.

Generally, daily irrigations of 0.25 to 0.40 inch were made each season from June to early September, except when crop water use did not exceed precipitation or when the irrigation pump was inoperable. Each plot received the same daily application amount, so plot run times varied according to dripline flow rate. Seasonal applications were 22, 15, 17 and 12 inches in 1998, 1999, 2000, and 2001, respectfully. The 1998 amount greatly exceeded the crop water requirements but allowed more rigorous testing of the system. Additional flow tests were conducted between growing seasons (Oct. 6-7 and Nov. 17, 1998 and Nov. 3, 2000). In Kansas, few crops require irrigation during the winter months, so the system was allowed to remain idle during the overwinter periods. This stagnation period might increase the potential for system degradation from clogging, but it represents practical operating conditions for this climate.

The flow rates for entire plots were measured approximately weekly during the season whenever the system was operational. Totalizing flow meters were used on each plot to measure the amount of wastewater delivered during an approximately 30 minute test. Pressure was measured at the dripline inlets during each flow test. To account for the variation due to minor fluctuations of pressures from test to test, the calculated flowrates were normalized to the design pressure (Table 2) using the manufacturer's emitter exponent for that dripline type.

Table 3. Dates of flushing and injection, Midwest Feeders, KS, 1998-2002.

Date	Flush	Injection	Date	Flush	Injection
July 9, 1998		Y	May 3, 2000		Y
July 27, 1998		Y	June 13, 2000		Y
Aug. 4, 1998	Y	Y	June 21, 2000		Y
Aug. 31, 1998		Y	June 23, 2000	Y	
Sept. 2, 1998	Y	Y	Aug. 1, 2000		Y
Sept. 4, 1998		Y	Aug. 3, 2000	Y	
Oct. 6, 1998	Y	Y	Aug. 8, 2000	Y	
Nov. 17, 1998	Y	Y	Aug. 9, 2000		Y
June 8, 1999	Y	Y	Nov. 3, 2000	Y	
June 9, 1999	Y		June 5, 2001	Y	
July 28, 1999		Y	June 19, 2001		Y
Aug. 5, 1999	Y	Y	June 20, 2001	Y	Y
Aug. 6, 1999	Y		June 25, 2001	Y	
Aug. 24, 1999	Y	Y	Aug. 23, 2001		Y
Aug. 25, 1999	Y		Aug. 24, 2001	Y	
Sept. 10, 1999		Y	April 16, 2002	Y	Y
April 28, 2000	Y		April 17, 2002	Y	Y

A blank means the operation did not take place on that day.

RESULTS AND DISCUSSION

The three higher-flow emitter sizes (0.40, 0.60, and 0.92 gal/hr-emitter) showed the least amount of clogging (Fig. 1). Flow rates at the end of four seasons for those emitters were between 7 and 13% lower than the initial flow rates, indicating that clogging appears manageable with these emitters. These emitters may be adequate for use with lagoon wastewater. However, the pressure compensating emitter (0.92 gal/hr-emitter) was declining.

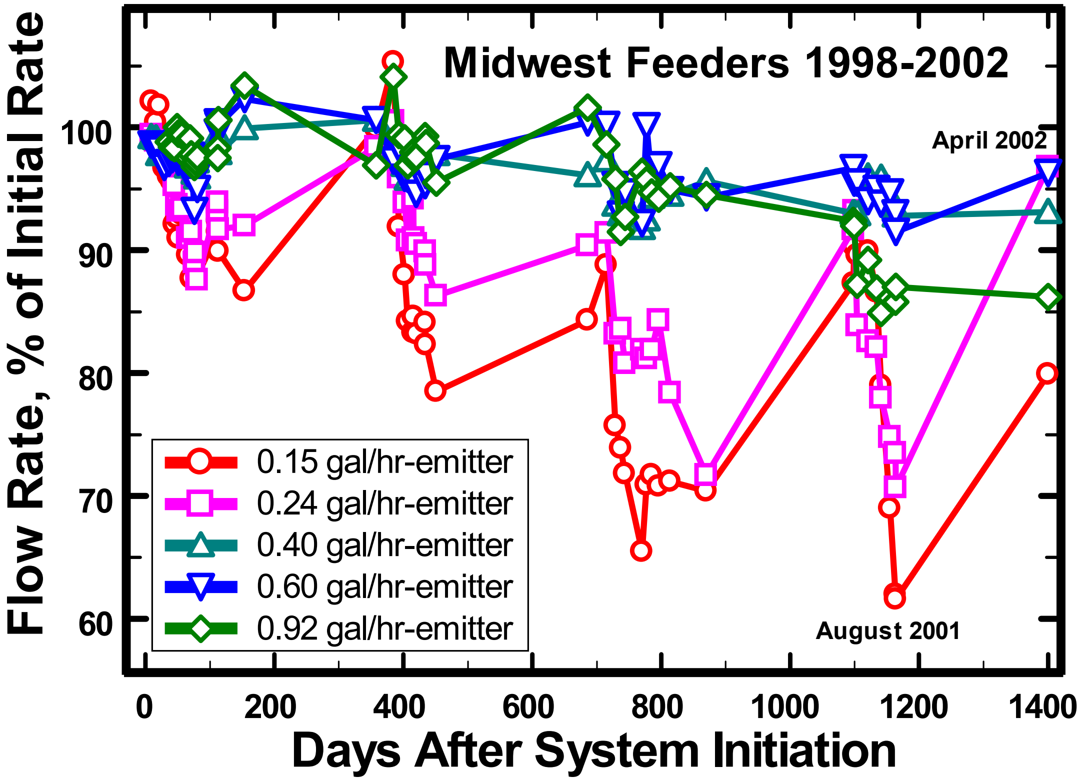

Figure 1. Measured flow rates for five dripline types with different emitter flow rates using lagoon wastewater, Midwest Feeders, KS, 1998-2002.

The two lower-flow emitter sizes (0.15 and 0.24 gal/hr-emitter) showed signs of emitter clogging (Fig. 1) during all four growing seasons. Within 30 days of system completion in 1998, the flow rates in plots with both smaller emitter sizes began to decrease. The 0.15 gal/hr-emitter plots showed a gradual decrease of flow rate throughout the remainder of the season. By November 17, 1998 (Day 154), the flow rate had decreased by 15% of the initial rate. The 0.24 gal/hr-emitter plots showed a decrease in flow rate of 11% of the initial rate by September 2, 1998 (Day 78). Following harvest and the first (32-day) idle period, flow rates in the 0.24 gal/hr-emitter plots increased approximately 5% over the minimum measured rate. This increase indicates that some cleaning of the emitters had occurred in response to the flushing. The flow rate then stabilized for the rest of 1998 at about 9% less than the initial rate.

Following the winter idle period (Day 368), all flow rates recovered to near their initial flow rates (Fig. 1). Possible explanations for this include (a) the longer time that the acid and chlorine remained in the driplines allowed better control of biological clogging agents or (b) the cooler temperatures during the winter resulted in partial control of the biological clogging agents and the acid and chlorine were then more effective at cleaning up the remaining agents.

The smaller emitter sizes continued to have decreasing flow rates during the 1999, 2000, and 2001 growing seasons (Fig. 1), similar to the response in 1998. By the end of the fourth growing season (August 24, 2001, Day 1164), flow rates had decreased by approximately 40% and 30% in the 0.15 and 0.24 gal/hr-emitter sizes, respectively, compared to the initial (maximum) flow rate.

The aggressive flushing, acid and chlorine program in April 2002 restored a significant portion of the flowrate reductions experienced by the smallest two emitters. Flowrates increased from the August 2001 values of 62 and 71% of the initial flowrates to April 2002 values of 80 and 97% for the 0.15 and 0.24 gal/hr-emitter treatments, respectively. This indicates that aggressive management may remediate wastewater clogging problems. There was substantially less improvement for the larger flowrate emitters and actually no flowrate improvement for pressure compensating emitter (0.92 gal/hr-emitter). It is believed that wastewater particles are being trapped in the flexible diaphragm of these emitters.

Over the course of the four seasons, a total of 66 inches of beef lagoon wastewater was applied with the SDI system and an estimated total of approximately 9300 lbs/acre of suspended solids passed through the system (Figure 2), minus the amounts of suspended solids that were removed in the periodic dripline flushing events. These are relatively harsh operating conditions. The disk filter and automated backflush controller operated well in all four years.

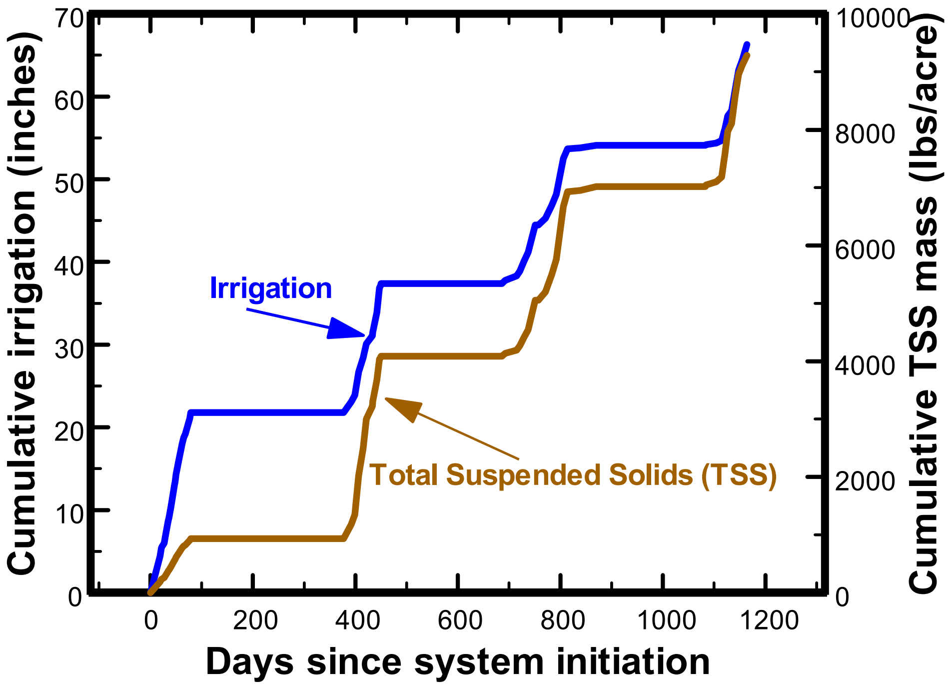

Figure 2. Cumulative wastewater irrigation amounts and estimated cumulative total suspended solids (TSS) that passed through the driplines during the four seasons, Midwest Feeders, KS, 1998-2001.

Excavation and visual inspection of dripline samples at the end of the first season showed that flushing was generally effective in removing the accumulations of materials from the driplines. Prior to flushing, a slimy substance probably containing both silt and biological materials was present in the driplines. After flushing, the main chamber of the driplines was clean.

Driplines from selected treatments were excavated from the lower 100 feet of the plots after the aggressive flushing, acid and chlorination program of April 16-17, 2002. The flowrates from individual emitters in an approximately 25 ft section of excavated driplines was measured in the laboratory on August 8, 2002 for the lowest, medium and highest flowrate treatments (0.14, 0.40, and 0.92 gal/hr-emitters). Flowrates were measured for 23, 12, and 12 consecutive emitters resulting from the 12, 24 and 24inch emitter spacings, respectively for these three driplines.

The lowest flow dripline (0.14 gal-hr-emitter) had 3 fully clogged emitters in the 3 driplines tested (3 driplines x 23 emitters = 69 total emitters). The average flowrate varied from 0.107 to 0.135 gal/hr-emitter for these three driplines as compared to two new driplines from the same roll that had average flowrates of 0.145 gal/hr-emitter (Fig. 3). The Coefficient of Variation (CV) of flows varied from 7.3 to 36.8% for the wastewater driplines while the CV for new driplines was only 2.5%. Likewise the Distribution Uniformity with the Lower Quartile method (DUlq) ranged from 54.3% to 90.7% for the wastewater driplines as compared to the new dripline DUlq of 97.1%. Clearly, the lowest flow driplines are experiencing some significant clogging problems.

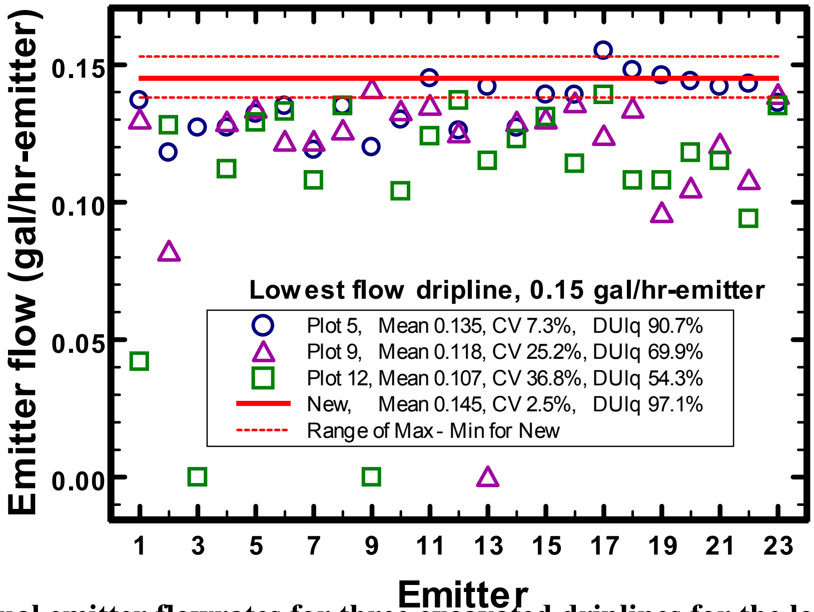

Figure 3. Individual emitter flowrates for three excavated driplines for the lowest flow dripline at the conclusion of the study as compared to the average flowrate of new dripline. Note, three emitters are fully clogged.

Flowrates from individual emitters for the wastewater medium flow driplines were very good with only small decreases (<10%) from the average flowrate of new driplines (Fig. 4.). The CV ranging from 2.4 to 2.8% and DUlq ranging from 96.4 to 97.9% for these driplines were excellent and differed very little from the new driplines.

Flowrates from individual emitters for the wastewater highest flow driplines (0.92 gal-hr-emitter) were generally good, but had two emitters out of a total of 24 with very high flowrates and one additional emitter with an approximately 25% flowrate reduction (Fig. 5.). It is believed these higher flowrate problems are caused by wastewater particles becoming stuck in the flexible diaphragm of this pressure compensating emitter. This problem has been reported elsewhere. These flow variations resulted in higher CVs for the wastewater driplines (10.8 to 20.5% as compared to 2.3% for new driplines) and lower DUlqs (87.1% to 92.6 as compared to 96.7% for the new driplines).

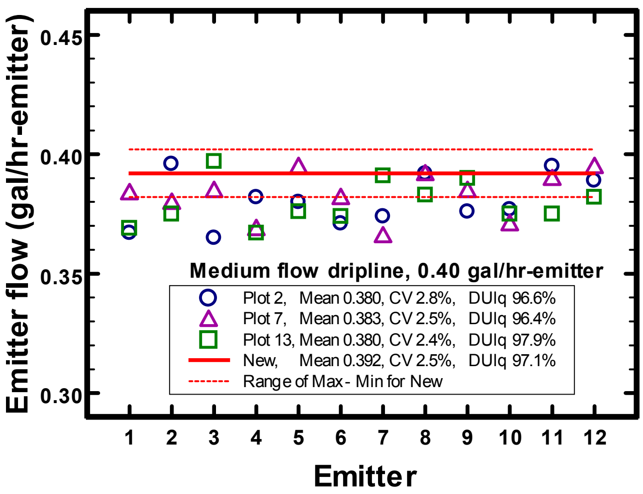

Figure 4. Individual emitter flowrates for three excavated driplines for the medium flow dripline at the conclusion of the study as compared to the average flowrate of new dripline.

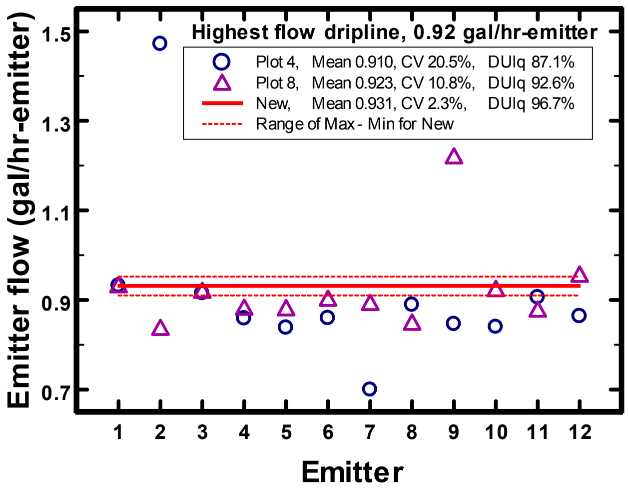

Figure 5. Individual emitter flowrates for two excavated driplines for the highest flow dripline at the conclusion of the study as compared to the average flowrate of new dripline. Note, two very high flowrate emitters and one lower flowrate emitter.

Other management procedures might prevent performance degradation in the lower flow-rate emitters or remediate it after it occurs. Such procedures might include more frequent flushing, flushing with fresh water, and more frequent and concentrated chemical-injection treatments. Additionally, many irrigation systems may apply the wastewater as a supplemental application instead of the sole irrigation source as used here. However, the objective of this study was to compare the different driplines under difficult but identical conditions. Further studies are needed to determine if the lower flow-rate driplines can be maintained at a higher performance with more aggressive management.

These results show that the drip irrigation laterals used with SDI have potential for use with lagoon wastewater. However, the smaller emitter sizes normally used with groundwater sources in western Kansas may be risky for use with lagoon wastewater. The dripline performance was similar during all four growing seasons, but questions remain about the long-term, multiseason performance of SDI systems using livestock wastewater. Long-term reliable performance probably will be necessary to justify the high investment costs of SDI systems.

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Utilization of Recycled Aquaculture Water and Effluents for Forage and Vegetable Crops in the U.S. Virgin Islands

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Abstract

Experiments were conducted from 1992 to 1999 to determine if aquaculture water and effluents can be used to replace expensive irrigation water and fertilizer for vegetable and forage crops. In 1992 and 1993, effluents were applied to bell peppers. (*Capsicum annuum* L.). In 1994 effluents were applied to leafy vegetable Pai tsai (*Brassica rapa* L. Chinensis). From 1997 to 1999 the benefits of utilizing aquaculture effluents was evaluated for guineagrass (*Panicum maximum* Jacq.) hay production. Trials for two seasons demonstrated the positive effects of using aquaculture effluents on vegetables and forage crops. Effluents increased vegetable marketable yield, dry matter and nutrient value of guineagrass. Studies indicated that recycled aquaculture water and effluents are potential sources of irrigation water and fertilizer.

Introduction

In semi-arid and water limited environment of the U.S. Virgin Islands (USVI), shortage of fresh water limits crop production. Vegetables and forage crops are dependent on well-distributed rainfall for year-round production, however, during dry seasons crop failure is common without supplemental irrigation. Vegetable growers incur high cost of irrigation water to maintain production year round. Although the USVI receive 1100 mm annual rainfall, more than 50% of this precipitation occurs only from September to November. High evaporation rates and erratic rainfall patterns contribute to shortage of water throughout the year. Shortage of water for crop production is a major problem facing agriculture in the USVI, therefore, alternative sources of water for irrigation must be explored.

A potential alternative is recycled water from intensive aquaculture system. Intensive aquaculture in tanks may be appropriate for fresh-water limited environment such as the USVI (Cole et al., 1997). A component of intensive fish culture in tanks is the removal of nutrient-rich effluents which are a potential source of irrigation water and nutrients for agronomic and horticultural crops (Chen and Malone, 1991; Palada et al., 1999; Valencia et al., 2001). Fish culture effluent contains essential plant nutrients (i.e., N, P, K, S and Ca) and significant amounts of water. Intensive recirculating systems have been integrated with vegetable hydroponics (Rakocy, 1989; McMurtry et al., 1993) and demonstrated the potential of using wastewater in irrigating greenhouse tomatoes and leafy vegetables. Effluents from pond culture were also used to irrigate cotton (Olsen et al., 1993), soybean (Ghate et al., 1994) and wheat (Al-Jaloud et al., 1993).

In recent years, there has been increasing concern on the adverse ecological consequences of nutrient-rich wastes discharged into bodies of water (rivers, lakes and oceans) which result in siltation and eutrophication (Bond, 1998). Application of effluents to field and vegetable crops can reduce environmental contamination since crops especially grass pastures can be a good sink for aquaculture effluents. An integrated approach using fish culture effluents for irrigation of forage and vegetable crops was evaluated in the USVI as a means of conserving water and reducing fertilizer costs. The major objective was to determine if aquaculture water and effluent can be used to replace expensive irrigation water and fertilizer for forage and vegetable crops.

Materials and Methods

Experiments were conducted from 1992 to 1999 at the Agricultural Experiment Station, University of the Virgin Islands (lat. 17º42' N, long. 64º48'W). In 1992 and 1993, effluents from tank culture of Tilapia (*Oreochromis niloticus*) were applied to bell peppers. Experiments in 1994 involved the application of effluents to leafy vegetable Pai tsai and from 1997 to 1999 the benefits of utilizing aquaculture effluents was evaluated for guineagrass hay production.

Bell Pepper. Two experiments were conducted to evaluate effluents generated from Tilapia tank culture for bell pepper (cv. 'Calwonder') production. In 1992, seven treatments were arranged in a randomized complete block design with four replications. Treatments allowed a comparison between tank water, tank sludge and conventional inorganic and organic fertilizers. The treatments were as follows: 1) LD-Low stocking density rearing tank water, 2) HD-High stocking density tank water, 3) SD-Sludge combined from low and high stocking densities, 4) FN-Liquid inorganic N fertilizer applied in drip at 200 kg ha^{-1}, 5) FL-Liquid inorganic N fertilizer applied manually at same rate as 4, 6) FG-Granular inorganic fertilizer applied manually at same rate as 4, and 7) CM-Cow manure applied at rate equivalent to 200 kg N ha^{-1}. Similar trial was conducted in 1993, but the treatments were modified. The hand-applied liquid fertilizer and the cow manure were replaced with tank sludge and tank water. Treatments were as follows: 1) FW1-Effluent from tank with 0% daily water exchange rate applied using Turbo Key (TK) drip emitter, 2) FW2-Effluent from tank with 0% daily water exchange rate applied using Hardie (E-2) drip emitter, 3) FW3-Effluent from tank with 5% daily water exchange rate applied using Turbo Key (TK) emitter, 4) FW4-Similar to 3 but used a Hardie (E-2) drip emitter, 5) TS-Sludge from all tanks combined and applied using Bow Smith Gripper adapter (BSG), 6) FN-Liquid inorganic fertilizer applied in drip irrigation similar to that in the 1992 trial, and 7) FG-Granular inorganic fertilizer applied in bands around individual plants. Data were collected on total number and weight of fruits and weight of marketable fruits. Data on weight of fruits (total and marketable) are reported in this paper.

Leafy Vegetable Pai tsai. Two experiments were conducted in 1994 to evaluate fish culture effluent generated from Tilapia tank culture for production of Pai tsai cv. 'Joi Choi'. Six circular tanks, each with a water volume of 31.2 m^3 were used to culture Tilapia. Tanks were stocked with fingerlings at 24 m^{-3} and cultured for 24 weeks. Solids were removed from the water in the three tanks while the other three had no solids removed. Pakchoi seedlings were transplanted into 6.0 x 1.8 m plots. Treatments included application of fish effluent with and without solids removal, drip fertigation, band fertilizer application, and sludge removed from culture tanks using three methods of irrigation. The first experiment was conducted from 8 July to 19 August followed by the second experiment on 29 August to 5 October. Both experiments used a randomized complete block design with four replications. Data were collected on plant fresh weight at harvest, whole plant tissue concentration of major nutrients and soil N, P and K.
Data on plant tissue analysis are not reported in this paper.

Forage Guineagrass. A three-year study was conducted to determine if fish effluent can be used to replace fertilizer N on guinea grass managed as hay. The experiment compared the effects of irrigated effluent and broadcast N rates of 60 kg ha^{-1} (N_{60}) 0 kg ha^{-1} (N_0) on yield and quality of hay. Experiments were established using a randomized complete block design. Treatments consisted of 1) fish effluent (FE; 120 kg ha^{-1} in 1997, 0 kg ha^{-1} in 1998, and 60 kg ha^{-1} in 1999), 2) N (ammonium nitrate) application of 60 kg ha^{-1} and 3) 0 N ha^{-1} (control). Native guinea grass was broadcast-seeded in late August, 1996 on 6 x 6 m plots. Plants were allowed to establish without interruption during the remainder of the year. Plants were clipped to 15-cm stubble height in February, 1997 and fish effluent was applied weekly thereafter for 18 weeks equivalent to a total application rate of 120 kg N ha^{-1}. Since effluent was not available in 1998, only inorganic N was applied. Result from this year was used to assess the residual effects of fish effluent in 1997. Limited amounts of effluents in 1999, resulted in dilution with water to provide a rate equivalent to 60 kg N ha^{-1} similar to the inorganic fertilizer N application. Forage was harvested at 8-wk interval from a 1 x 2 m section from the center of each plot (three harvests in 1997, 1998, and 1999) using a sickle-bar mower. Yield data were subjected to analysis of variance using SAS (1989).

Results and Discussion

Bell pepper. In 1992, application of effluents (water and sludge) resulted in significantly ($P<0.05$) larger fruit size compared to treatments applied with liquid N fertilizer and cow manure (Table 1A). Fruits produced from plots treated with effluents were on the average larger than fruits produced from plots applied with inorganic fertilizer and cow manure. However, plants under fertigation produced significantly ($P<0.05$) higher fruit yield than all other treatments. Highest fruit yield was obtained from plots fertilized with liquid N followed by plots treated with sludge. Percentage of marketable fruit ranged from 66% for low density tank water to 91% for high density tank water. More than 80% of the total fruit yield in plots applied with inorganic fertilizer and cow manure were marketable. Contrast comparisons of marketable yields between fish effluent, sludge and inorganic fertilizer were not significant, but when effluent (tank water) was compared to fertigation and granular N fertilizer, differences in marketable yield were significant ($P<0.001$ and $P<0.044$, respectively).

In 1993, smallest fruit size was produced from treatment with granular N fertilizer and the largest fruit size was obtained from treatment with 5% exchange rate using a TK emitter (Table 1B). Application of sludge resulted in significantly ($P<0.05$) higher total yield than fertigation. Plants applied with sludge produced the highest marketable yield. The lowest marketable yield was obtained from the fertigation treatment. Overall, the percentage of marketable fruits declined in 1993 compared to 1992. Contrast analysis showed no significant differences in yield among treatments. Combined mean total yields of all aquaculture effluent treatments (water and sludge) were not significantly different than yields from plots fertilized with inorganic fertilizers.

Superior yield under fertigation in 1992 can be attributed to a more rapid and efficient N uptake compared to other treatments. Except for treatments from low density effluent and sludge, the percentage of marketable fruits was above 80%. High yields from fish effluent treated plots during the second year can be explained by the accumulation and release of nutrients from the previous year through mineralization. Although the overall total yields in 1993 were higher than 1992, the percentage of marketable fruits decreased in 1993. Frequent harvesting in 1993 resulted in higher total and marketable yield, but more fruits had either insect damage or were diseased rendering them non-marketable.

Leafy Vegetable Pai tsai. In the first season trial, plant size with weekly sludge application was significantly larger than plants with fertilizer band-application, or with effluent (water), with or without the sludge removed (Table 2).

During the second season, weekly sludge application resulted in larger plants than the fertilizer-band application. Although not significant in both trials, Pakchoi applied with effluent (water) and sludge had higher total yields than fertigation or band-application. Plant size and total yield in the second season trial were higher than the first season trial and this can be attributed to increased soil N (data not shown).

Forage Guineagrass. Forage production in the eastern Caribbean are affected by nutrients and well-distributed rainfall. During the period of this study, guineagrass was irrigated with effluent and well-water (1997 and 1999). Because of the variation in rainfall and our interest in assessing carry-over effects of both the effluents and the inorganic fertilizer (1998), data was analyzed by year. Total rainfall in 1997 (739 mm) was below the 20-yr norm (1060 mm) on St. Croix U.S. Virgin Islands, but rainfall in 1998 (1867 mm) and 1999 (1340 mm) were much higher than the 20-yr norm. There were treatment x date of harvest interaction ($P<0.05$) for DM in1998 and 1999. These were reported in more detail by Valencia et al. (2001).

In 1997, DM yield of guineagrass irrigated with effluent (14.2 Mg ha^{-1}) did not differ ($P=0.10$) from the N_{60} (13.1 Mg ha^{-1}). There was, however, a trend for higher DM yield for guineagrass treated with effluent (Table 3). Both effluent and N_{60} treatments had >4 Mg ha^{-1} higher DM yield than unfertilized guinea grass (Table 3). Studies by Olsen (1972) reported a three-fold increase in DM yield of guineagrass and other tropical grasses when fertilized at high N rates (>400 kg N ha^{-1}). Rainfall in 1997 was below the 20-yr norm, but it is not clear if it had any effect on DM yield. Oakes and Skov (1962) evaluated the response of four tropical pasture grasses to N in the dry tropics and noted that differences in rainfall of this magnitude had no apparent influence on annual DM yield.

Similar results were observed in 1998, despite no treatment application. There was a difference in total annual yield ($P<0.05$) between effluent and N_{60} (Table 3). Dry matter yield was close to 4 Mg ha^{-1} higher for the effluent (13.8 Mg ha^{-1}) compared to N_{60} (9.9 Mg ha^{-1}), similar to what occurred in 1997. Studies by Olson (1992) and Cole et al. (1997) suggests that close to 90% of the N in aquaculture effluent or sludge is in an organic form and is not available in the first year of crop production. Further research with the application of biosolids to bahiagrass (*Paspalum notatum* Flugee) conducted by Muchovej and Rechcigl (1997) estimated a minimum N recovery rate of 70% over a two-year period. Guineagrass DM response to effluent applied the previous year suggests that residual organic N was mineralized in year two and was available for the guineagrass plant to use. Also in 1997, approximately 120 kg ha^{-1} N from effluent were applied and thus it is possible that this residual organic N sustained the higher yields obtained in 1998.

In 1999, there were differences ($P<0.05$) in DM yield for effluent (12.9 Mg ha^{-1}) compared to N_{60} (6.4 Mg ha^{-1}) . There was a two-fold increase in DM yield of guineagrass treated with effluent (Table3). Total yields, however, were much lower than the DM yields of 1997 and 1998. Guineagrass treated with effluent showed higher tiller density and less weed encroachment when compared to N_{60} or unfertilized guineagrass (E. Valencia; personal observations). A linear decrease in DM yield of unfertilized guinea grass was observed over-time (Table3). The low DM yields on unfertilized guinea grass in 1999 indicate that nutrients were lacking to support adequate plant growth. A steady decline in the stand of guineagrass was also observed.

Nutritive value [crude protein (CP) and *In vitro* organic matter disappearance (IVOMD)] were analyzed in 1997 and 1999. There was no treatment X harvest date interaction in 1997 for CP and IVOMD. Guineagrass CP concentration was not affected by treatment either. There was a trend ($P=0.11$), however, for higher CP of guinea grass when irrigated with effluent (9.6%) compared to those fertilized with N_{60} (8.6%). *In vitro* organic matter disappearance did not differ among treatments and averaged 56%. In 1999, averaged across three harvests, the CP of guineagrass treated with effluent (10.3%) was two percentage units higher (*P<0.05*) than the N_{60} CP (8.3%). There was no difference (*P>0.05*) in IVOMD (61.0%) in 1999. Soil pH (7.8), also, did not change in the three years of effluent application. Phosphorus was maintained at 22 mg kg^{-1} during the three years of the study.

Conclusions

Results of the study indicate that effluents can replace the recommended N application rates of 60 kg ha^{-1} per annum for guineagrass. The sustained and increased DM yield of effluent treated guineagrass compared to that of N_{60} in year two suggests that there was a strong mineralization of N. This gives aquaculture effluents the characteristics of a slow release fertilizer. Al-Jaloud et al. (1993) reported a 50% savings in inorganic fertilizer with use of aquaculture effluents containing 40 mg L^{-1} N. Under the arid conditions of the U.S. Virgin Islands, these savings may be higher, particularly with the use of the water source. The two percentage unit increase in CP with addition of effluent can serve to increase the quality of guineagrass hay. Because of the slow release of N from effluents, there would be less leachate of N in the soil profile. This study confirmed that guineagrass hay fields can serve as a sink for this nutrient-rich wastewater, and provide an economically sustainable, and environmentally acceptable effluent discharge method.

Overall, these studies demonstrated the positive benefits of aquaculture effluents in forage and vegetable crops production. Repeated applications of effluents over time accumulated soil nutrients which become available resulting in increased yields of bell pepper, Pai tsai and guinea grass. Studies also suggest that it is feasible to grow crops using recycled aquaculture waste water and sludge without external (commercial fertilizer) inputs. Yields can be sustained at levels comparable to yields obtained using commercial fertilizers. Crop irrigation with nutrient-rich aquaculture effluents is an example of sound resource management through the reuse of water and the recycling of nutrients.

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Table 1. Fruit size and yield of bell peppers fertilized with aquaculture effluents, organic and inorganic fertilizer.

1A. 1992 Trial

Treatment	Fruit size (g)	Total fruit yield ($Mg\ ha^{-1}$)	Marketable yield ($Mg\ ha^{-1}$)
Fish water (LD)	70.8 ab	2.82 b	1.85 b (66)
Fish water (HD)	80.8 a	4.12 b	3.75 b (91)
Fish sludge	74.0 ab	6.62 b	5.00 b (76)
Liquid inorganic N (drip)	69.4 abc	10.60 a	8.98 a (85)
Liquid inorganic N (manual)	58.1 cd	5.28 b	4.54 b (86)
Granular inorganic N	66.9 bc	5.60 b	4.63 b (83)
Cow manure	52.1 d	4.68 b	3.98 b (85)

For each column, means followed by common letters are not significantly different (P>0.05) by Duncan's Multiple Range Test (DMRT). LD=Fish cultured at low density (8 fish m^{-3}); HD=Fish cultured at high density (16 fish m^{-3}). Numbers in parenthesis are percentages of marketable fruits based on total fruit yield.

1B. 1993 Trial

Treatment	Water exchange (%)	Drip emitter type[a]	Fruit size[b] (g)	Total fruit yield ($Mg\ ha^{-1}$)	Marketable yield[c] ($Mg\ ha^{-1}$)
Fish effluent 1	0	TK	69.1	12.4 ab	7.05 abc (57)
Fish effluent 2	0	E-2	65.4	13.0 ab	7.29 abc (56)
Fish effluent 3	5	TK	69.7	13.0 ab	9.97 ab (77)
Fish effluent 4	5	E-2	67.5	11.3 ab	6.56 bc (58)
Sludge	combined	BSG	68.4	15.1 a	10.35 a (68)
Fertigation (drip)	0	E-2	63.6	10.5 b	5.76 c (55)
Fertilizer (manual)	0	E-2	57.6	11.4 a	6.93 abc (61)

For each column, means followed by common letters are not significantly different (P>0.05) by DMRT

[a]TK=Turbo Key; E-2=Hardie; BSG=Bow Smith Gripper Adapter.
[b]Based on marketable fruits.
[c]Numbers in parenthesis are percentages of marketable fruits based on total fruit yield.

Table 2. Plant size and total fresh yield of Pakchoi fertilized and irrigated with aquaculture effluent and inorganic fertilizers.

Treatment	Emitter	First Season Plant size (g)	First Season Fresh yield ($Mg\ ha^{-1}$)	Second Season Plant size (g)	Second Season Fresh yield ($Mg\ ha^{-1}$)
Effluent with sludge	Hardie E-2	288 b	19.3 b	614 ab	41.0 ab
Effluent without sludge	Hardie E-2	300 b	20.0 b	653 a	43.6 a
Sludge 1	Micro-tubing	333 ab	22.2 ab	612 ab	40.9 ab
Sludge 2	0.5 cm on ½" polyhose	353 ab	23.4 ab	662 a	44.2 a
Effluent+sludge (1x/wk)	0.5 cm on ½' polyhose	393 a	26.1 a	791 a	47.4 a
Fertigation (100 kg N ha^{-1})	Hardie E-2	320 ab	21.2 ab	674 a	45.0 a
Fertilizer band (100 kg N ha^{-1})	Hardie E-2	300 b	19.9ab	527 b	35.2 b

For each column, means followed by common letters are not significantly different (P>0.05) by DMRT.

Table 3. Total dry matter yield of guinea grass (*Panicum maximum* Jacq.) irrigated with aquaculture effluent and fertilized in 1997, 1998 and 1999.

Treatment	1997	1998	1999
		$Mg\ ha^{-1}$	
Effluent	14.2†	13.8	12.9
N_{60} (kg ha^{-1})	13.1	9.9	6.4
N_0 (control)	8.6	5.7	2.6
Effluent vs. N_{60}	0.10‡	0.05	0.05
Effluents vs. N_0	0.05	0.05	0.05
N_{60} vs. N_0	0.05	0.05	0.05

† Three harvests per annum.
‡ P level for planned contrast.

Drip irrigation with biological effluent

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This paper presents a brief overview of the application of biological effluent with microirrigation systems. In this paper, "biological effluent" is considered to be water that contains impurities derived from biological sources. Such impurities include human and animal metabolic wastes and domestic and industrial food processing wastes.

There are many potential advantages to applying biological effluent with microirrigation systems, especially drip irrigation systems. Advantages include (Gushiken, 1995; Trooien et al., 2000):

- Overspray and drift are minimized so liability exposure is minimized,
- Potable water resources are conserved,
- Pressure requirements are often reduced,
- Unusual field shapes and sizes are easier to irrigate in their entirety,
- Nutrients in the effluent can be utilized by the crop,
- Irrigation system corrosion is reduced because most of the system is made of plastic, and
- Cost/benefit compares favorably to other methods in some situations.

Additional potential benefits can be realized when using subsurface drip irrigation (SDI) systems (Gushiken, 1995; Trooien et al., 2000):

- Human contact and associated health risks are reduced,
- Spacing requirements from populations or other facilities are reduced because overspray and drift are eliminated,
- Vandalism is reduced,
- Application uniformity is high resulting in better control of the applied water, salts, and nutrients,
- Effluent is applied directly into the root zone reducing the potential for runoff,
- The soil surface stays dry, reducing weed germination and bacteria survival near the soil surface, and
- Weather constraints such as high wind or low temperatures are reduced or eliminated.

In this paper, we will consider biological effluent to be a resource so the approach will be efficient use of the resource rather than disposal of a waste product.

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Microirrigation system design and management for application of biological effluent

Because of their relatively high concentrations of salts, nutrients, and biologicals, effluents pose an increased risk of emitter clogging. Emitter clogging can be avoided by meeting these five criteria:

1. selecting and installing the proper system components,
2. filtering the effluent properly and effectively,
3. suppressing biological growth and chemical precipitation effectively,
4. flushing materials that may accumulate in the distribution systems, and
5. monitoring system performance to assure that partial clogging is treated before it becomes catastrophic.

System components

Emitters with smaller flow rates (within a single emitter type) are more susceptible to clogging (Ravina et al., 1992). Using emitters with low flow rates is an advantage because zone sizes can be larger and control hardware requirements are reduced. Using thin-walled collapsible hose (drip tape) can also be appropriate for applying activated sludge secondary treated effluent (Hills and Brenes, 2001), particularly emitters manufactured by attachment or molding. In a test with beef feedlot runoff effluent, the two smallest emitters tested (flow rates of 0.57 and 0.91 L/hr/emitter) showed reduced flow rates after two years of operation (Trooien et al., 2000). Those two smallest emitters were manufactured by indentation. Two larger emitters (flow rates of 1.5 and 2.3 L/hr/emitter), manufactured by attachment, did not decrease in flow rate during the first two years of operation. Adin and Sacks (1991) noted several design factors that could be implemented to reduce clogging potential: shorten and widen the flow path, round the straight edges on protruding teeth in the flow path, remove dead areas in the flow path, design the orifice entrance to act as a barrier to keep large particles out of the emitter, and place seams away from the flow path or remove seams entirely.

Filtration

Filtration is required to prevent large particles from entering driplines and physically clogging emitters. Physical clogging begins at the distal ends of driplines (Ravina et al., 1992). Particles accumulate at the distal ends of driplines where flow velocities are reduced (Shannon et al., 1982) unless biological agents intercept them.

Sand media filtration is often considered to be the standard for filtration protection of microirrigation systems. Testing has shown that media filtration (uniform bed with mean particle size of 1 mm) provided the best protection, followed by disk filtration of 140 mesh (Ravina et al., 1997). Screen filtration (155 to 200 mesh) was not as effective in protecting downstream elements. Oron et al. (1980) also found disk filtration (80 mesh) to be slightly better than screen filtration at removing total chemical oxygen demand.

Chemical injection to suppress biological growth and chemical precipitation

Emitters can be clogged by a mixture of biological and inorganic particles, protozoa, or bacteria that grow within the driplines (Ravina et al., 1992; Sagi et al., 1995). Bacterial slimes initiate clogging then suspended inorganic particles adhere to the slimes and cause physical clogging (Adin and Sacks, 1991). Additionally, bacterial growth within driplines may lead to the formation of biofilms. These biofilms include the interactions of microorganisms and the polysaccharide layer they produce (Picologlou et al., 1980). Biofilms can increase pressure loss due to friction along the length of driplines due to (1) reduction of the cross-sectional flow area, (2) oscillation of filaments attached to the biofilms, and (3) increased roughness.

Chlorination is one method used to control biological growth within driplines. Chlorination is especially challenging in effluents with high ammonia contents because chlorine reacts with ammonia to form chloramines. These chloramines are up to 80 times less effective than chlorine for biological control (Feigin et al., 1991).

Chemical precipitation can also be a concern, especially for surface-installed driplines. Acid injection to reduce pH from 7.6 to 6.8 was effective in preventing chemical precipitation-induced clogging in saline fresh water (Hills et al., 1989).

Flushing

Flushing requirements can be reduced with adequate filtration (Tajrishy et al., 1994) but no filtration system can keep all particles out of driplines. A flushing frequency of two weeks was effective for thin-walled collapsible hose when using effluent and the flushing velocity should be at least 0.5 m/s (Hills and Brenes, 2001). In extreme cases, flushing can take place daily (Norum et al., 2001).

Monitoring

Frequent monitoring of system performance can detect clogging before it becomes catastrophic because emitter clogging is progressive and continuous rather than a discrete event (Ravina et al., 1992 and Trooien et al., 2000) and partial clogging of emitters is more common than complete clogging (Ravina et al., 1992). Early detection of emitter clogging is important because chlorination of partially-clogged emitters is more effective than if the emitters are more severely clogged (Ravina et al., 1992).

Irrigating with biological effluent

Successful irrigation with biological effluent requires that the system be designed well, as noted in the previous section. Success also hinges on selecting the proper site and managing the unique characteristics of the effluent- salts, nutrients, and biological pathogens- the extra "stuff" that comes with the water and can be either and advantage or a disadvantage. In the case of nutrients, and added benefit of having nutrients in the water may be a disadvantage if the nutrients are lost to the crop and adversely affect the environment. Other elements, particularly heavy metals, may be of concern but will not be considered here.

Site and Crop considerations

The irrigation site must be located close enough to the effluent so that the effluent can be used economically. In addition, characteristics such as soils, climate, and available crops must be suitable. For example, soils must be permeable enough to allow rapid infiltration or water movement (including vertical drainage) yet hold water long enough to allow interaction of waste constituents such as nutrients with soil minerals, plants, and organisms; have sufficient exchange capacity to temporarily hold effluent constituents; and have sufficient thickness to provide adequate opportunity for water purification. The climate, particularly precipitation and temperature, must be conducive to irrigation. Crops suitable for effluent irrigation with sprinkler systems would also be suitable for microirrigation. Additional crops may suitable for microirrigation because its use reduces viral and bacterial contamination of the crop (Oron et al., 1991, 1992).

Salinity

Some biological effluents can be quite saline. Management of saline effluent requires the same caution and careful management as irrigation with saline fresh water. That is, adequate leaching is required to maintain a favorable salt balance in the root zone. In general, the major salinity issue is the sum of all salts rather than any specific ion, but individual ions such as chloride, sodium, or boron may raise plant toxicity issues. Finally, sodium levels in biological effluent may be elevated. Soil sodium concentration elevation has been measured when irrigating with septic tank effluent with high sodium concentration (Jnad et al., 2001). Elevated soil sodium concentrations, measured by sodium adsorption ratio (SAR) or exchangeable sodium percentage (ESP) can cause soil degradation by causing soil dispersion or swelling, reducing the soil infiltration rate.

Nutrients

Two nutrients are of particular concern when irrigation with biological effluent: nitrogen (N) and phosphorus (P). The total mass application of N, P, and water must be considered so that any one is not applied in excess. That is, effluent should be applied only until the crop requirement plus soil storage capacity for one of the three elements- water, N, or P- is met. Excessive application of N may result in excessive nitrogen leaching. Excessive application of P may result in leaching of mobile forms of organic P or runoff of P attached to soil particles. Excessive application of water will result in excessive runoff, leaching, or both.

In primary treated effluent, N is usually in the forms of ammonium and organic N. In secondary treated effluent, N is often in the form of nitrate. The N loss mechanism of primary concern is leaching with resultant contamination of groundwater resources. Leaching reduction is accomplished by careful management of N and careful water management to prevent excessive water application and resultant leaching. Nitrate leaching is especially rapid in porous, permeable soils where water movement is also the most rapid.

The P loss mechanism of primary concern is runoff carrying soil particles with P sorbed to them. Inorganic P is strongly sorbed to soil particles, making P less prone to leaching. However, some P can be leached (Sims et al., 1998), particularly organic forms of P that are more mobile. Solubility of P is mostly controlled by its concentration in the soil solution. Thus, a balance must be found between making adequate P available to the crop but avoiding excessive concentrations that may be lost.

Pathogens

Since the discovery about a century ago that eating raw vegetables grown on soil fertilized with raw sewage resulted in typhoid fever outbreaks (Gerba et al., 1975), pathogen transfer from effluents to humans has been recognized as a health issue.

Microirrigation appears to be especially well suited to applying effluents with minimal health risk. SDI that leaves the soil surface dry reduces the potential for transfer of bacteria because bacterial survival is reduced in dry soils (Gerba et al., 1975). However, high soil water content deeper in the soil profile is conducive to bacterial survival. Indeed, bacteria (Oron et al., 1991) and viruses (Oron, 1996) have been shown to accumulate in the soil near the driplines. In defense of surface drip irrigation, sunlight has been shown to reduce bacterial survival (Gerba et al., 1975) so surface emitters may reduce bacterial concentrations by exposing applied effluent to sunlight.

When considering or planning irrigation with biological effluent, additional laws and regulations may require additional compliance measures by the irrigator. In the USA, effluent irrigation is often regulated by states or municipalities. Practices that may be required to meet regulations include- but are not limited to- changing crops, performing additional effluent disinfection, or adding effluent stabilization ponds.

In summary, microirrigation application of biological effluent has many advantages. As is true of any microirrigation system, care must be exercised to maintain and protect the irrigation system so that it performs efficiently and as it was designed. Management strategies must be implemented to take advantage of the benefits such as supplying nutrients to the crop while avoiding potential problems.

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“Adopting best management irrigation practice for winery wastewater re-use onto a woodlot.”

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Introduction

The reuse of industrial wastewater onto land has become increasingly popular in Australia in recent years. In the wine industry, there has been a rapid growth in production in the past decade, which has placed greater pressure on wineries to implement more sustainable ways of managing the resultant increasing volumes of wastewater produced. One form of water reuse is the irrigation of tree crops to be used for firewood (woodlots).

A draft “Best Management Practice template for sustainable winery wastewater irrigated plantations” was developed by Sentek Pty Ltd in October 2000. The aim of this template was to compile all mandatory regulatory requirements in relation to irrigation of woodlots (Environmental Protection Agency, 1999, Thomas, 1983). Recommendations made by leading authorities such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and other leading researchers (Honeysett *et al* 1996, Myers *et al*1999) were also incorporated. In addition, many years of commercial practical experience in irrigation scheduling and management (Buss, 1994) was included to compile an irrigator’s action list as part of the Best Management Practice (BMP) template.

This paper outlines the approach taken by the wine company BRL Hardy Limited at their Berri Estates Winery in adjusting management practices to the methodology outlined in the BMP template in order to enhance the long-term viability of their wastewater disposal woodlot. The aim was to minimize the environmental impact and move beyond the more traditional approach of simply complying with mandatory regulations.

Background

The Berri Winery is located at Glossop near the Berri township in the Riverland region of South Australia. It is one of the largest wineries in the southern hemisphere, crushing 120,000 tonnes of grapes in the 2001 vintage. Approximately 280 Megalitres of wastewater is generated each year, which is disposed onto a 40 hectare woodlot planted to predominantly *Eucalyptus camaldulensis* (river red gum) trees. *E. camaldulensis* are particularly suited to this application due to their ability to coppice, and to withstand periods of waterlogging and drought (Stewart et al, 1986). The woodlot contains approximately 20 hectares of mature trees (15 years old), approximately 15 hectares of semi-mature trees (3 years old) and approximately 5 hectares of trees less than two years old. The climate in this region is semi-arid, with an average annual rainfall of 262 mm and a seasonal mean daily maximum temperature ranging from 31 degrees Celcius in the summer months to 15 degrees Celcius in the winter months. Most of the rain falls during the winter period.

The wastewater varies in quality at different stages of wine production throughout the year. The mean pH for the period of April 2001 to March 2002 was 4.5, mean electrical conductivity was 2370 μScm^{-1} and the average sodium adsorption ratio (SAR) was 11. Minimum pH has since risen with ion exchange corrections being made at the source with magnesium hydroxide. Mean chloride levels were 457 mgL^{-1} and mean biochemical oxygen demand (BOD) levels were 4170 mgL^{-1}, while Total Nitrogen averaged 54 mgL^{-1} and Total Phosphorus averaged 8 mgL^{-1}. The wastewater undergoes preliminary treatment where coarse solids are settled in wedges. It is then pumped 5 kilometres from the winery to the woodlot disposal site, where it is flood-irrigated onto 12 rows of trees at a time during an irrigation shift.

Implementing Best Management Irrigation Practice – Overview & Methodology

There were three stages to the process of implementing Best Management Irrigation Practices on the woodlot. The first step involved undertaking a preliminary analysis of the spatial variability of the site. The second step entailed performance of a detailed water balance study to determine the disposal potential of the woodlot. The third step involved the implementation of rigorous and site-specific monitoring programs.

Analysis of Spatial Variability

The soil, plant and hydrological properties can vary substantially across a 40 hectare area of land. Understanding that spatial variability enables management to be tailored accordingly. A soil survey on a 75 x 75 metre grid spacing was undertaken to assess the fundamental soil properties that influence the capacity of the soils to sustain long-term disposal of winery wastewater. The soils were then mapped according to areas that were similar in respect to their capacity to receive and store wastewater.

An audit of the existing irrigation system was undertaken to assess the distribution uniformity along the length of representative flood bays. Three real-time, multiple depth soil water monitoring EnviroSCAN® probes were installed along the length of a flood bay at three separate locations within the woodlot, with one probe situated close to the outlet, one near the middle of the flood bay and one at the furthest end from the outlet.

The planting and irrigation plan was then overlaid on top of the soil plan. Soil units were matched to irrigation valve units and varying tree ages were taken into account to define irrigation scheduling and management units. They were drawn up on a woodlot management plan and a list was made of each valve number that was contained within each scheduling unit. Irrigation batches were set up accordingly and programmed into the irrigation controller.

Water Balance Study

A water balance study was undertaken at the woodlot to determine whether it was being over-utilized or under-utilized in terms of its capacity to store and remove wastewater. A dual approach was taken, whereby a simplified water balance was calculated for every valve unit, and a detailed water balance was performed at five representative locations within the woodlot.

In the simplified approach, the deficit or excess was calculated for the 12 month period of April 2001 to March 2002. The inputs considered were: effective rainfall (measured by a rain gauge situated under the canopy) and applied wastewater (assuming an application efficiency of 85%). The only output taken into account was potential evapotranspiration (ET_o) and no consideration was given to drainage or soil storage. The ET_o figures were derived from pan evaporation and pan coefficient values published for eucalyptus trees in the nearby Mildura region (Myers *et al*, 1999). The following equation was used:

$$\text{Deficit/Excess} = \text{Effective Rainfall} + (\text{Wastewater volume} \times 85\%) - \text{Potential Evapotranspiration}$$

In the more detailed study, the water mass conservation at the woodlot between two consecutive time steps (t and t + 1) was determined using the following equation:

$$Storage_{(t+1)} = Storage_{(t)} + \text{Effective Rainfall} + \text{Wastewater Volume} - \text{Drainage} - \text{Evapotranspiration}$$

It was assumed that there was no runoff out of the flood bays. Drainage was determined using the zero flux plane method. The zero flux plane is a horizontal plane defined by reversal in the direction of the unsaturated hydraulic gradient. Above this plane, the water content decrease is due to evapotranspiration. Below the zero flux plane, the hydraulic gradient is vertically downward and decreases in soil water content are assumed to reflect a net movement of water vertically downward out of the monitored soil profile (Shimada et al, 1999).

Monitoring Plan

Ongoing monitoring of key environmental factors was seen to be critical to the success and long-term viability of the woodlot. The purpose of monitoring in relation to implementing Best Management Practice was to enable continuing adjustment and improvement to management strategies and to provide early warning against any possible detrimental effects to the environment. The monitoring of the Berri woodlot was split into 6 key areas, namely wastewater, soil, vegetation, irrigation, groundwater and weather.

Samples of wastewater were collected on a regular basis and analysed for a range of quality factors including pH, salinity, BOD and nutrient loading. This data was then used to assess the nutrient, salt and organic loading of the water being applied to the woodlot. Logging of the wastewater pH enabled the water to be lime adjusted directly where needed. Magnesium hydroxide adjustment of other streams enabled better pH control of the wastewater before the storage lagoon. The volume of wastewater being pumped onto the woodlot was recorded by a flow meter and logged at 10 minute intervals in the winery's central Citect data management system. This information was then transferred into a spreadsheet that logged the amount of daily flow to each valve unit.

Soil samples were taken twice a year (before and after the main periods of wastewater application) from multiple depths and from within each of the main soil groups. These were analysed for Electrical Conductivity (EC), pH and dispersibility. Soil samples were also analysed for key nutrient and organic content to monitor any increases over time as a result of wastewater disposal.

Tree health and woodlot condition was monitored by regular inspection by the woodlot manager. In addition, annual leaf samples were taken for tissue analysis to detect any build-up of nutrients or salts within the trees. The data trends over time were compared with recommended upper threshold levels for each element monitored.

The soil water content was recorded using multiple depth, real-time soil water monitoring probes installed in each of the 11 irrigation scheduling units and connected by cable to 2 EnviroSCAN® data loggers. A GSM phone modem was connected to each logger to enable remote download of the data into the winery computer system. Soil water data was displayed in the EnviroSCAN® software to enable soil water dynamics to be interpreted.

Water table heights were measured weekly during the peak irrigation season at piezometers located both within and outside the woodlot. The height of a nearby lagoon that stores drainage water from local salt interception schemes was also recorded. This information was plotted over time to detect any impact of the wastewater irrigation on the groundwater. Annual samples of the groundwater were collected and analysed for nutrient and total organic contents.

A Campbell Scientific weather station was installed at the woodlot to record: effective rainfall (with a rain gauge positioned under the canopy and a second rain gauge positioned outside the canopy), temperature, solar radiation, relative humidity and pan evaporation.

Results

Analysis of Spatial Variability

The analysis of spatial variability revealed that there were three major soil groups across the woodlot area. These were defined as: river flat clays with Monoman Sands underlying at 1.0 – 1.3 metres depth below the surface; river flat clays with no Monoman Sands within 1.8 metres from the surface, and profiles with shallow topsoils overlying a slow draining carbonate layer and clay. The active rootzone of the trees was predominantly located within clay of field saturated hydraulic conductivity values as measured with a Guelph Permeameter varying between 1.00×10^{-4} cms^{-1} and 5.2×10^{-5} cms^{-1}. The areas with underlying sands of higher permeability were differentiated as being areas with a higher risk of impact of wastewater irrigation on the underlying groundwater. The three major soil groups were mapped and subdivided into 11 key areas to account for variations in tree size, irrigation flexibility and variation in soil salinity levels.

Water Balance Study

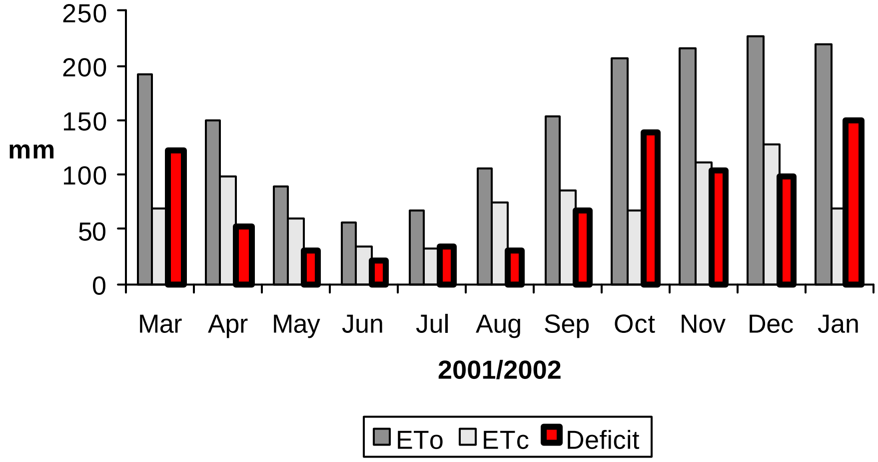
During the 11 month study period of May 2001 to March 2002 there was 206 mm of rainfall (equivalent to 156 mm net rainfall). The rainfall interception totalled 50 mm, which represented 24% of the total rainfall for this period. The total amount of wastewater applied during this period was 214.5 ML.

A monthly deficit/excess analysis of the woodlot taking into account ET_o, wastewater and net rainfall, and assuming no soil water storage potential or drainage, revealed that the woodlot was in deficit for most of the year. In other words, the amount of water that was applied to the woodlot in the form of rainfall or irrigation usually did not match the ETo of the woodlot. For the winter months of June and July (disregarding the large potential sink of soil storage) the woodlot was in excess by 9 mm and 8 mm respectively, whereby more water was applied than was lost through potential evapotranspiration.

The estimated total water storage capacity of the soil however, is 40 % and approximately 67% of the plant available soil water had been used by the plants at the start of the study period at the end of summer. Allowing for this soil storage potential over an active root zone depth of 1 metre, the excess water applied during June and July can be seen to be readily stored in the soil profile.

This was further verified by the detailed water balance study that took into account soil water content and drainage as well as actual evapotranspiration (ET_c) and ET_o, which revealed that for the 5 areas examined, the woodlot was in deficit for all months of the year. In June, the woodlot was used at close to its full potential, but was still in substantial deficit of the ET_o (22.2 mm to 36.5 deficit). Figure 1 shows the difference between ET_c and ET_o as a deficit in millimeters for Valve Unit 8. There was some variation between the 5 sites, with annual deficits ranging from 870 mm to 1290 mm. Valve Unit 8 represents the area that was used at closest to its full potential of any of the areas studied. Other valve unit results are not shown.

Figure 1. Water Balance for Valve Unit 8



Monitoring Program

Table 1 lists the wastewater volumes applied over the period of April 2001 to March 2002. The peak volumes of wastewater production occurred in the months of March, April and May.

Table 1. Monthly wastewater volumes produced at the Berri Winery

Month	Apr 2001	May 2001	Jun 2001	Jul 2001	Aug 2001	Sept 2001	Oct 2001	Nov 2001	Dec 2001	Jan 2002	Feb 2002	Mar 2002
Wastewater produced (megalitres)	44.32	27.69	18.96	16.27	18.24	16.41	14.74	13.47	9.24	9.58	17.95	51.98

The relatively high total organic loading in the wastewater was observed to lead to a build-up of organic matter in the flood bays. A minimum time of 7 days during the winter months between irrigations was necessary to break down the organic surface layer. More frequent irrigation would lead to surface crusting which substantially reduced the water infiltration rate. This was addressed through irrigation scheduling and the allowance of sufficient drying times, and by cultivation.

Figure 2 shows soil water content data from sensors at 10 cm, 30 cm, 50 cm, 70 cm, 100 cm, 130 cm, 160 cm and 200 cm below the surface from Valve unit 8 stacked on a graph and plotted against time. From this it was possible to visualise: the active depth of rootzone[a] as seen by diurnal variation in the rate of soil water use; the depth of effective irrigations[b] and hence the area of likely salt build-up[c] and the relatively static moisture content within the deeper profile[d] indicating no deep drainage.

Figure 3 shows a sum of the data collected from each of the sensors within the active root zone in Valve unit 8 plotted over time. Upper and lower management thresholds were set within which the soil water content was maintained. Different lower thresholds, or refill points, were set at different times of the year to account for the varying evapotranspiration rates.

Water table heights varied throughout the year from 2.8 m to 6.0 m below the soil surface across the woodlot. The flux in groundwater height under the woodlot appeared to be directly related to the height of water in the nearby regional storage lagoon. Further piezometers were installed on the southern edge of the woodlot to show any impact on the water table heights in that area as a result of irrigation on neighbouring vineyards. Results from these piezometers are not yet available.

Figure 2. Stacked graph of soil moisture with time

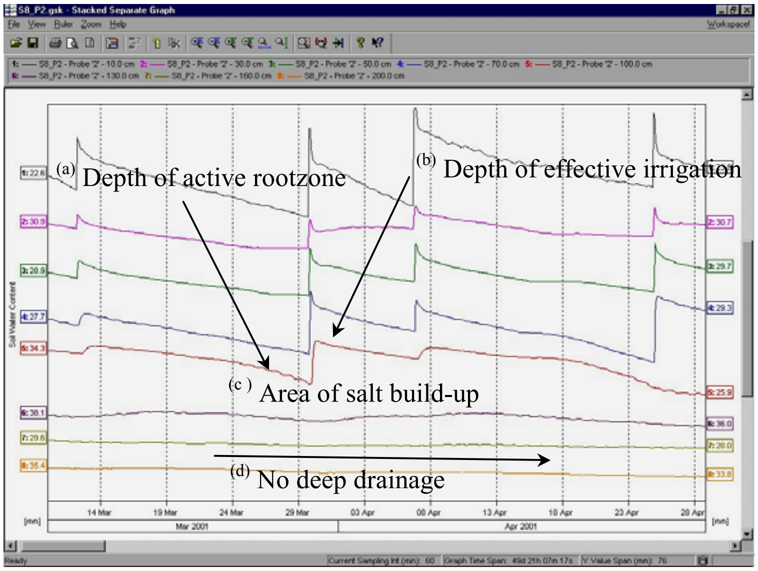
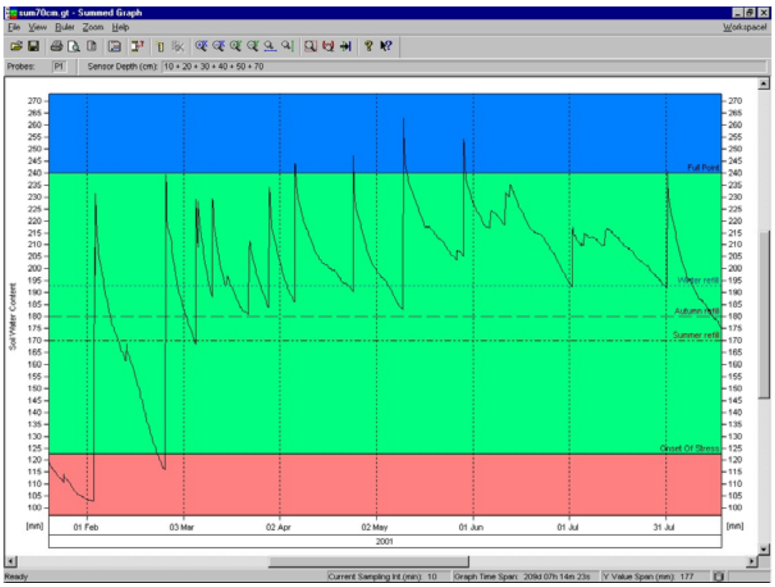


Figure 3. Graph showing sum of data from soil water sensors within the active rootzone over time



The information from the weather station was combined with the flow data and the soil water data to make informed irrigation scheduling decisions. The aim of irrigation scheduling was to ensure that:

- the full depth of active rootzone was receiving water
- sufficient leaching was applied to prevent the build-up of salts within the rootzone
- deep drainage of wastewater that would impact on the underlying groundwater was avoided
- tree stress due to a lack of water was avoided
- water logging was avoided.

The ultimate aim was to maximise plant water uptake by keeping the soil water content at an optimum level for good tree health.

Discussion

Although a monitoring program had been in place for some time at the Berri Woodlot, the aim in the past 12 months was to make the monitoring program a more substantial and proactive part of the woodlot management. An integral part of this was the appointment of a “woodlot champion”, to take on total responsibility for the monitoring and management of the woodlot.

Subdividing the woodlot into distinct management units enabled the “woodlot champion” to manage the woodlot as 11 separate irrigation batch units, rather than trying to cope with the logistical challenge of scheduling 66 individual valve units. In that respect it helped to simplify the irrigation scheduling process. Soil water data was used in conjunction with weather and flow data as well as a calendar of cultural activities (e.g. cultivation, gypsum application) to produce of a priority-based irrigation schedule for each irrigation batch unit.

In addition, it ensured that each area was being managed according to its true potential to store and utilize wastewater. This prevented problems of over-irrigation in some areas of the woodlot and under-irrigation in others. Volumes of wastewater applied in each irrigation event could be readily altered for different areas by changing the batch run times.

This water balance study was conducted when implementation of the comprehensive monitoring program had only just begun. At this time, irrigation scheduling decisions were largely based on a visual assessment of the woodlot, with irrigation events cycling through each valve unit one at a time. This accounts for the variation in how much potential had been used between sites within the woodlot. Irrigation scheduling decisions that take spatial variability into account should ensure a much more consistent utilisation of the woodlot potential, and reduce the hazards of over use in particular areas within the woodlot and potential environmental harm.

In the past, the sole determining factor for irrigation scheduling in many woodlots has been the rate of effluent production, without any consideration of the plant’s ability to transpire the water (Myers, 1992). Real-time monitoring at the Berri Woodlot enabled more accurate irrigation scheduling decisions to be made within each of the separate management units, leading to better control of the impact of wastewater irrigation on the surrounding environment. Real-time soil water data showed a slow-down in daily plant water use due to saturated and waterlogged conditions, which meant that these conditions could be readily avoided. Multiple depth sensing detected the wetting fronts of irrigation and rainfall events moving through the soil profile. Deep drainage was avoided while applying leaching irrigations in a controlled manner. Regular groundwater monitoring was seen to reinforce these data. The need for provision of water from an alternative source during the summer months when there is no wastewater generated was also identified.

Implementation of Best Management Irrigation Practice on the Berri woodlot is an ongoing process. Detailed monitoring continues to highlight new sets of problems to be addressed. For example, measuring the irrigation distribution uniformity down a row demonstrated the need for the irrigation bays to be re-laser levelled. In addition, as technology advances, new innovations need to be incorporated into the woodlot management system.

Adjustments made to the wine production process will also impact on the woodlot as a result of changes in the wastewater quality. The winery has made significant reduction to water use in terms of litres used per tonne of grape processed. While this reduces the hydrological pressures on the woodlot, the changing water quality and resultant nutrient, organic and salinity loading will need to be taken into account. The winery has a number of environment improvement programmes in place, which focus on cleaner production. These should result in improvements in wastewater quality, which will help to enhance the long-term viability of the woodlot.

Conclusions

The key to the ongoing sustainable management of winery wastewater re-use onto the woodlot lies in the treatment of the woodlot as a living entity that must be maintained at optimum health to maximise its potential. The Best Management Practice template described here is a plan to achieve this objective. In addition, implementing this plan has brought significant cost-savings to BRL Hardy Limited through better use of existing resources.

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APPLICATION OF SWINE LAGOON WATER TO CORN AND ALFALFA

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Abstract: Increasingly more large swine production facilities are faced with the dilemma of being involved in a production system that can produce more waste that there is land available for distribution at agronomic rates. Alfalfa represents a crop that utilizes a large amount of nitrogen, has a deep rooting system, and provides a larger window for application than other crops. The goal of this study was to determine how much nitrogen could be applied to irrigated alfalfa without resulting in excessive nitrogen leaching losses. A line-source irrigation system was used to apply swine lagoon water at rates from 0 to 140% of the anticipated nitrogen utilization rate to corn and alfalfa. Later work included planting nonfixating alfalfa which appeared to have similar production capability. Lagoon water application above about 250 lbs. N per acre caused nitrate concentration of leaching waters to rise above 10 ppm. Buildup of potassium and phosphorus also occurred at the high lagoon water application rates.

INTRODUCTION

A substantial amount of manure is produced by midwest animal production facilities. Production statistics indicate that the five states of Colorado, Iowa, Kansas, Nebraska, and South Dakota typically produce nearly 13 million head of cattle, 8 million head of swine, 48 million chickens, and 60 million turkeys each year in confinement facilities (National Ag Statistics, 1999). Based on published values, these animals produce approximately 6.5 Tg ($6.5x10^{12}$ grams) of manure each year (Van Dyne and Gilbertson, 1978). The nutrient content of the manure is equivalent to approximately 0.3Tg of nitrogen, 0.09 Tg of phosphorus, and 0.16 Tg of potassium. Animal manures also contain micronutrients that are necessary for plant growth and development (National Research Council, 1993). Though storage and handling loss reduces the nitrogen content by 30 to 70%, failure to distribute these nutrients and utilize them in a cropping system can contribute to contamination of ground and surface water in the region and down stream (King et al., 1990; Rabalais, 1992).

The trend toward increased concentration of animals in large production units makes it difficult to find enough available land for economical manure distribution at agronomic application rates. In Nebraska, pigs per farm have increased from 250 in 1982 to 507 in 1997. As the number of pigs per enterprise have increased, there has not been a corresponding increase in the number of acres per enterprise available for land application and crop utilization of the stored swine manure. Large concentrated hog production facilities commonly install water flush units in buildings for removing swine manure. Slatted floors allow manure to pass through to a sloped concrete floor poured below the slats. Large volumes of water are flushed over the concrete floor transporting manure into an exterior storage basin or lagoon. Typical designs utilize approximately 2000 gallons of flush water annually per head in confinement. A lagoon is an appropriate storage media for this dilute manure because it minimizes the surface area devoted to manure storage and climatic conditions can reduce the water volume by evaporating water into the atmosphere. The manure stored in lagoons is typically distributed via center pivot or knife applicator with an umbilical hose supply line. Though manure is commonly applied to crop land planted to corn, some producers use other crop rotations, corn for forage, or pastures as sites for application of swine manure. These factors have led to situations where ground and surface water quality are at risk of contamination.

Using alfalfa to substitute for nitrogen fertilizer in corn production has been calculated to have the potential to save 14% of the nitrogen applied to corn (Peterson and Russelle, 1991). Using alfalfa as a scavenger crop for nitrogen is proposed primarily since its deep rooting allows for moisture uptake from deeper in the soil profile than annual crops (Kiesselbach et al., 1929). Deeper rooting and moisture uptake increases nitrogen uptake (Mathers et al., 1975). These properties of alfalfa have been used to minimize nitrogen movement under abandoned feedlots (Mielke and Ellis, 1976; Schuman and Elliot, 1978). Researchers in Minnesota found that nonfixating alfalfa removed 31% more subsoil nitrogen than fixating cultivars suggesting that nonfixating cultivars would be useful for bioremediation of nitrogen contaminated sites.

In the south, research has been conducted to determine the cropping systems that maximize nitrogen removal with bermudagrass, ryegrass, and corn silage using liquid dairy manure (Johnson et al., 1991). They were able to achieve a maximum of 543 lb/acre nitrogen yield. Previous work has been conducted with a tall fescue, Kentucky bluegrass, and ladino clover mixture in North Carolina (Evans et al. 1984; Westerman et al. 1987; Burns et al. 1990; and King et al. 1990). Burns found that effluent rate was important since at high rates the forage mixture did not remove all applied nutrients. Most notably, the grass or forage mixture did not remove all the nitrogen, potassium or phosphorus applied with the irrigation water. Buildup of these and other nutrients is evidence of potential groundwater contamination. If groundwater contamination is to be minimized, a broader range of nutrients must be accounted for when investigating swine lagoon water application rates.

Animal waste can be applied using a variety of ground application equipment or via sprinkler irrigation. Sprinkler application offers a couple of advantages over other methods: 1) The timing of application can be geared more to crop requirements since the applicator can move freely over the crop without damage; and 2) Large volumes of water can be applied in a short period of time with a high degree of uniformity thus minimizing air and water quality concerns.

The goal of our research was to evaluate alfalfa as a nitrogen sink for nutrients contained in swine lagoon water. An established stand of irrigated alfalfa can remove more than 700 pounds of nitrogen per acre in the harvested hay. If alfalfa removed applied nitrogen at that level, producers could potentially reduce the land base for lagoon water distribution by over 50% when compared to the 200 pound removal rate for corn followed by winter rye. This could be beneficial to producers who do not have sufficient land to apply lagoon water at agronomic rates to row crops.

Advantages to alfalfa also include: it covers the ground all year round which reduces the erosion potential; the nitrogen use curve is more constant through the season than for annual crops; uptake of phosphorus and potassium are relatively high; lagoon water application can occur at times that are not possible in a corn system; and alfalfa is deep rooted and can scavenge nitrogen from deeper in the soil than most other crops grown in Nebraska.

METHODS

A line-source sprinkler system was used to distribute a range of lagoon water rates to both alfalfa and corn. Figure 1 shows the distribution of the lagoon water and of fresh water. The experiment was designed so that the distribution patterns of both the fresh and lagoon water waters produce an even amount of water application. Therefore, only lagoon water rates changed. Rates of lagoon water were chosen that provided from 0 to 140% of the predicted nitrogen harvest for the corn-winter rye and alfalfa treatments. Irrigation of each crop could be controlled and was applied based on soil moisture and crop nitrogen needs with the caveat of needing to apply up to 600 lb-N per acre near the centerline.

Laboratory analysis showed that the lagoon water contained about 90 lbs total nitrogen, 100 lbs K_2O, and 10 lbs P_2O_5 per acre-inch of water (Table 1). The goal was to apply sufficient lagoon water so that at the end of the growing season both the corn and alfalfa would have plot areas with an excess of applied N. 1994, soil samples, leachate and crop harvest took place at 6 equally spaced areas across each cropping system plot for a range of 0 to 140 percent of anticipated nitrogen removal rates.

At each sampling site a porous cup extractor was installed 6.5 feet in the ground (Insert, Figure 1). The soil water solution passing the cup was sampled and analyzed for nitrate. Neutron readings were recorded to determine the rate of water flow past the 6.5 foot depth. This information was used to determine the amount of nitrate leaching at each sampling site (Table 3).

The original alfalfa stand was planted in the fall of 1992 and replanted in 1993. In 1996 the corn-rye and alfalfa areas were switched. However, the gradient of increasing levels of swine lagoon water application remained the same. In 1996, a non-nodulating alfalfa variety (Saranac) was planted along with the conventional variety and the number of subplots was reduced from 6 to 5 (Figure 1). Unlike the conventional variety, the non-nodulating isoline could not use atmospheric nitrogen for crop growth needs.

In each year, alfalfa samples were collected from each subplot using a flail-type forage harvester. Sampling protocol was designed to mimic a range of harvest management schemes. Thus, each replicate contained subplots that were harvested 3x, 4x, or 5x times per year. The 3x treatment was harvested at full bloom and the 4x and 5x at tenth bloom. The 5x treatment had the 5th harvest after a killing frost. Plant dry matter was collected from a 30 square foot area and used to estimate total dry matter production for the treatment. Laboratory analysis provided the N content in each alfalfa sample.

RESULTS

In 1994, dry matter production ranged from 9 to 10 tons of alfalfa per acre. Thus, the addition of 560 lb-N resulted in an additional ton of dry matter production (Table 2) and a slight increase crude protein of about 1.5% (data not shown). Yields were highest when the alfalfa was harvested 4 times per season at approximately 10% bloom. Apparently, the harvest after a killing frost reduced yields for the 5x treatment.

Subsurface drainage was greater than would be typical of a field managed using irrigation scheduling techniques (Table 3). This was due in large part due to near normal precipitation and below normal temperatures so irrigation need was minimal. Drainage ranged from 6 inches in plots receiving no lagoon water to 4 inches in plots receiving 560 lb-N. This reduction in drainage is attributed to the additional production (1 ton/ac) resulting from the lagoon water application.

The N concentration of soil water at the 6.5 foot depth had flow-weighted average concentrations that ranged from 4.9 ppm in plots receiving no lagoon water to 37 ppm where 560 lb-N were applied (Table 3). The acceptable N concentration is up for discussion, however, if the maximum contaminant level for drinking water of 10 ppm NO_3-N is used, our data would suggest that approximately 340 lb-N could be safely applied to irrigated alfalfa. We were not in a position to estimate losses of N to the atmosphere during and after application, but published values are typically greater than 30%. Assuming 30% application loss, the actual removal in the alfalfa dry matter would be close to 235 lb-N. This level of utilization agrees with laboratory research from Minnesota that suggests that alfalfa will preferentially fix up to 2/3 of the N removed in the forage. This happened despite N applications that would have met crop needs. Thus, a high percentage of the N contained in the alfalfa forage will continue to be fixed from the atmosphere.

Nitrate leaching losses ranged from 7 to 33 lb-N per acre (Table 3). Though a zero tolerance rule could be applied, these levels are within the range recorded for crops fertilized with commercial fertilizer. Leaching losses would be reduced if subsurface drainage could be reduced by irrigation management strategies that allow plants to lower soil water content near the end of the season. Another beneficial practice would be to leave room in the soil profile for rainfall by accounting for the deep rooting depth of the crop. Both of these practices were not possible during this research due to timely rainfall events and the need to apply 6-7 inches of lagoon water.

In 1996, the non-nodulating alfalfa nitrogen harvest was 70 percent of the nodulating alfalfa at the zero lagoon water rate, but equal to the nodulating alfalfa at the higher nitrogen rates. Due to it being a crop establishment year, sufficient rainfall, and the use of irrigation scheduling, the maximum nitrogen applied in

1996 was 75 lbs total nitrogen/acre. Actual N removal in the forage was within 10 lb-N per acre for the non-nodulating and nodulating isolines (Table 4).

A severe winter in 1996 caused winter kill in the experiment, so the alfalfa was replanted in 1997. Subsequent work continues to support the notion that non-nodulating alfalfa will produce forage of the same quality and quantity as nodulating alfalfa if N is applied to meet crop needs. Failure to apply sufficient N tends to reduce plant stand by allowing weed competition, and it appears to increase the potential for winter-kill in the isoline we tested. Plant breeding efforts will likely reduce the winter-kill problems.

DISCUSSION

Documenting the environmental effects of swine lagoon water application is the major objective of this research. Two indicators have been monitored 1) soil nutrient levels in the spring and fall and 2) nitrate leaching.

Using book-values, 9 tons of alfalfa would remove about 500 lb-N, 135 lb-P_2O_5, 540 lb-K_2O per acre. In 1994, laboratory analysis of the dry matter indicated that about 700 lb-N were removed in the forage. Field data indicate that alfalfa can remove more applied N than a more traditional crop like corn. Thus, the lagoon water can be distributed over fewer acres of land when alfalfa is used as a scavenger crop.

Soil samples taken in the spring of 1997 indicated that a buildup of both phosphorus and potassium at the higher application rates was occurring (Table 5). The phosphorus levels are increasing despite removal at rates up to 50 lb-P_2O_5 per acre greater than the application rate. Research evaluating the long term impacts of manure applications have suggested that manures high in NH_4-N can change soil pH sufficiently to allow additional phosphorus to enter the available pool from the organic pool. In addition, increased microbial activity tends increase P mineralization rates. Both of these factors are likely present in fields where swine lagoon water is applied. Thus, long term application of swine lagoon water may need to account for the additional P in the management plan.

Potassium application was in excess of the removal rate so buildup was anticipated. However, continued buildup of soil potassium could cause soil structure problems in the future. At some point, lagoon water might need to be reduced until potassium levels decrease.

Leaching of nitrate may occur when drainage through the soil profile occurs. When irrigation scheduling techniques are used correctly, drainage is held to a minimum. When rainfall is greater than crop use, drainage is inevitable. Research using commercial fertilizer applications tends to suggest that off-season losses are a definite concern in Nebraska. So even if good irrigation management is practiced, over application of N may lead to leaching losses. This is of particular significance where manure storage capacity considerations necessitate land application regardless of soil water availability, thus, increasing the risk of a drainage and N leaching event.

Application of swine lagoon water to alfalfa shows considerable promise based on the results of this research. Alfalfa uses large amounts of nutrients contained in animal manures and provides ample opportunities to spoon feed applications in much the same was as commercial fertilizers. Further development of the non-nodulating alfalfa isolines will enhance the value of alfalfa as a crop suitable for use in crop rotations used by animal producers.

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Table 1. Nutrient concentrations of monthly water samples collected from the swine lagoon in parts per million. Concord, NE.

Year	No. Sample	Total N	NH_4-N	P_2O_5	K_2O	S	Zn	Na	Ca	Mg
		-------	-------	-------	ppm	-------	-------	-------	-------	-------
1993	12	400	310	9.8	401	4.1	0.13	103	59	23
1994	12	420	371	12.8	554	2.1	0.14	114	65	26
mean		410	340	11.3	472	3.1	0.13	108	62	24

Table 2. Mean dry matter yields as affected by swine effluent application in1994. Concord. NE.

Effluent N Rate	Alfalfa Harvests per Season 3x	4x	5x	Mean
kg N / acre	----------------- tons DM per acre		--------------------	
0	8.5	9.3	8.9	8.9
90	8.3	9.7	9.1	9.0
210	8.4	10.4	9.5	9.4
340	8.4	10.0	9.7	9.3
450	8.7	10.7	10.0	9.8
560	8.8	10.1	10.3	9.7

Table 3. Total nitrogen harvested after irrigation with swine effluent as alfalfa hay and in a corn/rye system. Concord, NE.

Year	Alfalfa type	Nitrogen	Crop	Nitrogen
		lbs/acre	lbs/acre	
1993	Nodulating	230 - 250	Corn/rye	154
1994	Nodulating	680 - 745	Corn/rye	213
1995	Nodulating	337 - 520	Corn/rye	162
1996	Nodulating	270 - 383	Corn	205
1996	Non-nodulating	189 - 396		

Alfalfa was established in 1993 and 1996.
Rye cover crop did not survive winter in 1996.

Table 5. Effect of swine effluent application on drainage, leachate nitrate nitrogen and nitrate nitrogen leached. 1994. Concord, NE..

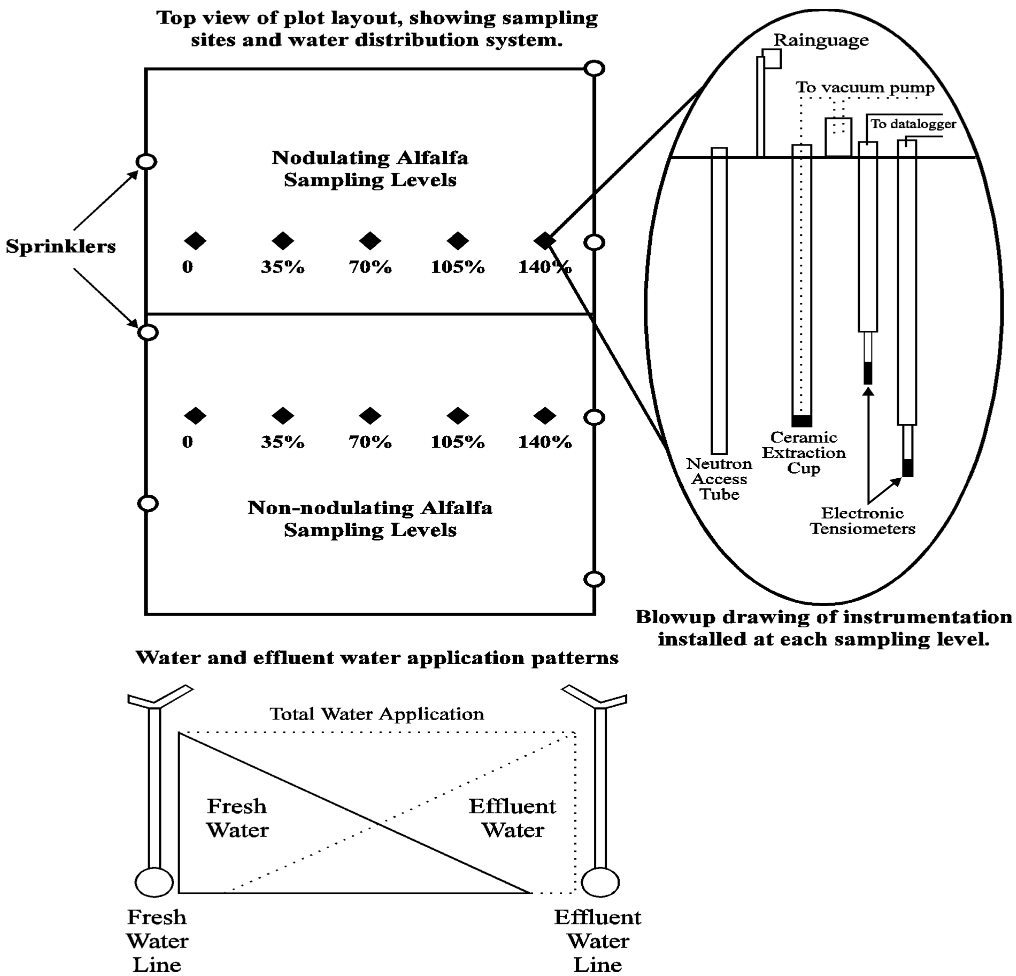
Effluent N-Rate	Drainage	Nitrate-Nitrogen Concentration	Nitrate-Leaching
(lb/ac) (inches)	(ppm)	(lb/ac)	
0	6.3	4.9	7.0
90	5.7	8.2	10.6
210	5.5	8.2	10.2
340	6.3	10.0	14.2
450	4.7	19.9	21.2
560	3.9	37.1	33.1
Mean	5.4	14.1	16.0

Table 4. Effect of lagoon water on soil phosphorus and potassium after four years of irrigation with swine effluent. Concord, NE.

Swine Effluent Application Intensity	Soil P	Soil K
% of estimated N removal	----------ppm-------------	
0	31	188
35	42	213
70	51	306
105	70	383
140	66	364

Soil sampled spring 1997; corn grown 1996-97 and alfalfa 1993-95.

Figure 1. Field layout, water distribution and porous cup installation. Concord. NE.



Field plot detail of instrumentation and water application system for fresh and effluent waters.

RECYCLED WATER: HISTORY, USES, COMPOSITION, AND PROBLEMS

I remember when I was young, I used to fish from inner tubes in very shallow water in the Gulf of Mexico. The water was a crystal clear, blue-green and you could see the bottom at a 20 ft depth. My cousin and I would catch fish as long as my arm all day long. It was only a matter of how long we wanted to fish, not whether we would catch any fish. That was forty years ago. Today, if you want to go fishing for big fish, you have to go offshore 50 miles. There used to be an abundance of sea shells on the beaches. We would collect shells to make periwinkle soup. Today there are no more shell on the beaches in America. What happened in 40 years?

HISTORY:

Let’s go back and look at the history of waste treatment. When America was first settled, houses were far apart and there weren’t any problem with waste disposal until cities began to form. In the urban setting, waste disposal became a serious problem. Previously in Europe, wastes had been poured into the streets which led to serious diseases including the great plague. Open culverts had been used during the Roman Empire for the collection of waste in a central location. Ben Franklin changed this in America in 1870 by using logs that were hollowed out to be used as pipes.

The first waste treatment facilities were simple lagoons located outside of town. These lagoons became a problem as cities began to expand. Odors, overflows from heavy rains and disease were problems that plagued this method. However, this continued to be the normal method of waste disposal until the 1950s. During the 1950's settling tanks, aerators, drying beds, and other contraptions were placed into use. From the 1950s to the 1970's, waste treatment facilities were set up in conjunction with the storm water runoff system. All that was needed to operate the facility was a steady stream of precipitation that would flow through the facility and flush the solids out of the waste treatment plant and into the waterways. The waste treatment facilities normal practice was to dump “*treated water*” into streams, creeks, rivers, oceans, and other waterways. In the 1970's the EPA stepped in and began to require separation of the storm water run off and waste treatment systems. Today that has not been completed in most areas of the country. Most cities still allow storm water runoff to run through the waste treatment facilities and then into the waterways.

With the population explosion in urban areas across the country, many cities quickly found their waste treatment facilities overloaded and with great problems. Instead of increasing the capacity of the waste treatment facilities or building new plants, many waste treatment programs simply decreased the time of treatment and passed the “less treated” “*treated water*” out and into the waterways. Less treatment for more money. Sounds familiar doesn’t it? When new waste treatment facilities are built, they are very much like our highways, it’s too little too late. The waste treatment facilities are overcapacity as soon as they are finished. Almost no treatment facility has the capacity to allow the wastes to remain in the facility for the time required for effective treatment.
However, governments soon found that water and waste treatment were the only areas that produced income. The costs of new facilities and overhead quickly raised the sewer charge. On the average bill, sewer charges quickly doubled, tripled, quadrupled, or went even higher without increasing the effectiveness of the waste treatment facilities. Septic systems were banned in many areas simply to allow governments to collect more money while not showing enough concern for the environment or looking at the long term water supply.

In the 1980s, the EPA increased the number and scope of tests required by treatment facilities. The allegations of heavy metals, pesticides, and other undesirable compounds were discovered in the solids removed from waste treatment facilities. Previously, solids were removed from the waste treatment facilities and placed in pastures, farms, and other areas for organic enrichment of soil. After more than200 years of civilizations placing the waste solids on farmlands, the EPA declared that this practice must cease. With the new testing standards, the EPA began to require that these solids be placed in landfills. Not only was disposing of liquid a problem, but now disposal of the solids also became a problem. This resulted in the cost of treating waste water to go up with no change in the results.

Why is recycled water now of interest to these same with government entities? Why all of a sudden is recycled water important? It's important because they are running out of water. They can't sell water they don't have. Water treatment plants would have been content to dump the waste water into our streams and oceans forever. It's only when America is running out of water thus threatening the income from waste water treatment that recycled water has become an issue.

USES:

RECYCLED WATER SHOULD NEVER, EVER BE INJECTED INTO THE GROUND WATER SUPPLY

Recycled water must be allowed to seep back into the ground in order to naturally replenish the ground water supply. Although septic tanks have been looked down upon as something only country folks have, its design is simple, effective, low cost, and it returns clean water to the aquafer using the ground as an excellent filter to remove solids and organisms. Septic tanks should be become the preferred method of waste treatment and should be used whenever possible. However, with large systems already in place, the water must be disposed of in some manner. Using this water for irrigation is an excellent method of increasing the water supply in the aquifer. Golf courses should be the first priority for use due to the large volume of water that they use and close proximity to populated areas. Some cities have installed recycled water systems and are returning the water to residential and commercial customers for a small monthly fee. Other cities have gone as far as making it mandatory to customers to pay for the service whether they use it or not. Many more are looking into the effectiveness of recycled water for their community.

Agriculture use of recycled water has been spotty due to the distance from the facilities to more rural areas where farms are located. Due to large volume of water consumed and the need for continuous water, agricultural irrigation would be an excellent use of this water. Although treatment would be required in order to use treated water, it would be an excellent way to safely get water back into the aquifer.

WATER SHOULD NEVER, EVER BE INJECTED INTO THE GROUND WATER SUPPLY

Using recycled water in irrigation is an excellent way to return water into the aquifer. The ground works as a great filter for removing the nutrients and organisms found in the "treated water".

RECYCLED WATER QUALITY:

What should we expect from the quality and quantity of waste treatment recycled water? There have been many debates about the usefulness and desirability of using recycled water. Using recycled water never would've been required if we had continued to use septic tanks or waste disposal in residences. One of The most consistent qualities of recycled water is the inconsistency of the water. When considering the quality of the recycled water, all one has to consider is the source. There are two sources to consider in the constituency of recycled water. The makeup water (or source water) and the constituents added by the users (us). Consider all the things that people dump down the drain. Everything from the leftover gravy, chicken and animal fats, other foods and peelings, motor oil, furniture polish, detergents from dishwashers and washing machines, drain openers, shoe polish, paint and thinners as well as the normal load of human wastes. The quality of recycled water will depend on the constituents that are placed in the wastewater stream.

Mineral Content - Typical analysis of recycled water from a mineral content is consistent with the quality of the water that was used as the water source. What this means is that there is a little change to the water's mineral content going through the processes in the waste treatment facilities. There are small changes in the amount of phosphorous, chlorides, and calcium, but overall the mineral content remains unchanged in the treatment process. Slight increases and variations are to be expected but there should not be a significant change in the mineral content of recycled water as it relates to irrigation. A typical recycled water analysis from Tampa FL is listed below. All of the constituents are soluble and there isn't any noticeable precipitation. The "gray" water label has to do with the color of the water and not the content. While there are higher levels of phosphate, hardness, and chlorides, it is not the mineral content that will be of greatest concern.

RECYCLED WATER ANALYSIS
7-05-95

Temperature 77°F

	Recycled Water	Domestic Water
P Alkalinity (as $CaCO_3$)	0.0	0.0
M Alkalinity (as $CaCO_3$)	164.0	124.0
Chlorides (as Cl)	261.6	120.0
Total Hardness	256.0	120.0
Calcium (as $CaCo_3$)	160.0	108.0
Magnesium (as $MgCo_3$)	96.4	12.0
Silica (as SiO2)	17.3	13.5
Sulfate (as SO_4)	78.2	0.0
pH	6.85	7.68
Conductivity	1200	250
Iron (as Fe)	0.4	0.5
Phosphate (as PO_4)	4.5	1.6

Biological Content - The greatest challenge of using recycled water will be overcoming the rich nutrient base. With the amount of detergents, food, and other contaminants suspended in the water, it is a rich source of culture growing media. The biological content of recycled water will be the greatest detriment to using recycled water. With all the processing, treatments, and procedures of the waste treatment facilities, there is significant biological contamination of the treated water. Every bacteria, algae, slime, virus, and other organisms known to man can be expected to be in the recycled water at some time or another.

In July of 2000, a man was swimming in the Gulf of Mexico and a cut on his leg became infected. After several days in the hospital, he died. The infection was from the biological contamination of the Gulf from a waste treatment facility. Oysters used to be the staple crop of Apalachicola FL, but today if you eat raw oysters, you are taking your life into your own hands. There have been numerous deaths and serious illnesses from eating oysters. This is why the fish near the shore have died, or have left. The animals that produce shells have either died or left the area for a safer living environment.

How will this affect irrigation? Expect to see large colonies of algae, slime, and bacteria growing in the systems. Chlorine will be ineffective to control these growths as the water is already chlorinated and it is unable to control or kill the large number of organisms in the water. Much of the chlorine will attach itself to the contaminants in the water and is not available for attacking the pathogenic organisms in the water.

System filters will begin collecting organic masses on the surface of the filter media and the pressure in these systems will increase. Back washing will begin to be required more often until the pressure is too great and the filter media will require cleaning or replacing. Automatic filters that back wash when the pressure differential gets to a certain point, will begin flushing frequently and eventually will be flushing as often as it is filtering, rendering the filter system useless. In working with highly contaminated water, there have been situations when using seep irrigation that a 2" PVC pipe has been plugged with organic matter. I would not have believed it if I didn't witness it myself.
As in most irrigation systems, the smaller the orifice, the more likely it is too plug. Drip tape and microjets will be the first to plug. Using well water or surface water, these micro irrigation systems can and do plug within as little time as a week or two. An entire field can plug within a month. With the drought conditions of recent years, these situations have become even more of a problem and growers are looking for answers to solve their water problems.

Even larger orifices such as bubblers and shrub misters will have severe problems with organic plugging. Usually larger orifices, such as those found in rotary and other larger volume pop up sprayers, don't have problems. However, the larger systems may also have problems over time when using recycled water. It will depend on the lay out of the system, frequency of water, temperature, and other factors.

One type of treatment that is effective in removing and preventing the formation of organic deposits that cause plugging are products such as Line Blaster. An organic composition formulated for specific use in removing these deposits. The oxidizer qualities in Line Blaster are able to overcome the rich nutrient base and to burn off the organics. Low dosages (50 to 100 ppm) and high concentration (over 75% active) make Line Blaster effective against high concentrations of organics. The salient characteristic of these types of products is that they have the ability to penetrate into the biomass and break up the mass and remove the entire mass and prevent its regrowth. These products are a new technology developed to attack and control these biomasses. These products are the only type of product available that are able to handle these new water problems and are just beginning to reach the market across the US.

Dealing with Changes in Volume and Quality of Effluent at the Dodge City Wastewater Recycling Project over the last Sixteen Years – 1986 through 2001

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Abstract

The Dodge City Wastewater Recycling Project began handling effluent from the municipality of Dodge City, Kansas and a beef packing plant in 1985. The project was originally designed to irrigate 1,400 acres through center-pivot sprinklers. Initially, City management and farmers adopted methods to deal with salinity. Various factors have increased effluent volume and N content of the effluent. Extensive soil monitoring showed that sodium tended to accumulate more in certain soil types and nitrate is leaching through the subsoil. Management has dealt with these challenges by adding to the land base and including alfalfa in the crop mix to remediate nitrate-laden soils. Expanded treatment and storage facilities are in the design stages.

Introduction

The managers of the Dodge City Wastewater Recycling Project (DCWRP) have adapted to unforeseen layers of complexity. The project designers focused primarily upon engineering solutions to conveyance and treatment of wastewater. They did not foresee the challenges that would be caused by changes in domestic and industrial influent nor the intricate interplay of effluent volume, quality and cropping choices. Project priorities have changed from only managing effluent volume to simultaneously managing salinity, volume, and nutrients.

The Dodge City Wastewater Recycling Project was conceived and proposed in the late 1970's by a prominent Dodge City businessman and farmer (Engineering Enterprises, 1980). He was the managing partner of a beef packing plant that utilized the wastewater treatment facility operated by the City of Dodge City. The facility discharged into the Arkansas River. It was outdated and a new plant was being planned at the time. The packing plant would have been charged 25% of the cost of the new conventional wastewater treatment facility. So he was looking for a less expensive alternative and was interested in obtaining the effluent to irrigate his farmland.

State and federal regulatory agencies looked favorably upon the land application alternative. It was especially attractive in western Kansas where the primary water source, the Ogallala aquifer, was being depleted. The irrigation aspect was put out to bid and two neighboring farmers located closer to town joined forces to win the bid. The farmers would receive the value of the crop nutrients in the effluent and the benefits of reduced pumping costs. In return the City would be deeded 160 acres for the treatment plant and receive future groundwater rights from the farmers equal to the effluent volume.

Project Details

The project was largely funded by the Environmental Protection Agency and began operating in the latter half of 1985. Much of the system infrastructure remains close to its original design today (Engineering Enterprises, 1985) (Slattery and Looney, 2002). Originally the influent from the packing plant comprised 19% of the total volume, by 2001 it was roughly 30% of the flow. The rest came from domestic sources. There are no other significant industrial contributors to the waste stream. The untreated sewage is collected and combined at the site of the former wastewater treatment plant. It is pumped eleven miles from the collection point to the treatment facility. The sewage enters two covered, anaerobic digesters each 1.2 acres in surface area. It passes into two aeration basins each 0.8 acres and then into two storage lagoons covering a total of 92 acres. The combined capacity of the storage lagoons is 1,642 ac-ft.

There are four electric, centrifugal pumps that supply 10,000 gpm to the network of irrigation systems located within a three-mile radius. Two nearby fresh water wells are plumbed to supply dilution water to the storage lagoons. The system is managed by Operations Management International under contract with the City.

Originally the effluent was used to irrigate 1,400 acres under eleven center-pivots and a small amount of gated pipe furrow irrigation. There were 2,550 acres under irrigation in 2001, with 21 center pivots irrigating 2,505 acres and 45 acres flood-irrigated. The irrigated acreage base has grown in order to accommodate increased effluent volume and nitrogen content. Another 120-acre center-pivot will be added in the year 2003 and additions to the treatment plant are in the design stage.

Salinity Concerns

Farmers noticed leaf burn on alfalfa during the first full growing season of 1986 and asked our agronomic consulting firm, Servi-Tech, Inc., to assess the situation and recommend solutions. Thus began our association with the project.

The leaf damage was most prevalent within the innermost spans of the center-pivots. Most of the systems at that time had overhead, impact nozzles that emitted a fine spray along the inner spans. Farther out from the center, the water droplets were larger and the effect was less noticeable. We concluded that the finer droplets were drying upon the leaf surfaces and desiccating the leaves of the alfalfa.

The electrical conductivity (EC_w) of the effluent at the time of the leaf burn was 2.4 dS/m. The sodium adsorption ratio (SAR) was 8.7. The engineering design (Engineering Enterprises, 1980, 1982) anticipated salinity and sodicity levels to be about this level and the overall water quality was rated as "good" by the laboratory that did the initial analyses. These salinity and sodicity levels would be acceptable where wastewater disposal has priority over yield expectations (FAO, 1985). However, these farmers had farmed this land for multiple generations and were accustomed to high yields. Thus they were alarmed at the possible risk to their land and their livelihoods.

We designed a soil and effluent monitoring protocol to provide the necessary feedback to make the project successful. Permanent monitoring sites of each soil series on each field were sampled incrementally to at least five feet (60 inches) in spring and fall. The surface soil increment was split into two six-inch segments (0"-6" and 6"-12"). The remaining soil depths were divided into twelve-inch increments (12"-24", 24"-36", etc). This sampling protocol has been carried out since 1987, except that some fields were sampled to greater depths.

Both storage lagoons were sampled monthly and analyzed for salts and nutrients. The state regulatory agency also mandated that monitoring wells be placed at various locations near the effluent-irrigated fields.

Based upon our previous experiences elsewhere, we expected to see runoff problems with SAR levels exceeding 5.0. The soils across the project were loess-derived silt loams with slopes as steep as six-percent and were potentially prone to infiltration problems when irrigated with sodic effluent. Corn grain yield reductions of 20 percent were expected with an EC_w of 2.4 dS/m due to osmotic effects (FAO 1985). Leaf burn caused by saline effluent could reduce alfalfa yields. Normal annual precipitation in the Dodge City area is 21 inches so dilution of soil salts can ameliorate the negative osmotic effect on crops and at the same time exacerbate the sealing effect caused by sodium saturation of soil cation exchange sites. The potential effect on corn yields depended on the distribution of in-season rainfall. Normal rainfall from June through August averages 9 inches.

Based upon our recommendations, the growers and the City agreed to a contract that allowed the farmers to dilute the effluent in the storage lagoons with fresh water to a point where the EC_w would not exceed 1.5 dS/m and the SAR would be less than 5.0.

The City agreed to pay for gypsum application to soils where the exchangeable sodium percentage began to climb beyond 5 percent. The soil-monitoring program tracked soils with rising exchangeable sodium percentages and identified soil series that accumulated sodium faster than others. Every fall since 1989, the City has used funds derived from user load fees paid by the packing plant to apply gypsum to several fields.

The farmers have adopted several tillage techniques that decreased runoff from their fields. The corn fields have all been converted to ridge-till. They have also used in-row rippers and dammer-dikers to aid water infiltration. Spike tillage tools were used in alfalfa fields to create small reservoirs that enhance infiltration.

The farmers averted the problem of salt buildup on leaves by converting their sprinklers from higher-pressure overhead nozzles to lower-pressured drop nozzles. The land application system was originally designed for high-pressure impact sprinklers with a predicted efficiency of 75 percent and it called for an application rate of 36 ac-in/ac. The change in nozzle packages effectively decreased crop demand but increased the risk of runoff.

Both dilution and the change in sprinkler design had the effect of increasing the amount of water to be disposed of. Additionally, the population of Dodge City went from 21,000 to 25,000 and the slaughter capacity of the packing plant doubled.

<u>Increasing Effluent Volume</u>
The initial influent flow volume to the treatment system was 8.6 ac-ft/day with 17 percent of the volume coming from the packing plant. This equated to 3,139 ac-ft/yr. Loss to seepage and evaporation less precipitation was estimated at 323 ac-ft/yr. A total of 2,816 acre-feet of effluent - about 2 acre-feet per acre per year - was predicted to be available for irrigating 1,400 acres.

Fresh water dilution of the storage lagoons began in 1987. About 450 acre-feet of low EC_w water (< 0.50 dS/m) was pumped into the lagoons. The quantity of diluent has varied through the years according to the amount of in-season precipitation received, but has averaged about 400 ac-ft/yr.

By the year 2001, influent flow volume had increased 36 percent to 11.7 ac-ft/day or 4,270 ac-ft/yr and the packing plant influent had increased to 29 percent of total volume (Slattery and Looney, 2002). The system was designed to handle 12.7 ac-ft/day by 1997 but logistical problems have made it difficult to handle even the current volume properly.

The growers have never been able to utilize the 36 ac-in/ac-yr as slated in the original design. Annual application to corn has run about 19 ac-in/ac and alfalfa about 27 ac-in/ac (Servi-Tech, 1987-2001).

Fortunately, there was ample land available in the vicinity of the treatment plant to expand the acreage base by 82 percent – from 1,400 to 2,550 acres in 2001. Most of the problems were the result of undersized storage capacity. The irrigators ran short of water in-season. In the off-season they were often forced to over-irrigate alfalfa and wheat or "pre-irrigate" row crop fields. If the fields were saturated, frozen or snow-covered the state regulatory agency granted temporary permission to divert overflow to three different farm ponds.

The farmers have retained the option to switch to groundwater wells on a few fields during the peak demand periods from mid-June to mid-August. This has been necessary to produce a crop in dry years. For example, if one assumed an ET demand of 0.25 in/day across 2,550 acres for those 90 days, there would be a demand for 4,781 ac-ft. The storage capacity was 1,642 ac-ft and influent for 90 days would be 1,053 ac-ft for at total available supply of 2,695 ac-ft. Ignoring rainfall, dilution and evaporation, there is a shortfall of 2,086 ac-ft during the peak demand season. Most of the deficit should be made up if the normal rainfall of nine inches occurs during that period. Off-season storage becomes an issue. Figure 1 illustrates the average annual precipitation compared to the water demand for corn and alfalfa. Irrigation demand tapers off dramatically at the end of August and the storage lagoons are nearly empty. Alfalfa can usually be irrigated until the end of September or early October. Irrigation is often not feasible after mid-October due to freezing temperatures. It has not been uncommon to accumulate 1.5 times the lagoon storage capacity in cold or wet years. Even in dry years some excess irrigation was applied in the off-season.

Nitrate Leaching Concerns

The original proposal for the project (Engineering Enterprises, 1980) stated that since groundwater was over 100 feet deep there was no "significant chance for groundwater pollution from lagoons or the irrigation area." It further stated that since the wastewater would supply only 20-30 percent of crop requirements for nitrogen and phosphorus there was practically no chance for groundwater pollution. Groundwater lies between 75 to 170 feet beneath various fields.

The original design assumed influent concentrations of total nitrogen at 22 mg/L and phosphorus at 3.4 mg/L. During the 1987 growing season, the first year of the monitoring program, N concentration averaged 27 mg/L and P was 14 mg/L. Thus about 170 lbs N/ac and 75 lbs P_2O_5 /ac was available for land application. Phosphorus has not accumulated to levels of concern.

The farmers made few adjustments to their normal nitrogen fertilization practices for many years even though the deep soil profile monitoring results indicated significant carryover nitrate. The farmers were unsure how much of the effluent nitrogen would be available to their crops (Nicholson, 2001). They were reluctant to reduce fertilizer nitrogen applications, fearing significant yield loss. Soil samples taken by their crop consultants often indicated that the top two feet of the soil profile lacked enough carryover nitrate to sustain the upcoming corn crop (see Figure 2). They were also unsure of the degree of loss from ammonia volatilization. At least 100 lbs of fertilizer N/ac was applied to corn prior to planting until very recently.

We were unsure as to how much of the N would become plant available nitrogen (PAN). Review of post-season soil tests and crop yields helped us to estimate that approximately 65% became plant available. Assuming 65% PAN factor then approximately 110 lb PAN/ac was available from effluent in the early years of the project. However, the nitrogen concentration of the influent wastewater has increased steadily, more than tripling over the sixteen years of the project. In 2001, the applied effluent averaged 91 mg/L total nitrogen; equivalent to 411 lbs total N/ac or 267 lbs PAN/ac.

The early results of the soil monitoring showed that significant amounts of nitrate were passing beyond the upper five feet of the soil profile. We sought to understand how deeply these plumes or slugs of nitrate moved.

We initially sampled some fields to ten feet and then twenty feet. As of this date, the deepest depth that we have sampled is 50 feet.

The semi-annual sampling of the soil monitoring sites has allowed us to track the movement of nitrate slugs leaching through the upper vadose zone. We have estimated that once the slugs leave the upper five feet of the root zone they can leach as much as four feet in a wet year. Figure 2 illustrates the nitrate concentrations to a twenty-foot depth, located under a pivot irrigation system that was connected to effluent within the last five years and has been planted to corn for fifteen years. The nitrate distribution patterns beneath this field do not look different than other fields with a long history of corn. Thus we believe that much of the nitrate found in the upper vadose zone was derived from commercial fertilizer applied before the onset of the project.

There are fourteen monitoring wells placed near effluent-irrigated fields. Nitrate levels have increased in four of those wells. We are unsure as to the source but based on the soil monitoring data. Soil nitrate could reach the groundwater beneath these fields if not removed from the soil profile or a dry-zone, hydraulic barrier is not created.

<u>Crop Choices for Effluent Management</u>

Crop uptake is an important nitrate mitigation strategy. Corn is the primary crop grown at the Dodge City project. The corn fields received an average of 19 inches of effluent in 2001. This volume of effluent would have supplied 253 lbs PAN/ac. It takes a very high yielding corn grain crop (250 bushels per acre or greater) to utilize this amount of nitrogen. Irrigated corn yields have typically been about 180 bushels per acre.

Other crop management practices can help improve nitrate removal. Harvesting corn as silage removes the nitrogen in the stalks as well as the grain. Double-cropped winter wheat followed by soybeans or grain sorghum can remove fairly large quantities of nitrogen. Winter wheat production also provides a sink for off-season effluent application.

However, the most effective practice was to simply produce less corn and more alfalfa. Soil monitoring showed that alfalfa utilized virtually all the applied nitrogen and removed soil profile nitrate as well. Figure 3 illustrates the dramatic effect that alfalfa had on removal of nitrate from the soil profile at depths of five feet and greater. The graph shows changes in the profile nitrate concentrations from a monitoring site sampled in 1997 and planted to alfalfa for the previous six years. We do not know the history of that field prior to the DCWRP project but we do know that it was planted to corn from 1987 through 1989, grain sorghum in 1990, then planted to alfalfa in April 1991. The higher nitrate levels in the soil surface in 1997 would be the result of effluent applications the previous fall that had not been utilized by the crop.

By 2001 the primary management concerns had shifted from salinity to volume to nitrate leaching. We estimate that the alfalfa crops have removed well over 300 lbs N/ac/yr as protein in forage tissue and that volatile nitrogen losses through leaf surfaces may have also occurred. Alfalfa production became a strategy to mitigate nitrate leaching. The shift toward producing more alfalfa production also extended the irrigation season, but stretched an already short in-season effluent supply.

The crop mix across the project in 2001 was 67% corn, 24% alfalfa, 5% soybeans, 2% winter wheat, and 2% grain sorghum. The project managers would prefer more alfalfa production for increased effluent and nutrient disposal, while the farmers prefer corn production for greater profitability. Corn has historically generated higher income than alfalfa and is eligible for federal farm programs. Alfalfa has recently been a profitable crop, but has had wide price fluctuations in the last 16 years (Schuckman, 2002). Alfalfa also has less production flexibility. Once a farmer plants alfalfa he is committed to that crop for at least five years. Alfalfa production is labor intensive and somewhat more difficult to market than corn.

All parties now realize that crop mix is a critical component. Long-term success of the project will depend upon wise cropping choices. City management, the farmers and their consultants are considering crop choice carefully because of the increased nitrogen content of the effluent. The treatment plant expansion will remove more ammonia from the effluent. The increased storage capacity will allow the growers to better match irrigation timing with crop demand. Until the expansion is fully implemented, the various parties are working toward solutions that will allow the City to effectively dispose of wastewater, the farmers to grow crops profitably, and at the same time protect ground water.

Conclusions

The project designers of the Dodge City Wastewater Recycling Project did not anticipate the layers of complexity that future project managers would face. Agronomic considerations coupled with engineering considerations have been necessary to assure success of this project. The availability of extra land and groundwater provided critical flexibility. Future designers of effluent irrigation projects can take a lesson from this one and note that volume, salinity, and nutrient content must be balanced to properly manage an effluent-irrigation project. These factors are interrelated; changing one factor often requires secondary changes to manage the other factors properly.

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Figure 1. Relative seasonal water use demand by alfalfa and corn.

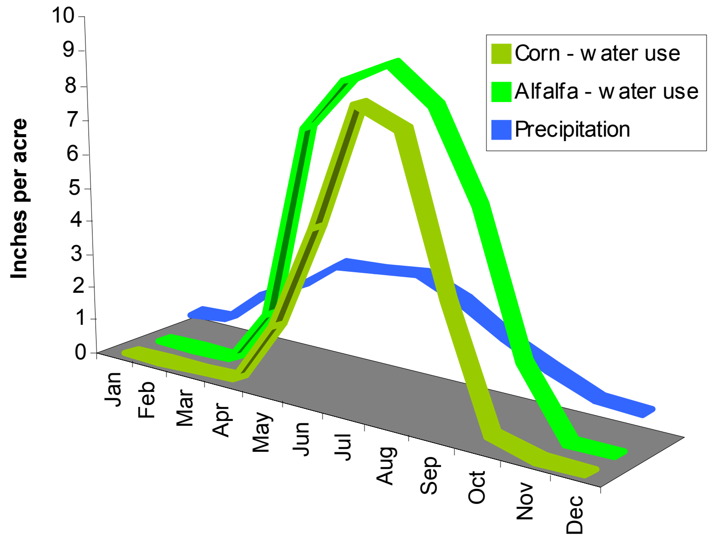


Figure 2. Typical distribution curve of soil nitrate in corn fields.

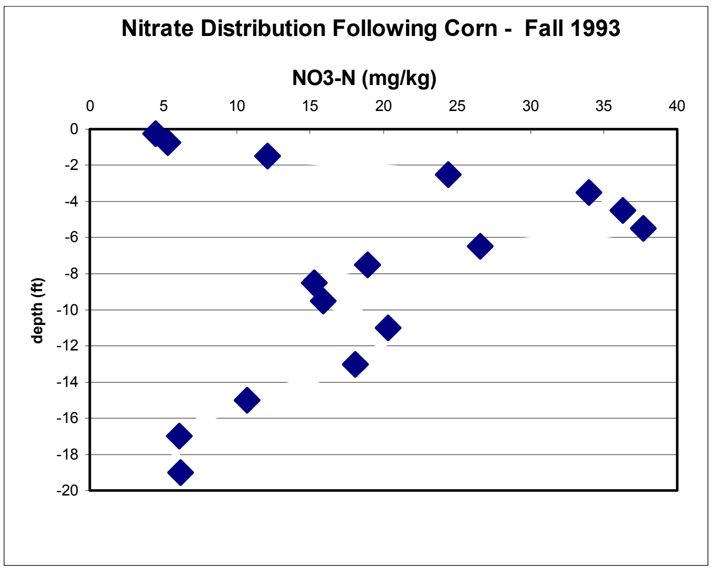
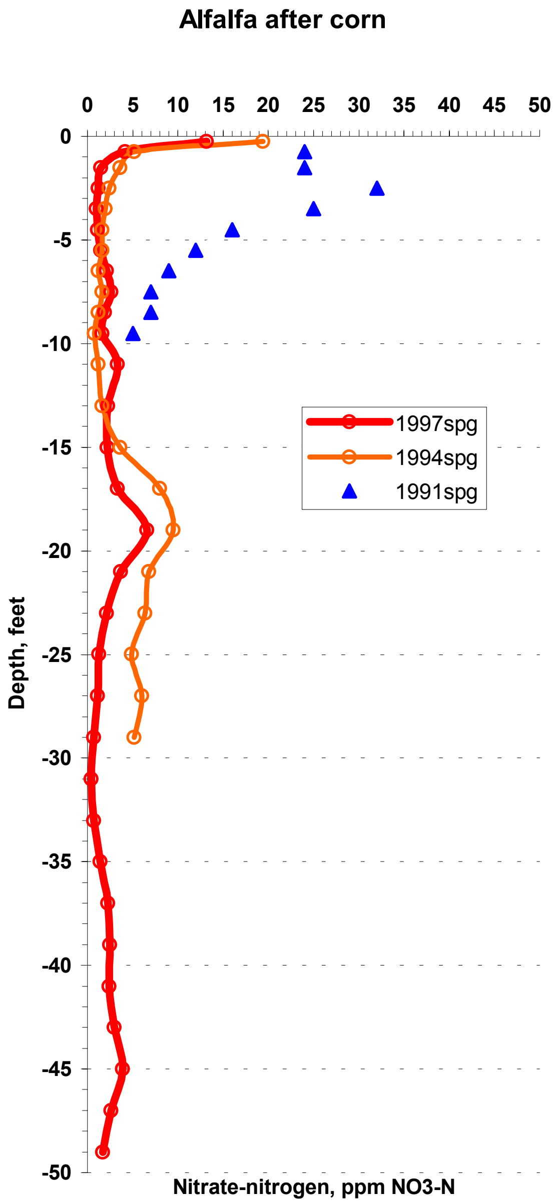


Figure 3. Decrease of soil nitrate with alfalfa following corn.



Reclaimed Water for Citrus Irrigation in Florida

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ABSTRACT

Before 1980, many communities in Florida considered wastewater to be a disposal problem. When it was initially proposed to convert wastewater to reclaimed water for crop irrigation, some citrus growers refused to accept the water because of fears of heavy metals, flooding, or disease. Ultimately, several reclaimed water projects were started, and Water Conserv II west of Orlando has become one of the world's largest agricultural reclaimed water irrigation projects of its type. This project provides irrigation for more than 4300 acres of agricultural crops and two golf courses. The water is chlorinated, is odorless and colorless, and has been used successfully for crop irrigation for 15 years. Excess reclaimed water is discharged to rapid infiltration basins (RIBs). The water meets drinking water standards for a number of compounds including nitrate, sulfate, Na, Cl, Cu, Zn, Se, and Ag. Initial fears that reclaimed water would cause problems were unfounded. In the sandy well-drained soil, excessively high irrigation rates with reclaimed water (100 inches/year) promoted excellent tree growth. Because of a recent severe drought in Florida, attitudes toward reclaimed water have changed. Once believed to be a disposal problem, reclaimed water is now considered to be a valuable resource that can meet irrigation demands. Average statewide reuse flow rates increased by 119% in 11 years, and reclaimed water was being used on 40,152 acres for agricultural irrigation in 2001.

Introduction. As water shortages become more common, competition for water among various sectors becomes more acute. Increasing urban growth, along with agricultural and industrial needs, lead to greater competition for limited water resources. Interest has increased in developing new water resources to meet the greater demand. Florida has relied heavily on groundwater pumping, and concerns have arisen regarding declining aquifer levels. This has led to serious discussions on developing alternate water supplies such as desalination, aquifer storage and recovery, and reclaimed water. Reclaimed water use has evolved in an interesting way in Florida, and the objective of this paper is to briefly discuss one project, Water Conserv II, which illustrates how attitudes toward reclaimed water can change when water supplies get short.

Background. Disposal of wastewater is a problem for many urban areas. In the 1980s, disposal of wastewater effluent was considered to be a growing problem, primarily because of environmental concerns about lake degradation. Urban wastewater disposal had commonly been handled by treating the wastewater to a certain level and then disposing of it in the most convenient or cheapest manner. Usually, this meant discharging the water into a nearby river or lake, spraying it onto a field, or loading it into a percolation pond. Disposal was the primary consideration since the amount of wastewater continued to increase as an unavoidable consequence of population growth. As wastewater volume increased,

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concerns were raised about the effects on discharge sites. This led to consideration of alternate uses such as irrigation. While the idea of converting wastewater to reclaimed water for irrigation was not a new one, using reclaimed water for irrigation was a relatively small-scale activity in Florida before 1980. Eventually, increasing disposal problems led to several large Florida projects set up to reclaim water from wastewater treatment plants for irrigation of agricultural crops or landscape vegetation. Examples include projects in Tallahassee, St. Petersburg, and the Water Conserv II project of Orlando and Orange County (Allhands et al., 1995; Parnell, 1988; Roberts and Vidak, 1994).

Before 1987, Orlando and Orange County each discharged treated wastewater from their treatment plants into Shingle Creek that flows into Lake Tohopekaliga, a lake with high recreational value. Concerns were raised over the potential eutrophication of the lake due to nutrient loading. Thus, the U. S. Environmental Protection Agency required Orlando and Orange County to develop an alternative plan for the disposal of the wastewater they were discharging into Shingle Creek. Several plans for the effluent were proposed, such as: 1) building a pipeline approximately 68 miles long to carry the effluent to the Atlantic Ocean, 2) establishing a "Groundwater Conservation Program" which would inject reclaimed water meeting primary and secondary drinking water standards into the Floridan aquifer, 3) purchasing large tracts of land for rapid infiltration basins (RIBs), 4) increasing the treatment level to convert the wastewater to meet reclaimed water standards and have growers apply it to their citrus groves, and 5) injecting the wastewater into deep wells over 3000 feet deep using high pressure. None of the plans by themselves proved to be acceptable for a variety of reasons. Following further review, a combination of citrus irrigation and RIBs was determined to be effective. This combination was selected and named Water Conserv II.

Citrus grove owners initially rejected the plan because of concerns about possible heavy metal contamination, potential virus or disease problems, flooding, and lack of flexibility in water application during periods of high rainfall. Growers also raised concerns over psychological aspects and feared that there might be a degradation of fruit quality from trees irrigated with reclaimed water. Ultimately, Orlando, Orange County, and the growers developed a plan that provided for the establishment of reclaimed water standards, regular monitoring of the water, greater grower flexibility on timing of use, and research on the effects of the reclaimed water on citrus tree performance. In addition to applying the reclaimed water to citrus groves, the project also included the purchase of land for RIBs for disposal of excess water. Water Conserv II has since become the largest reclaimed water agricultural irrigation project of its type in the U.S., and was the first project in Florida to be permitted to irrigate crops for human consumption with this water (McMahon et al., 1989).

At present, the reclaimed water is applied primarily to citrus, but it is also used for irrigation of several other crops. At the Orange County National Golf Center and West Orange Country Club, golf courses with a total of 45 holes have RIB sites incorporated into them and use the reclaimed water for irrigation. At present, over 4,300 acres of citrus, 12 nurseries and tree farms, and two landfills use this reclaimed water for irrigation. One hundred acres of willow is irrigated in a "browse farm" to provide feed for the Walt Disney World Animal Kingdom theme park. A new pipeline has been installed to extend the reclaimed water to additional areas.

Water Treatment, Distribution, and Quality Standards. Two treatment facilities receive the wastewater and process it to meet reclaimed water standards. These facilities were upgraded to meet the stricter water quality standards. In addition to the normal treatment, advanced secondary treatment capability was added to meet high-level disinfection standards. This involves coagulation and filtration facilities similar to potable water treatment plants. Pump stations at both reclamation facilities transmit the reclaimed water through a pipeline about 21 miles long to a distribution center in western Orange County. The distribution center is located in a citrus production area with deep, well-drained, sandy soils. The center can store up to 20 million gallons of water in four large covered concrete tanks. A computerized control system monitors the distribution of reclaimed water continuously. Water is pumped from the distribution center to either grower's fields or to RIBs. Under current conditions, about 60% of the water goes to citrus groves and the remaining 40% goes to the RIBs. This project presently delivers 30 to 35 million gallons per day (mgd). Permitted average daily flow capacity is 44 mgd with ultimate average daily flow capacity of 50 mgd with peaks to 75 mgd. The source of the wastewater is primarily residential properties, restaurants, motels, and tourist attractions in western Orlando and Orange County. There is very little factory or heavy industry input into the incoming wastewater.

During freezes, there is a high demand for irrigation water, and the reclaimed water provided to citrus groves is supplemented with well water for frost protection in order to meet that demand. Most groves are irrigated with undertree microsprinkler irrigation, which can provide some frost protection (Parsons et al., 1982; 1991), as well as normal irrigation for citrus trees.

Under the current contract, growers agreed to accept either 25 or 50 inches of water per acre per year for 20 years. Water is delivered at no charge to the edge of the grower's property at a minimum pressure of 40 psi. Growers can terminate their participation in the 20-year agreement at any time through a buy-out clause by repaying the city and county $3600/acre the first year with the repayment decreasing by 5% each following year. To date (15 years into the project), no grower has chosen to opt out of his contract. This indicates grower satisfaction with the reclaimed water.

The University of Florida established water quality guidelines for citrus trees. They are rigorous and apply only to the Water Conserv II project. The maximum average concentration limits (MACLs) for some elements such as sodium, chloride, barium, chromium, copper, selenium, silver, sulfate, and zinc are more stringent than Florida drinking water standards (Parsons et al., 2001). Water samples are tested monthly for bacteria, virus, and most of the mineral elements. Drinking water standards, Conserv II standards, and typical values are presented in Table 1. The treatment facilities have been required to meet the drinking water standard of 10 mg/L for nitrate nitrogen. In terms of crop mineral nutrition, meeting the nitrate drinking water standard is a disadvantage because this reduces nitrogen supplied to the tree.

The water is chlorinated which provides virtually complete removal of viruses and bacteria. The water is colorless and odorless. Florida regulations presently state that only indirect contact methods such as drip, subsurface, or ridge and furrow irrigation can be used to irrigate the "salad crops." Any type of irrigation method can be used to irrigate tobacco, citrus, or other crops that will be "peeled, skinned, cooked, or thermally processed" before human consumption (York et al., 2000). Most of the oranges in Florida are processed for juice, but some do go to the fresh market.

Reclaimed Water Research at Water Conserv II. Growers have now used Water Conserv II reclaimed water successfully for over 15 years. At the request of growers, studies were initiated to determine the effects of this reclaimed water on citrus trees. The first studies were conducted in commercial groves to make comparisons between reclaimed and well water (Zekri and Koo, 1990). In these plantings, growers using reclaimed water commonly used more water than those using well water. Hence, soil water content was usually higher in the groves using reclaimed water. Appearance of trees irrigated with reclaimed water was usually better than the trees irrigated with well water (Koo and Zekri, 1989; Wheaton et al., 1996).

Table 1. Florida drinking water standards, typical well water values, Conserv II maximum average concentration limits (MACL), and typical values in Conserv II water. All values are in mg/L except for pH, EC, and SAR.

	Drinking water Max. Contam. Level (mg/L)	Well water typical values (mg/L)	Conserv II water MACL (mg/L)	Conserv II water typical values (mg/L)
Arsenic	0.05	–	0.10	<0.005
Barium	2	–	1	<0.01
Beryllium	0.004	–	0.1	<0.003
Bicarbonate	–	–	200	105
Boron	–	0.02	1.0	<0.25
Cadmium	0.005	–	0.01	<0.002
Calcium	–	39	200	42
Chloride	250	15	100	75-81
Chromium	0.1	–	0.01	<0.005
Copper	1	0.03	0.2	0.002-0.05
EC (umhos)	781	360	1100	720
Iron	0.3	0.02	5.0	0.01-0.37
Lead	0.015	–	0.1	<0.003
Magnesium	–	16	25	8.5
Manganese	0.05	0.01	0.20	0.006-0.042
Mercury	0.002	–	0.01	<0.0002
Nickel	0.1	–	0.2	0.01
Nitrate-N	10	3	10	6.1-7
pH	6.5-8.5	7.8	6.5-8.4	7.1-7.2
Phosphorous	–	0.01	10	1.1
Potassium	–	6	30	11.5
SAR	–	0.6	–	2.5
Selenium	0.05	–	0.02	<0.002
Silver	0.1	–	0.05	<0.003
Sodium	160	18	70	50-70
Sulfate	250	23	100	29-55
Zinc	5	0.02	1.0	0.04-0.06

Since disposal of wastewater was of concern early in this project, it was important to determine if citrus could tolerate high application rates of reclaimed water. In research plantings, very high rates were applied to two citrus varieties, 'Hamlin' orange and 'Orlando' tangelo trees on four rootstocks. In addition to normal rainfall of approximately 48 inches/year, these trees were irrigated with rates of up to 100 inches/year (~2 inches/week). Application of 2 inches/week of reclaimed water in a 20-acre experimental planting significantly increased canopy volume and fruit yield compared to 0.3 inch/week of well and reclaimed water applications (Parsons et al., 2001). Because of the scheduling method used, the lower irrigation rate did not provide adequate water for optimum tree growth and production. The excessive irrigation diluted the juice soluble solids somewhat, but because of the greater total fruit production, total soluble solids per acre were increased at the 100-inch irrigation rate (Parsons et al., 2001).

Weed growth was excessive because of the high reclaimed water irrigation rate (Parsons and Wheaton, 1992; Zekri and Koo, 1993). Such growth has been controlled with proper herbicide use and mowing.

Irrigation with reclaimed water increased soil P, Ca, Na, and pH (Parsons and Wheaton, 1992; Zekri and Koo, 1993). Most fibrous roots are located in the top three feet, and much of the Na in the soil was leached below this depth. This reclaimed water supplies all the P, Ca, and B required by trees in central Florida soils. While levels of some elements have increased in the soil, they have not built up over the years (Zekri and Koo, 1993). This lack of buildup is attributed to low soil organic matter, low cation exchange capacity, and leaching rainfall. Leaf P and Ca levels were also increased. Leaf levels of Na, Cl, and B were elevated but remained below toxic levels.

Because the nitrate-N level is low (less than 10 mg/L), the amount of nitrogen extracted from this reclaimed water is unknown. In a small grower test, young trees that were given no fertilizer and irrigated only with Water Conserv II reclaimed water took 2 to 5 years to show nitrogen deficiency symptoms and yield declines (Ross, 1993, pers. comm.). Other work in the Vero Beach area showed that reclaimed water alone did not provide adequate nutrition for young grapefruit tree growth (Maurer and Davies, 1993). Preliminary data showed that high application rates of reclaimed water maintained yield for one year, but yields declined in the second year without additional fertilizer application (Wheaton et al., 1996).

Have Attitudes Changed? Attitudes in Florida toward reclaimed water have changed since the mid-1980s. Once considered to be an urban disposal problem with no beneficial use, treated wastewater effluent was discharged into a water body or spray field as a low cost method of disposal. Environmental concerns ended such disposal. Growers were initially opposed to the Water Conserv II project because of fears about salts, heavy metals, odors, contaminants, flooding, disease, and potential tree damage. Once water quality standards were established and the initial fears of flooding, disease, and tree damage were proved to be unjustified, research went on to show that reclaimed water had no adverse effects. Sufficient flexibility was also given to growers so they could acceptably manage their water in a region that has quite variable rainfall.

The water management districts in Florida have encouraged the use of reclaimed water by funding a number of projects. Reuse capacity in Florida increased noticeably in the 1990s (Fig. 1, Fla. Dept. Environ. Protec., 2002). Utilities initially wanted to encourage the use of reclaimed water since disposal was of primary interest. Hence, many utilities gave reclaimed water to users on a low or no cost basis (Ferraro and York, 2001). Unlimited use was commonly allowed. In the 1980s when utilities had abundant supplies, the low fees encouraged the inefficient use of reclaimed water. Many customers used more reclaimed water than was necessary for proper irrigation. A severe drought in 2000 that lasted into the spring of 2002 caused some reuse systems to run low in reclaimed water. This angered some

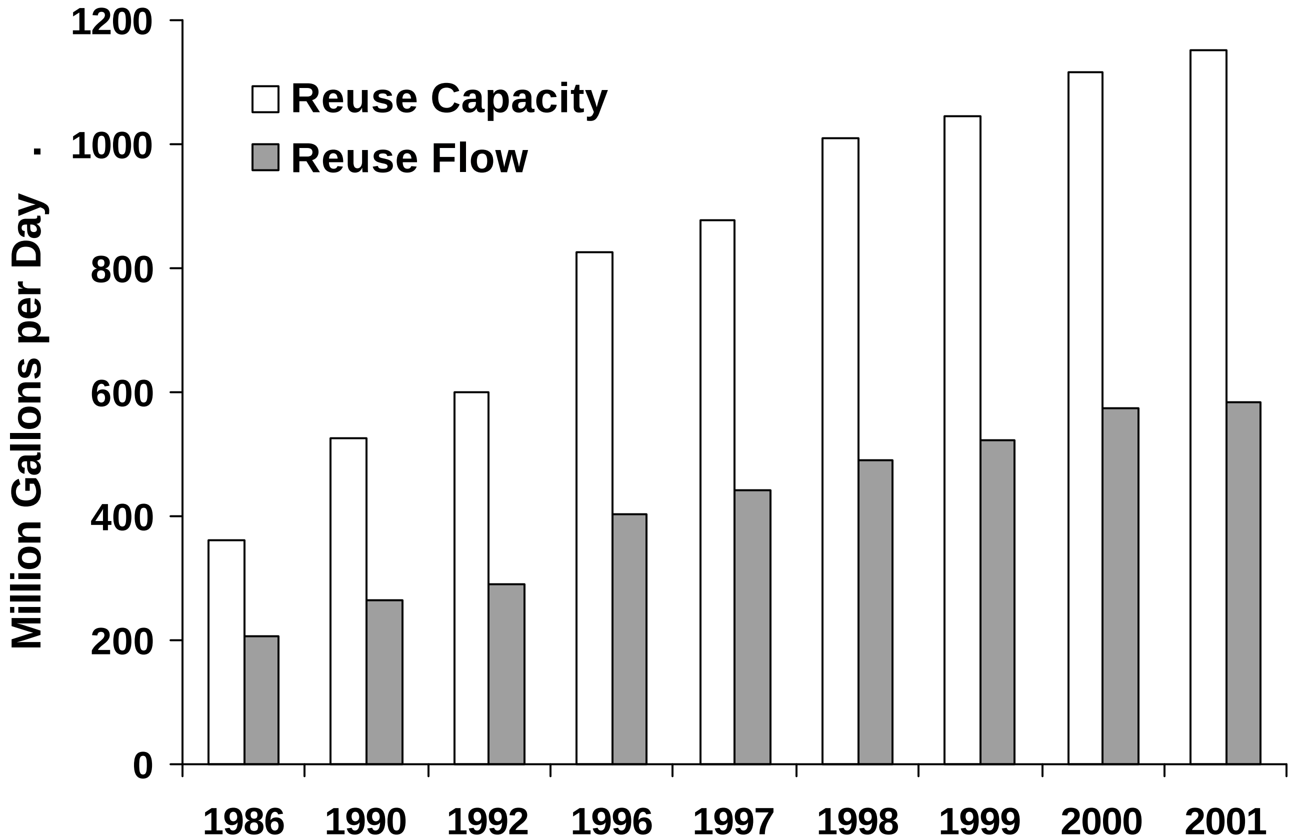

Fig. 1. Florida reuse invertory

customers who had been promised unlimited quantities of reclaimed water as a low cost, drought-proof water supply. Metering of reclaimed water will probably become necessary to improve efficiency of use.

Earlier wastewater systems were designed for effluent disposal and reuse was not of interest. One example is in southeast Florida where the low-cost way to deal with effluent was to dispose of it to surface water bodies or deep well injection. Ferraro and York (2001) point out that "It is interesting to note that Dade and Broward Counties account for about 24 percent of the state's population and about 27 percent of the state's permitted domestic wastewater treatment plant capacity. However, these two counties, which make extensive use of ocean outfalls and deep well injection systems, account for less than four percent of the state's reuse capacity." More recently developed treatment facilities can better incorporate reuse into their plans.

With the recent drought, public acceptance of nonpotable reuse has been relatively high. Reclaimed water has now become recognized as a water resource of some value. Procedures to encourage more efficient use for conservation of reclaimed water will need to be set up.

Summary. The benefits of Water Conserv II are now apparent. Orlando and Orange County benefit by meeting the mandate for zero discharge of effluent into surface waters. Withdrawal from the Floridan aquifer for irrigation has been reduced. Recharge of this aquifer has been accelerated due to the application of reclaimed water to the RIB sites. Because reclaimed water has been used safely and effectively, some groups and agencies are promoting the use of reclaimed water as a way to make up for water shortages. The recent drought in central Florida lasting up to the spring of 2002 has greatly increased interest in water reuse. Statewide reuse flow increased by 119% to 584 mgd from 1990 to 2001. By 2001, agricultural reclaimed water irrigation reached a total of 40,152 acres (14,621 acres of edible crops and 25,531 acres of other crops) (Fla. Dept. Environ. Protec., 2002).

Reclaimed water is no longer considered to be a disposal problem, but a limited resource of value. Quality of the water, along with supply and demand forces, will ultimately determine how much reclaimed water is used for irrigation or other purposes. Some growers still have a concern that there is a psychological stigma attached to reclaimed water that may damage the market reputation of Florida citrus which has rested on its quality over the years. Nevertheless, initial opposition to use of reclaimed water has decreased as demand for the water has increased. In the case of Water Conserv II, reclaimed water has been used in a productive and environmentally safe manner in a successful cooperative effort between growers and government agencies that has solved problems for both and proven the value of reclaimed water as a resource.

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A Mobile Irrigation Lab For Water Conservation: I. Physical and Electronic Tools[1]

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Abstract

A Mobile Irrigation Lab (MIL) has been developed to promote water conservation in agricultural irrigation production systems through education and technical assistance. This paper discusses and provides details on physical and electronic tools developed to help irrigation managers know more about their systems. A non-evaporating, low cost, in-field irrigation depth measurement gauge, called the IrriGage, has been developed and field tested. IrriGages are easily deployed and allow a field technician to perform performance evaluations of center pivot systems. IrriGages are also provided to educational program participants as a tool to enhance their knowledge of the irrigation depth component of their field water budget. Electronic tools currently include an irrigation energy/cost evaluation program (FuelCost) and a water budget based irrigation scheduling program (KanSched). Both of these have been widely accepted by farmers and government agency personnel. These electronic tools and other information are available on CD's and the MIL website (http://www.oznet.ksu.edu/mil/).

Overview

The Mobile Irrigation Lab (MIL) project is an educational and technical assistance program that is focused on enhancing irrigation and water management practices by Kansas agricultural producers, system managers, and crop consultants. The Mobile Irrigation Lab field unit is a 16 foot long, 8 foot wide trailer that has been subdivided into two 8 ft by 8 ft partitions. The front half has a classroom equipped with computers and decision management software that allows on-site, hands-on educational activities with a specific emphasis on irrigation and water management. The rear half of the MIL field unit houses field equipment that is used to conduct evaluations of irrigation systems, and to provide on-site technical assistance and other educational activities related to irrigation and cropping systems. Details on the MIL field unit and field data are discussed by Rogers et al. (2002) and in a companion paper by Rogers et al. in this proceedings.

IrriGages

The IrriGage is an in-field, non-evaporating rainfall and sprinkler irrigation measurement device. Several processes were involved in the construction of IrriGages (Fig. 1). Most of the gage materials were PVC pipe and could easily be attached by solvent welding with PVC cement. IrriGages were constructed using an 8-inch long piece of SDR 35 PVC sewer pipe for the body tube [4-inch nominal size], and a PVC sewer and drain cap for the barrel bottom cap [4-inch nominal]. The top lip of the body tube was beveled using a router to create a "sharp edge". A 4-inch long piece of ¾-inch nominal PVC pipe was capped on one end and solvent welded to the side of the IrriGage barrel tube for use as a mounting tube. Prior to solvent welding onto the IrriGage, one

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edge of the side mounting tube was sanded flat to eliminate the protruding edge of the end cap and to increase the surface area of contact for the solvent welding procedure.

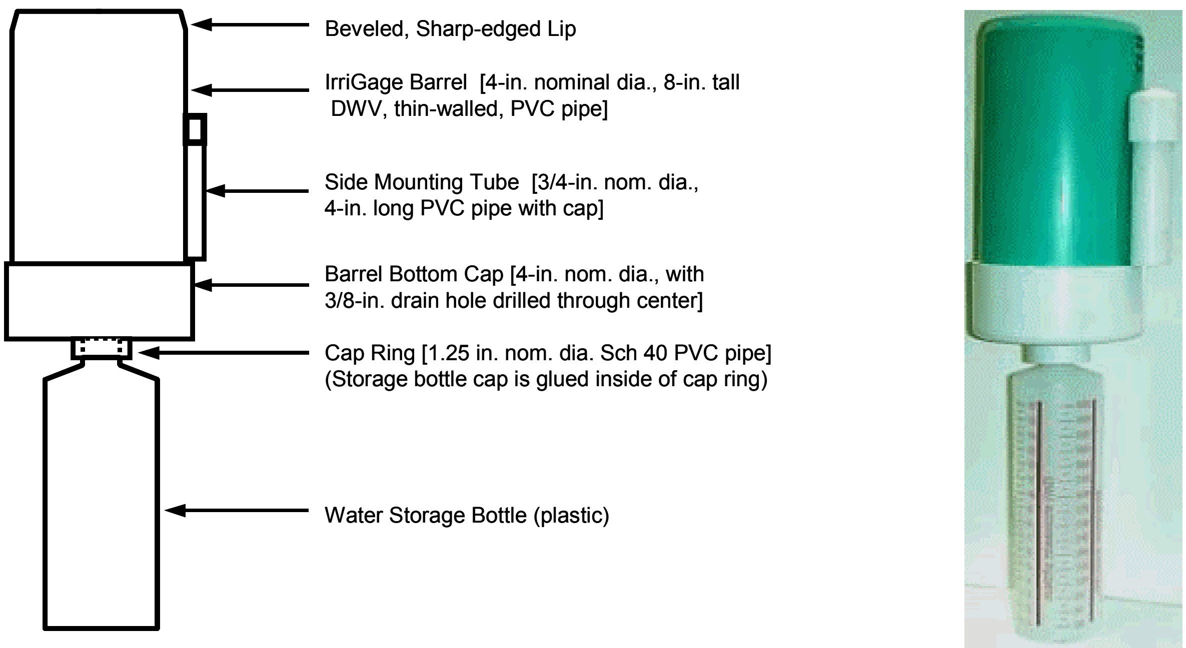

Figure 1. Construction and material details of the IrriGage with a completed device.

Several bottle types were used for storage bottles and because of different plastic types it was challenging to find a glue or adhesive material to attach the bottle cap to the barrel bottom cap. Some of the initial bottles had large diameter caps, which were attached to the barrel bottom cap with a silicone sealer and screws. The current storage bottle is a graduated and marked 500 ml plastic bottle with a 1.25-inch diameter hard plastic cap. In order to secure the bottle cap to the barrel bottom cap, a ½-inch long ring of 1.65-in. outside diameter (1.25-inch nominal) schedule 40 PVC pipe was solvent welded onto the center of the outside of the barrel bottom cap for use as a cap ring support. The storage bottle cap fit inside of the cap ring and was attached to the barrel bottom cap using Plumbers Goop[3] adhesive and sealant, which also acted as a supportive filler between the storage bottle cap and the cap ring.

The 500 ml capacity of the storage bottle was sufficient to hold 2.5-inches of precipitation, and was considered adequate for most irrigation events and many rainfall events. Because the Irrigage could be used as an in-field device for multiple irrigation and rainfall events that may exceed the 2.5-inch depth capacity, excess water would be stored in the body tube and an air hole was not drilled into the top of the storage bottle. Rather a 3/8-inch diameter hole was drilled through the center of the storage bottle cap and the barrel bottom cap to allow collected water to flow into the storage bottle. Extensive field-testing has shown that the IrriGage is an effective tool to measure sprinkler irrigation application or rainfall without any evaporative loss for an extended period (Clark et al. 2002).

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[3] Mention of specific products, trade-names, or companies does not imply endorsement by the authors or Kansas State University.

KanSched

KanSched is a computer program that can be used for irrigation scheduling or general field water management purposes. The KanSched program has been field tested in south central and southwest Kansas by farmers, crop consultants, and researchers. The program started out as a coded Excel file that could only handle one field at a time, but is now coded in an executable Visual Basic format that is very easy to use and can handle multiple fields. The program was designed for irrigation management and scheduling of summer annual crops. A "field" is an irrigated field that is managed as a single zone. The opening window (Fig. 2) allows the user to create a new field, edit an existing field, to update the ET (evapotranspiration) data set, or to view the different ET groups. An ET group is simply the name of a weather station or unit to which several fields may be associated.

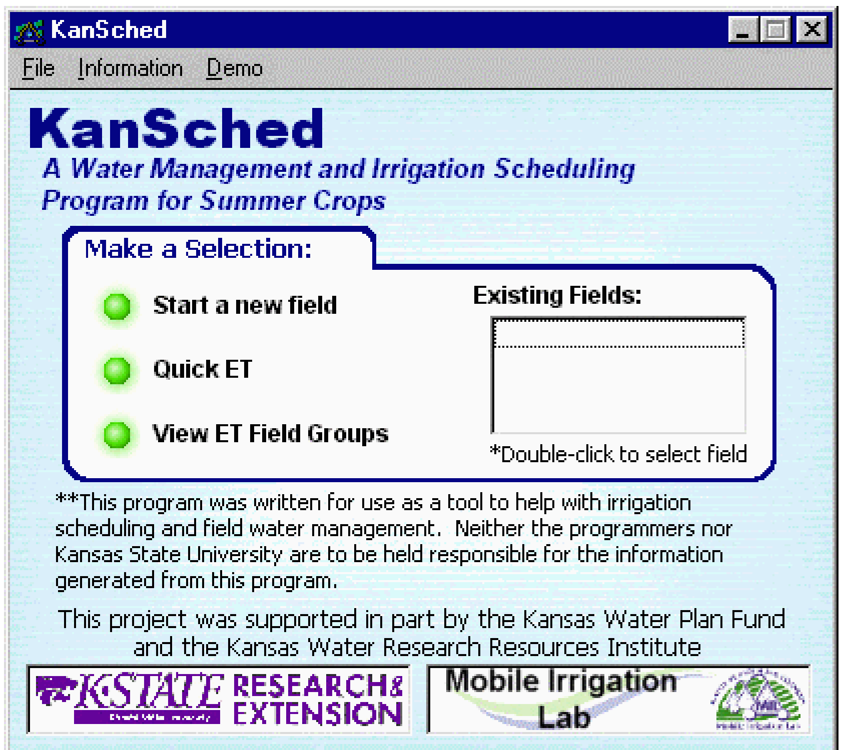

Figure 2. KanSched opening window.

Field specific characteristic data are entered onto the "Input" data page (Fig. 3, upper). These data include soil and crop characteristics that are used to create the capacity of the water budget reservoir, and to internally generate a crop coefficient data curve that is used to modify the inputted reference evapotranspiration (ETo: grassed-based; or ETr: alfalfa-based) to a crop evapotranspiration (ETc) value. The user may enter soil and crop characteristics value, or default soil data based upon different textures and crop data based on crop type, emergence date, and season length may be used.

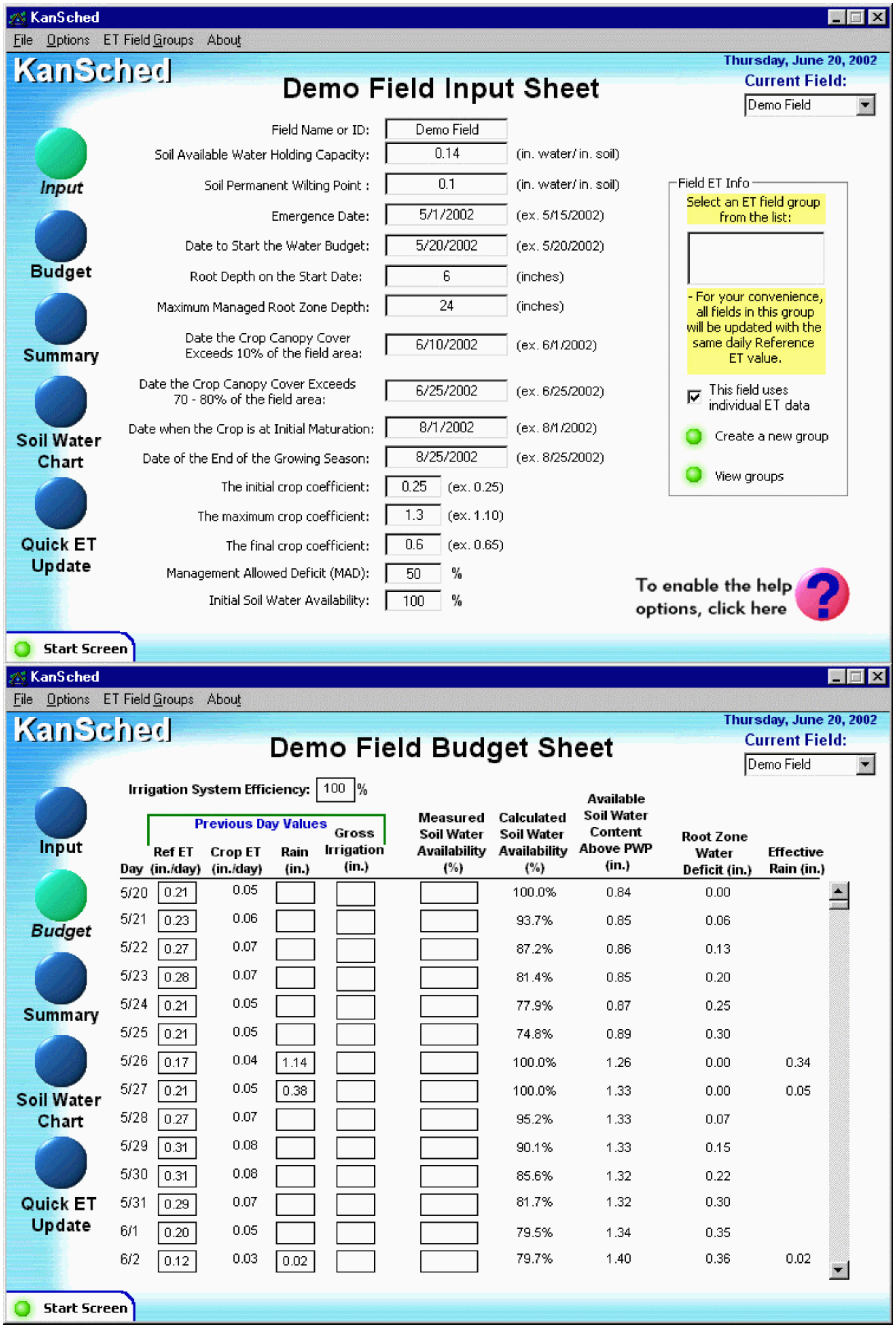

Figure 3. “Input” page (upper) for general field characteristic data, and “Budget” page (lower) for entering and monitoring field water budget data.

The input data page (Fig. 3, upper) and other pages include a sidebar of "page buttons" to let the user access other pages. The "Budget" page (Fig. 3, lower) is the page that calculates and shows the field water budget information. ET data can be entered on this page or on the "Quick ET" page (not shown). Calculated crop ET data are then displayed in the third column. Site-specific rainfall and "Gross Irrigation" are entered into columns four and five on this page for the field that is identified in the upper right-hand corner. Irrigation system (application) efficiency is entered in the upper left window of this page and is used to adjust the gross entered irrigation depths to net depths.

Column seven displays the calculated soil water availability. Zero represents permanent wilting point and 100% represents the field capacity value for the profile. If the user has measured field data of soil water content (as a percent of "full") they can enter that value into column 6 ("Measured Soil Water Availability") to adjust "calculated" values into field calibrated values. Column eight shows the available soil water content for the profile that is above the permanent wilting point and column nine shows the root zone water deficit value that is below field capacity. Thus, the user can estimate how much water remains in the profile and how much water the profile can hold until it is full.

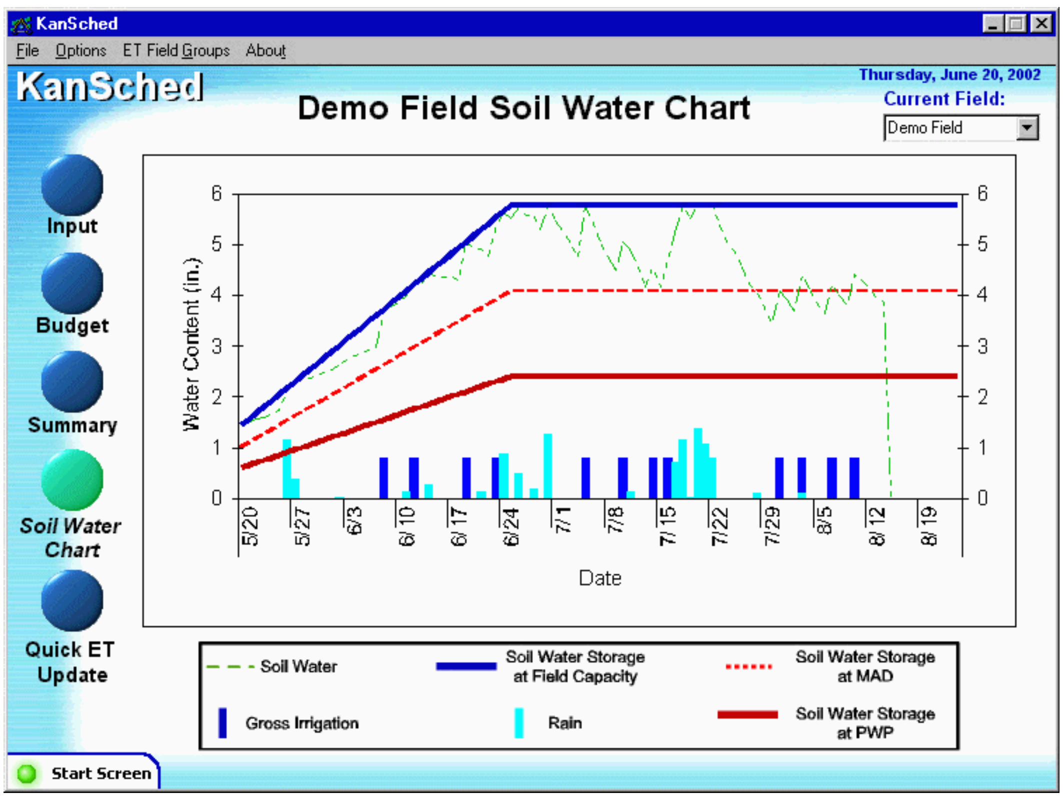

Figure 4. "Soil Water Chart" page showing the field soil water content with field capacity, management allowed deficit (MAD) and permanent wilting point limits along with rainfall and irrigation events.

The rightmost (tenth) column displays "Effective Rain" which is defined as the amount of rain that the profile could hold at the time of a rainfall event. For example, on May 26 (Fig. 3, lower) a 1.14-inch rainfall event was recorded for May 25. The root zone water deficit on May 25 was 0.30 inches and the crop ET was 0.04 inches (as shown on May 26 for the previous day value). Therefore any rain in excess of (0.30 + 0.04 inches) 0.34

inches was considered "not effective" since the profile did not have the storage capacity to hold it. These data are also shown graphically on the "Soil Water Chart" (Fig. 4). This chart helps the user to visually monitor their soil water profile along with upper and lower storage limits, and rainfall and irrigation events.

Finally a "Summary" page (not shown) provides the users with seasonal cumulative summary information on net and gross irrigation amounts, total and effective rainfall, and crop evapotranspiration.

Irrigation Fuel Cost Evaluator

The Irrigation Fuel Cost Evaluator program (FuelCost) is a simple, executable program that can be used to assess the cost of irrigation and to initiate pumping plant system performance evaluations. The user needs to input irrigated field size (acres), irrigation system capacity (gpm), operating pressure (psi) at the wellhead, an estimate of lift and friction head (feet), and their individual event or seasonal irrigation depth (inches). Help windows open to provide assistance with determining these values. The user then selects the type of power unit (Natural Gas, Electric, Diesel, or Propane) and enters the cost per unit of fuel. If they know their cost for the irrigation event or season, they can enter that value. The program then calculates what the energy cost "should" be with the Nebraska performance criteria and compares that to what the user entered.

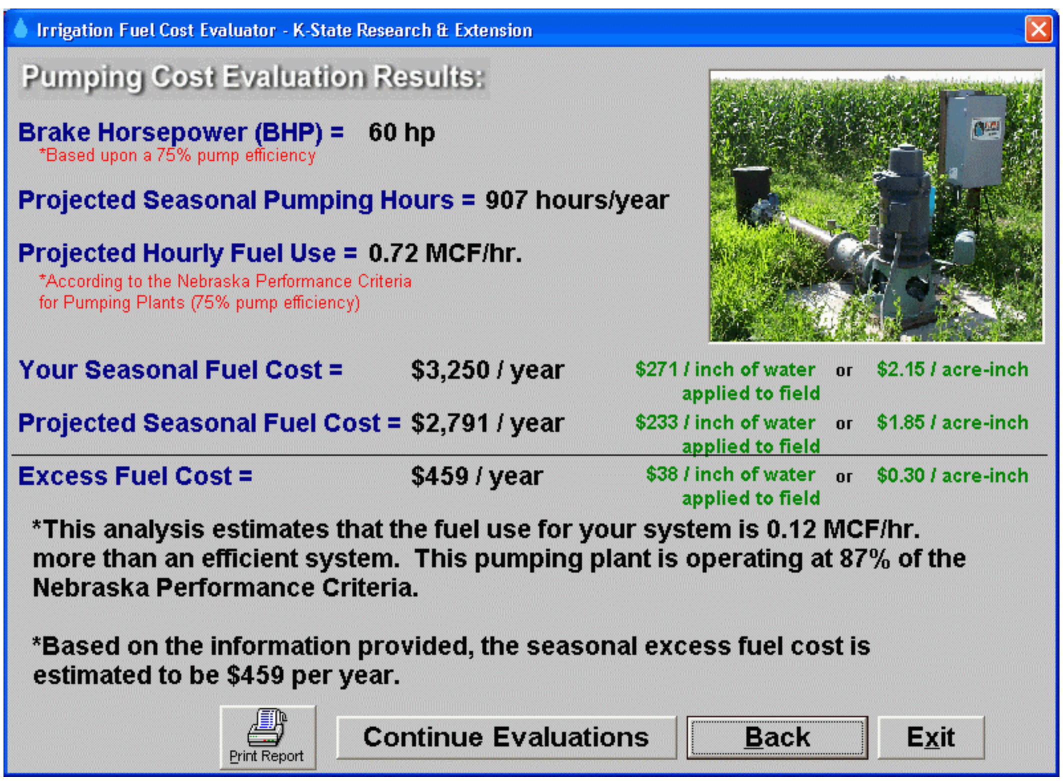

Figure 5. Irrigation Fuel Cost Evaluator program output for the example data set.

For example, consider the following inputs: Field size:126-acres; System capacity: 750 gpm; Operating pressure at the well head: 35 psi; Pump lift anf friction head: 155 ft; Annual irrigation application depth: 12 inches; Price for natural gas: $4.25/MCF; Current seasonal irrigation fuel cost $3250/yr. These data were entered into the Irrigation Fuel Cost Evaluator program. The output screen in Fig. 5 (above) shows that the while the actual seasonal irrigation fuel cost was $3,250 the projected cost based on the Nebraska performance criteria for pumping plants would be $2,791. Thus, the system perhaps has an "excess" fuel cost of $459. This information is used to help the owner/operator to decide if a physical pumping station performance evaluation should be conducted. In addition, the output shows that the current application costs average $271 per inch for the entire field. This other piece if information is useful when discussing the economic savings associated with irrigation scheduling.

Center Pivot Depth Calibrator

The Center Pivot Depth Calibrator program (http://www.oznet.ksu.edu./mil/) is an online tool that can be used to provide a timer setting / application depth chart for a center pivot system using on-site, in-field data. The user enters from one to three sets of data points (Fig.6) that would have in-field measured water depths and the associated center pivot system panel setting (%) value. The program then calculates a scaled output chart of irrigation system application amounts for different panel setting values (Fig. 6). The program also includes a print option to print a copy of the application table.

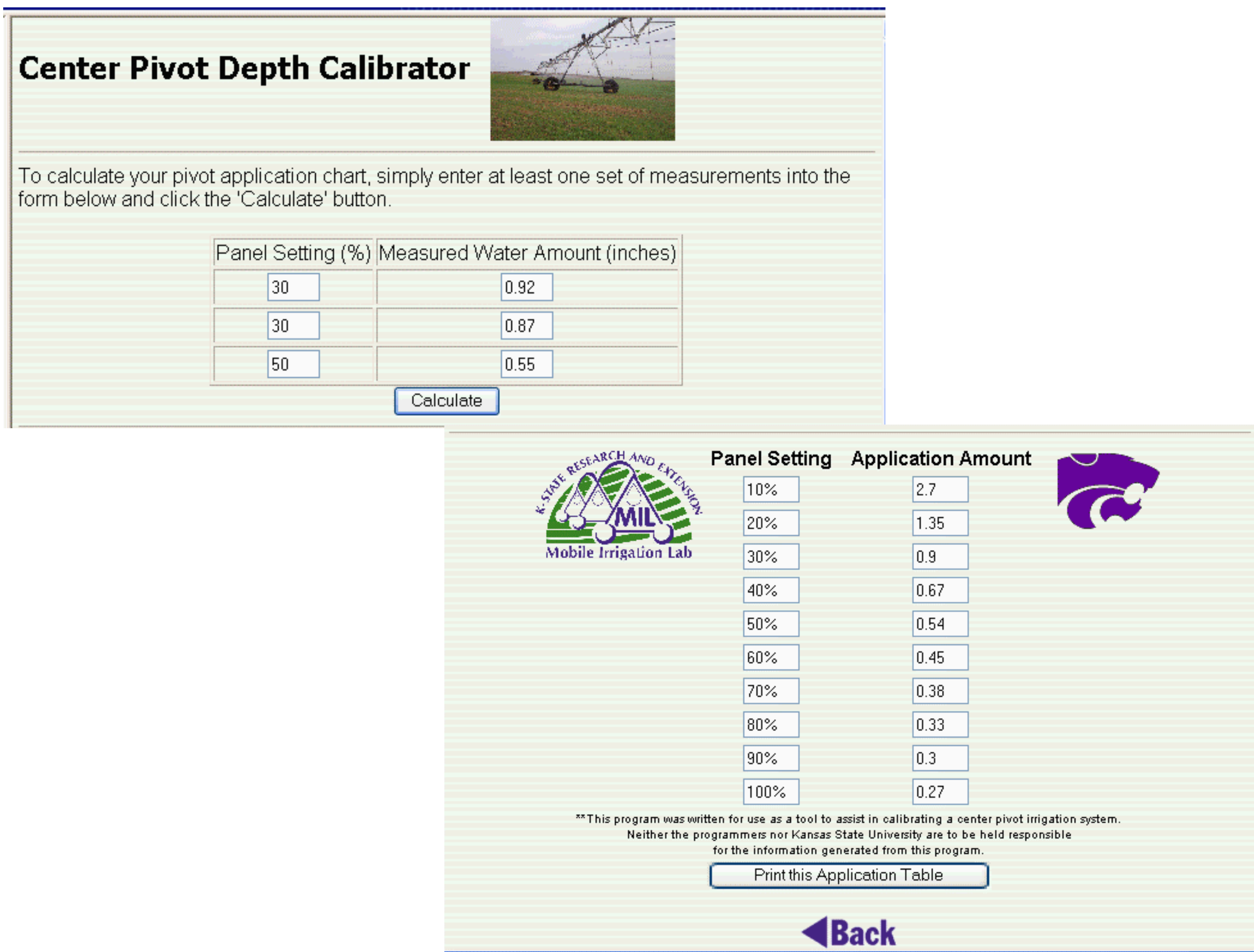

Figure 6. Screen shot of the online center pivot system application depth calibration program.

Mobile Irrigation Lab (MIL) Website

The previously discussed programs are available as downloadable electronic tools on the Mobile Irrigation Lab (MIL) website (http://www.oznet.ksu.edu./mil/). Users manuals with supporting audio files are also available on the MIL website. Additional resources on the MIL website includes other printed and electronic media with information related to irrigation systems and water management, a photo gallery of relevant pictures, and links to related websites.

Summary

This paper presented information on both physical and electronic tools that can be used for irrigation system performance evaluations and system management. Tools included the IrriGage: a non-evaporating, in-field precipitation measurement device; KanSched: an easy to use, computer program that uses reference crop evapotranspiration (ETo or ETr) in a water budget based irrigation scheduling and water management program; FuelCost : a simple program that can be used to assess current irrigation fuel costs and to compare with standard performance criteria; and Center Pivot Depth Calibrator: an online electronic tool that creates a center pivot timer setting / application depth calibration chart based on measured field data.

Acknowledgements

The authors would like to acknowledge the financial assistance of: The State Water Plan Fund through the Kansas Water Office for the development, operation, and maintenance of the Mobile Irrigation Lab and associated website; The Kansas Water Resources Research Institute for the initial development of the FuelCost and KanSched Visual Basic programs; and The Kansas Corn Commission for additional support to continue and expand the Mobile Irrigation Lab program.

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Rogers, D. H., G. Clark, M. Alam, D. L. Fjell, and R. Stratton. 2002. A mobile irrigation lab (MIL): Bringing education and technical assistance to the farm in the computer age. . ASAE meeting paper 022021 presented at the 2002 ASAE International Meeting, Chicago, IL. 10 p.

A MOBILE IRRIGATION LAB FOR WATER CONSERVATION: II EDUCATIONAL PROGRAMS AND FIELD DATA

Danny H. Rogers, Gary Clark, Mahbub Alam, Robert Stratton, Steven Briggeman[1]

Abstract

A Mobile Irrigation Lab (MIL) has been developed to promote water conservation in irrigated agricultural systems through educational programs and technical assistance. Educational programs include hands-on computer training for producers and consultants on irrigated related software. Software examples, developed as a part of MIL, include KanSched, an ET-based scheduling tool, and FuelCost, an irrigation energy cost evaluation program. Producer acceptance and use of software packages has been increased with hands-on computer training. Center pivot sprinkler package uniformity evaluations have also been conducted as a part of MIL. Field tests have been conducted using a MIL measuring device called an IrriGage. MIL software and information are available on the MIL website (http://www.oznet.ksu.edu/mil/). Field results indicate many systems have water distribution weaknesses.

Introduction

The Mobile Irrigation Lab (MIL) project is an educational and technical assistance program that is focused on enhancing the irrigation water management practices of Kansas irrigators. It is an outgrowth of experiences gained from long-term on-farm demonstration projects in south-central and western Kansas. The MIL field unit is a 16 foot trailer partioned into a classroom/office area in the front and an equipment compartment in the rear (Figure 1). The front office area allows on-site training and data analysis opportunities. The bulk of the equipment carried by MIL are IrriGages. IrriGages are non-evaporating, in-field measuring devices used to catch irrigation applications by center pivot and linear irrigation systems. The catch data can be used to calculate a distribution uniformity coefficient which is a measure of the sprinkler package performance.

Educational Activities I: Computer Software Training

MIL educational activities have included the traditional classroom/lecture format with program information and study results are presented in a lecture. These presentations have been both stand alone presentations of MIL materials only, while other presentations were incorporated into other agronomic and/or irrigation management meetings and field tours. The special educational focus of MIL has been hands-on computer training for producers and agency personnel. While the bulk of the training has been conducted in a class room setting, using MIL laptops to set up as a computer lab (Figure 2), a unique feature of MIL is the ability to do one-on-one computer training at the field site (Figure 3). The front half of the MIL trailer can easily accommodate 2 or 3 individuals. The laptop computers can also be carried into the home or office of an interested producer.

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The ET based irrigation scheduling program, KanShed, described more completely in the companion paper by Clark et. al in this proceedings, has been the primary focus of the computer training sessions. Other software covered in the training sessions have included FuelCost, an irrigation energy pumping cost evaluation program and Center Pivot Depth Calibration, (also see Clark et. al., this proceedings).

Formal training sessions have been attended by producers, irrigation managers, crop consultants, NRCS and Conservation District personnel, county agents and other agency personnel. KanSched has been accepted and approved by Kansas NRCS and the Kansas SCC (State Conservation Commission) as a cost-share eligible program. In addition, producers and agency personnel have received instruction from previously trained individuals. Several hundred MIL resource CD's, containing both information and software, have been distributed upon request. Resources are also available via the MIL website at http://www.oznet.ksu.edu/mil/.

Educational Activities II: Center Pivot Uniformity Testing

The second aspect of MIL is an emphasis on field evaluation of cropping systems and resource management. The initial emphasis has been evaluation of center pivot sprinkler packages for distribution uniformity. The initial rational for testing was that if irrigation scheduling procedures result in "just in time, just enough water application", then the water must be distributed so that plants have equal access to the water to prevent over- or under-water within the field, which would have yield implications.

Center pivot systems are the dominate irrigation system in Kansas, representing about 80 percent of the irrigated acres. The sprinkler package design is based on a number of factors. They have been largely assumed to be properly operating if the pivot point pressure and flow rate are set at the design operating conditions. Routine evaluation of the center pivot sprinkler package after installation is seldom, if ever, performed by the installer. Testing involves placement of multiple catch containers along the lateral of the system and then measurement of each catch. The catch containers used had to be measured quickly in order to avoid measurement error that would be introduced by evaporation losses. Therefore, a number of individuals had to be present at the test site for quick measurement. Measurement required entry into a very wet field, making for difficult data collection.

Development of a more streamlined testing procedure has been made possible through the use of IrriGages. IrriGages are a non-evaporating collection device (see Clark et. al., this proceeding for further description) as shown in Figure 4. A series of IrriGages are placed along the center pivot or linear lateral and are normally spaced at about 80 percent of the nozzle spacing. The IrriGages are placed so that all water from a complete pass of the center pivot is collected. The data collected includes the volume of catch and the position radius of the IrriGage relative to the center pivot point or the end of the linear system. System operating and package characteristics also recorded the catch data which are entered into a MIL uniformity evaluation program where the average depth of application and the coefficient of uniformity (CU) value is calculated. The program also plots the catch data which helps to visually identify the location of package weakness.

The MIL uniformity testing program has several goals including 1) development of the testing procedure, 2) development of a data base of characteristic uniformity performance criteria for various nozzle package types and configuration that could improve design and installation recommendations, and 3) improved performance for individual operator's systems.

The 2002 growing season has, in general, been very difficult throughout Kansas, resulting in watering problems that indicate poor uniformity. Examples of poor uniformity are shown in Figures 5 and 6, where corn height differences are seen.

Test Result Examples

The uniformity test results for four systems are shown in Figures 7 through 10. Figure 7 is a rotator equipped center pivot system with a CU of 84 percent. The major spike in application depth in the inner part of this system, was a leaky tower boot. The inner span of many systems have higher than average application depth.

Figure 8 shows a flat spray system with a very low CU valve of 50 percent. The water supply for this system has very high iron and other mineral content and there was visible accumulation of materials on the system, nozzles and splash plates. A number of nozzles that had a deficient spray patterns were noted. Problems were related to either partial plugging of the orifice or crust accumulation on the splash plate.

Figure 9 shows the results from a flat spray equipped system in rolling sandhills near Garden City, Kansas. The non-pressure regulated flat spray nozzles were tested in high wind conditions. During the set up of the test, it was expected that the CU value would be very low due to the elevation differences along the center pivot lateral and the high wind conditions. However, the CU value of 82 percent was higher than expected. Two leaks are noted as spikes in the application depth. The center point spike was due to continuous over-spray near the center pivot point, due to the high wind conditions. The spike at the mid-point of the system may have been an unobserved leak.

The results for a new system equipped with I-Wob nozzles (Figure 10) showed an increasing depth of application with increase of radius. The application depth was approximately one-third greater in the outer portion as compared to the inner portion. This is the most problematic of the examples shown, but the cause may be related to improper flow or pressure conditions. The CU value of 82 percent was surprising good, however, the variation in average application down the lateral needs to be addressed.

Other tests have revealed installation problems, such as missing drop nozzles and reversal of tower nozzle sequences. Poor performances have also been attributed to changes in operating conditions as compared to original design specifications. Another possible cause of low uniformity could be internal incrustation similar to the material encrusted on nozzles splash types, which would alter friction loss characteristic of the system resulting in loss of design integrity.

Future Activities

Development of additional decision-support software and computer training activities will continue. Distribution of the information will continue via educational meetings, conferences and training sessions. However, resource materials are also web-based. Refinement of the uniformity evaluation procedure will continue but an immediate goal will be to develop an IrriGage test kit which would include testing procedure instruction, IrriGages, and data forms and other necessary test equipment. Test kits would be made available for use by producers or agency personnel to increase the number of systems evaluated.

Acknowledgment:

The Mobile Irrigation Lab is supported in part by the Kansas Water Plan Fund administered by the Kansas Water Office, the Kansas Corn Commission and USDA Project 00-34296-9154.

Figure 1: MIL is a combination classroom and field laboratory.

Figure 2. MIL computers in use in a conference room for on-hands computer software training for a large group.

Figure 3. The front portion can be used for on-site one-on-one software training.

Figure 4. Series of IrriGages being positioned prior to an evaluation.

Figure 5. Corn height differences were noted in many fields in 2002 due to non-uniform water application.

Figure 6. Corn growth was suppressed under a plugged nozzle.

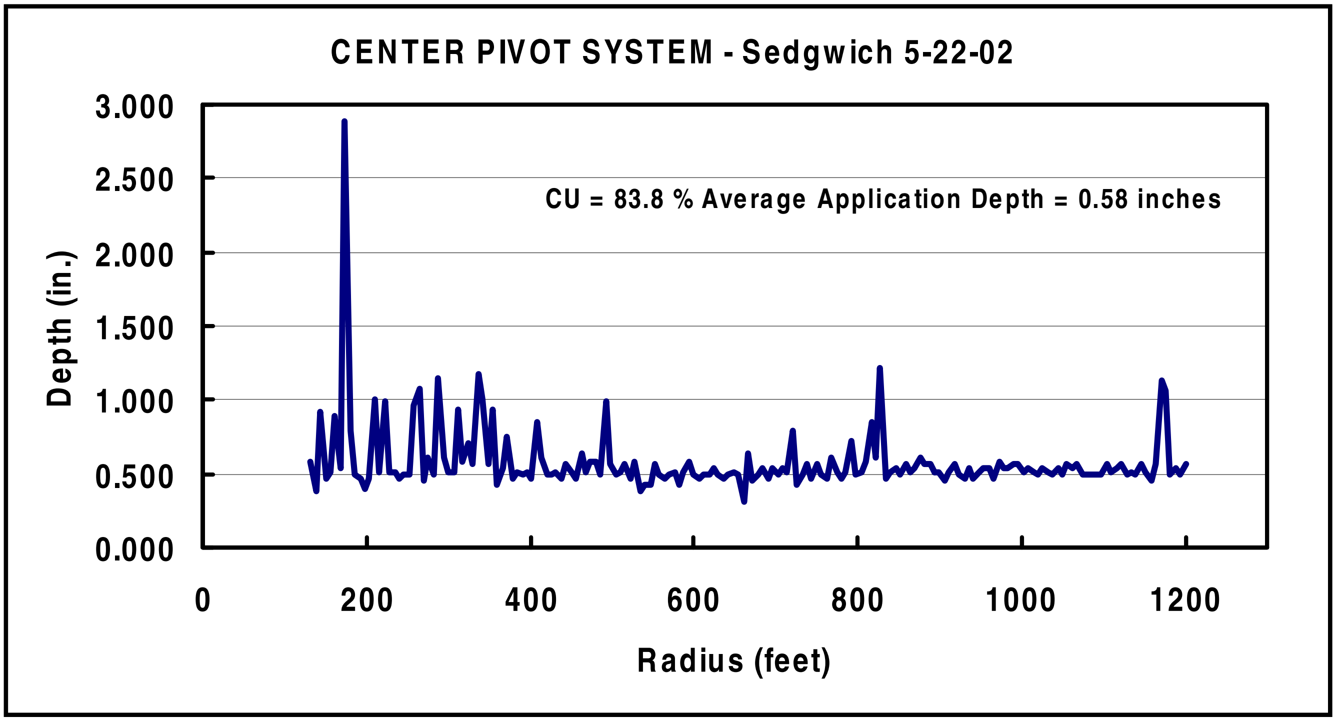

Figure 7. MIL uniformity test results for a center pivot equipped with rotator nozzles

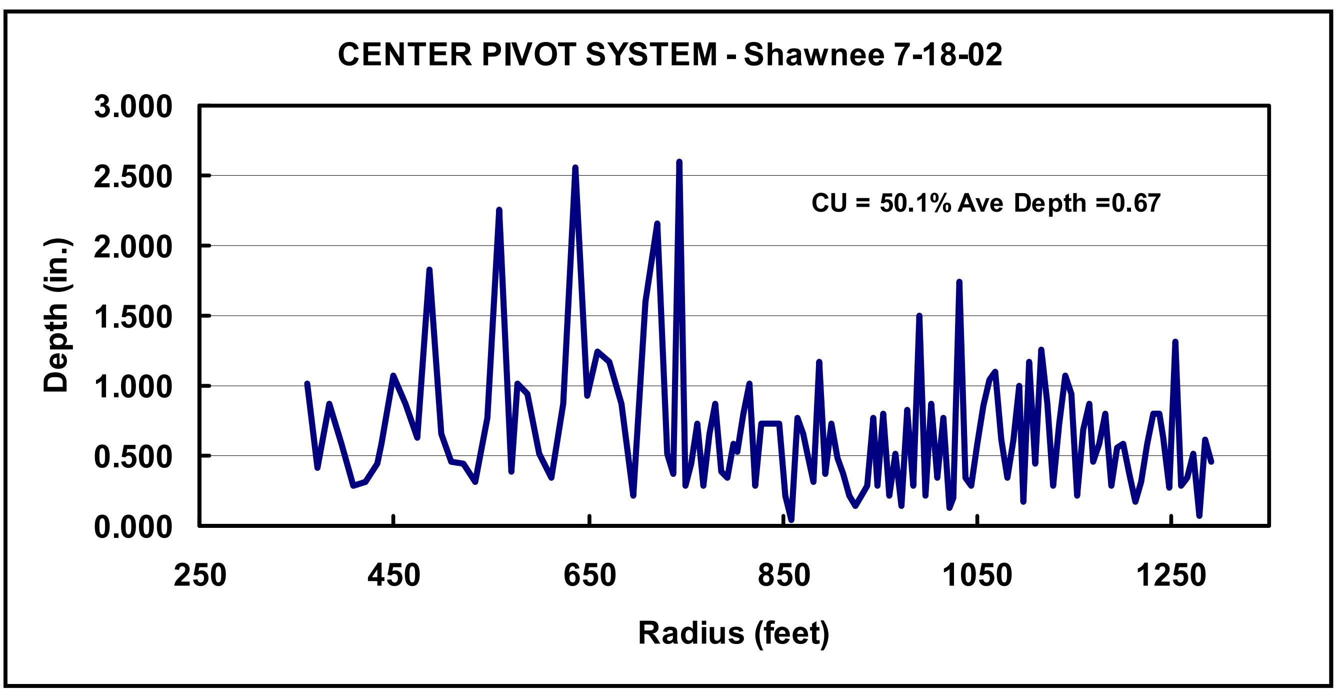

Figure 8. MIL uniformity test results for center pivot equipped with flat spray nozzles.

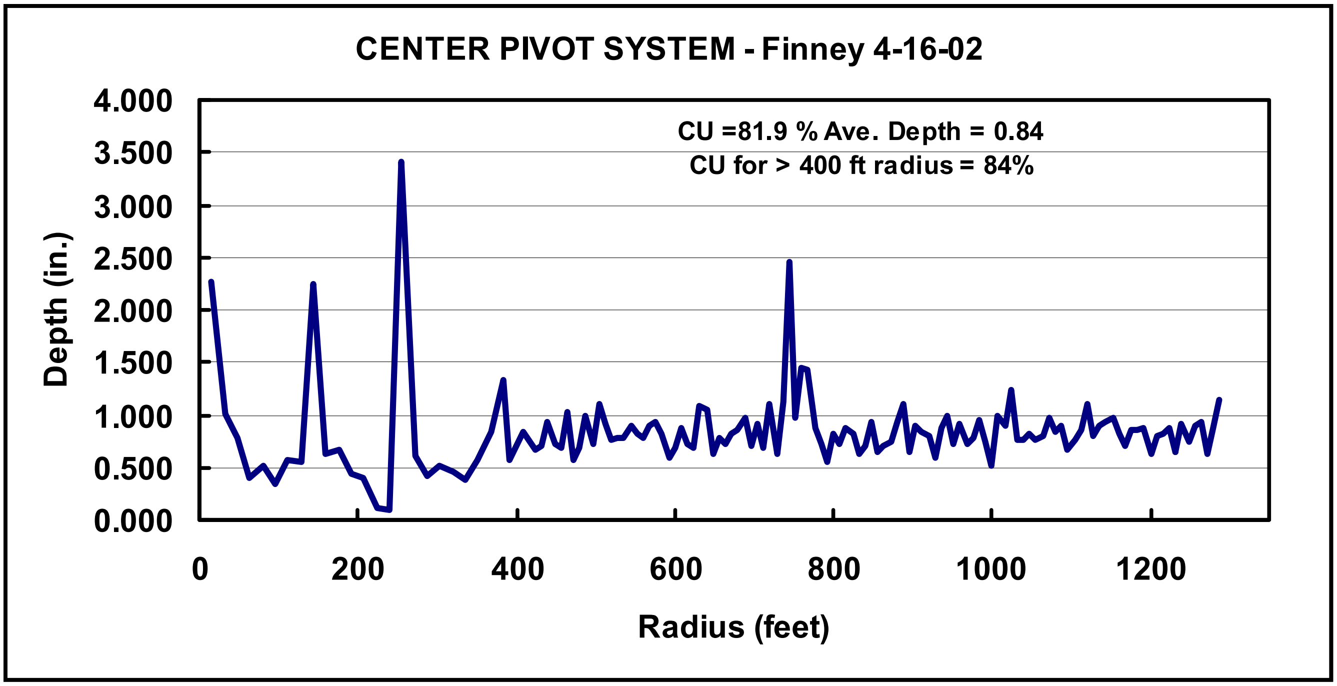

Figure 9. MIL uniformity test results for a center pivot equipped with flat spray nozzles.

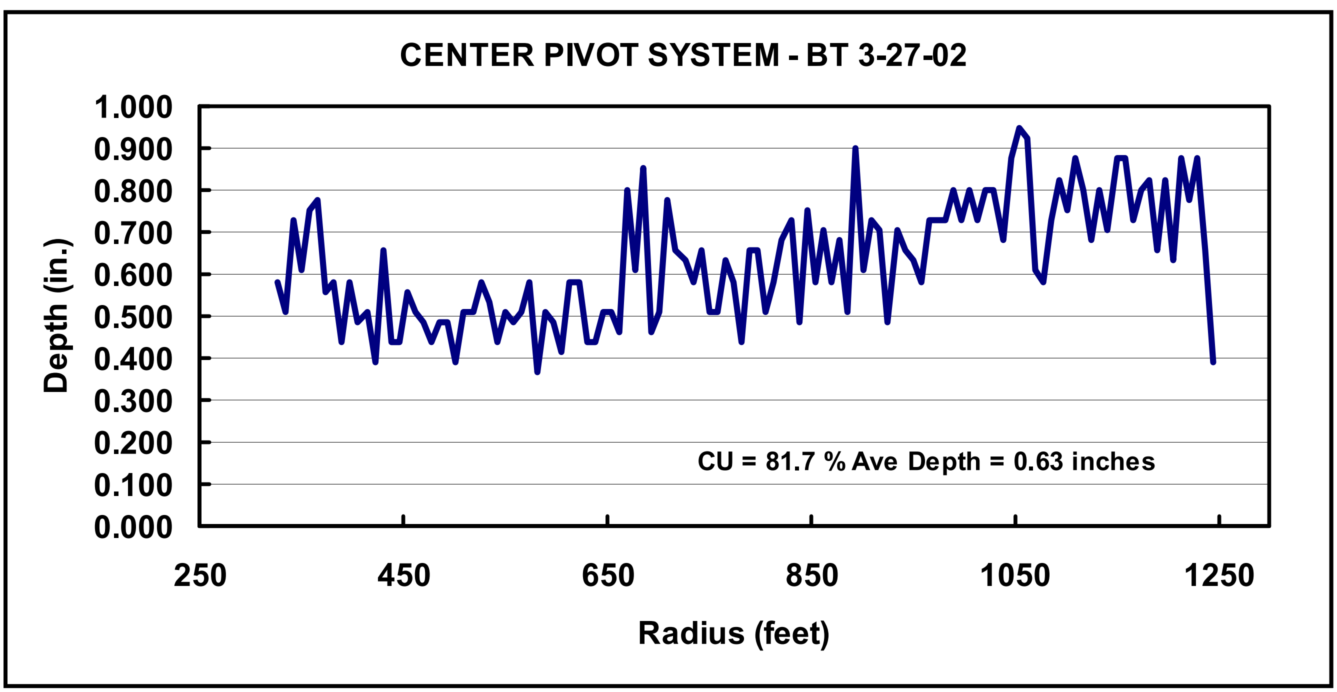

Figure 10. MIL uniformity test results for a center pivot equipped with I-Wob nozzles.

Spatial variation in crop response: I. Overview for variable irrigation of corn.

E. John Sadler and Carl R. Camp[1]

Abstract

During the 1990's, independent research at four sites created methods to apply irrigation water in a site-specific manner, both along the direction of travel and along the boom of moving irrigation systems. At one of these, ARS - Florence, SC, research in this area produced more than 25 publications dealing with specific aspects of the system and research results, and these need to be integrated into a comprehensive summary. This paper provides an overview of the project, sets it in the context of the preceding Florence research, and provides the foundation for a companion paper that examines site-specific irrigation and nitrogen production functions for representative soils of the southeast US Coastal Plain. In these two papers, data are discussed from two experiments that were conducted during 1999-2001 using the two site-specific center pivots in the irrigation facility. Both used corn as the first test crop. One was a 144-plot irrigation x nitrogen experiment on the predominant soil map unit for the area, and the other was a 396-plot irrigation x nitrogen x soil experiment on a field with 12 soil map units. This paper shows the spatial variation in crop response that was obtained; the companion paper discusses implications for irrigation management.

Introduction

For more than two decades, two series of research projects conducted at the USDA-ARS Coastal Plains Soil, Water, and Plant Research Center in Florence, SC, have converged toward the site-specific application of irrigation water and nutrients to address the problems of managing crop production on fields with extreme soil variation. During this time, research reports have documented individual studies, but no comprehensive summary has been done. This paper and the companion paper in this proceedings (Camp et al., 2002) comprise an overview of the suite of studies and discuss the implications of the collective findings. Space constraints necessarily prevent an extensive treatment of literature in this paper. For a discussion of the state of the art of site-specific irrigation, the reader is referred to Sadler et al. (2000), Evans et al. (2000b), and Buchleiter et al. (2000). For general issues relating to irrigation in humid regions, see Camp et al. (1990) and Sadler et al. (2002d)

In 1979, a 5-state southeast regional irrigation scheduling project was initiated for the coastal plain from Florida through Virginia (Camp and Campbell, 1988). The experiences at the Florence location (Camp et al., 1988) highlighted the difficulty in fine-tuning the management of irrigation for center pivots sited on typically variable Coastal Plains soils. Despite the relatively small size of this irrigation system (4 towers), it encompassed one soil with substantially more sand and another with substantially more clay than the prevalent soil, which was a loamy sand. No matter which set of physical parameters were used in the computer-based irrigation scheduling program, the result was inevitably not optimized for nearly two-thirds of the system. However, equipment to

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independently manage these soils was not available from any source.

In a separate study, inherent productivity of various soil types in a typical Coastal Plain field was examined to build a basis for soil productivity ratings (Karlen et al. 1990). In this and subsequent examinations (Sadler et al. 1995, 1998), it became apparent that site-specific management of soil fertility, by itself, could not address the variation observed in grain yields for several field crops. By this time, commercial equipment for variable-rate fertilizer application was available, but only in other regions of the country.

Consequently, a site-specific center pivot irrigation machine was designed (Camp and Sadler, 1994), and two 3-tower, 140-m commercial systems were modified to meet these specifications (Camp and Sadler, 1997;Omary et al., 1997; Camp et al., 1998). The design called for the capability to apply irrigation independently to 9-m square cells, and by varying application depth while injecting nutrients for a constant concentration, to apply nutrients independently to these same 9-m square cells. The small size of these areas necessitated locating nozzles with very small (<3 m) wetted radii (Omary et al., 1997). The control of this system also required a separate PC/PLC (programmable logic controller) unit that communicated with the commercial system's controller. The modifications also included 3 separate manifolds that applied geometrically larger flow rates for each of the 13 section along the center pivot main boom. These were chosen to be 1x, 2x, and 4x, so that all three, or 7x, applied 12.7 mm when the center pivot was moving at 50% of full speed. System performance was evaluated and documented in Camp and Sadler (1997), Omary et al. (1997), and Camp et al. (1998).

These machines were used in two experiments, the first from 1995-1998 to prove the function of the design on center pivot #1 (CP1) on a reasonably uniform soil (Camp and Sadler, 2002), and the second from 1999-2001 to evaluate irrigation (Sadler et al. 2002b) and nitrogen (Camp et al., 2002) production functions on both center pivots. The varied irrigation applications on center pivot #2 (CP2), on a typically variable field, had correspondingly varied water stress, which provided an opportunity to examine capabilities of infrared thermometers to detect stress with suitable precision under Southeastern climatic conditions (Evans et al., 2000a; Sadler et al., 2002a).

Irrigation production functions were reported by Sadler et al. (2002b) for map unit means and field means for the three years. While the production functions for the different soil map units were significantly different by classical analysis of variance, it was clear that there were also different functions for the different experimental blocks within most of the soil map units. Therefore, a re-analysis on a strictly spatial basis was conducted that ignored the soil map unit delineations (Sadler et al., 2002c). In this analysis, spatial patterns were evident in both irrigation response and the irrigation amount that produced the maximum yield.

The studies above for the period 1999-2001 under center pivot #1 and #2 provide the data used in this and the companion paper. Results will be briefly summarized here, to illustrate the salient findings and provide the data basis for the companion paper, which reports irrigation and nitrogen production functions and discusses the implications of these findings (Camp et al., 2002).

Materials and Methods

Under CP1, a 144-plot replicated factorial experimental design (Fig. 1) was used to specifically examine nitrogen production functions for the most-prevalent soil, which was a Norfolk loamy sand. Plots were 9 m by 7.5 degrees of travel, which was 9 m for the innermost ring and 14 m for the outer one. There were 4 levels of

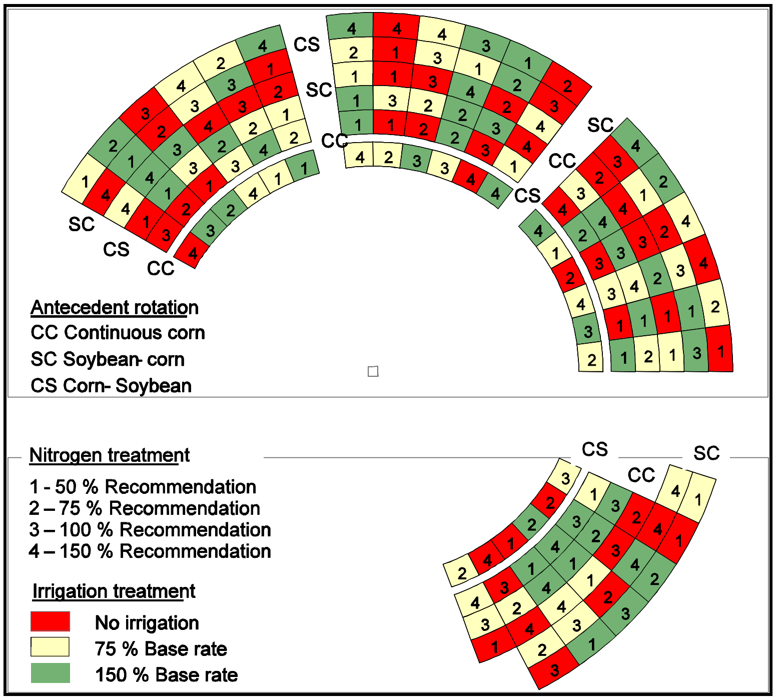

Figure 1. Experimental design for CP1 experiment on corn during 1999-2001.

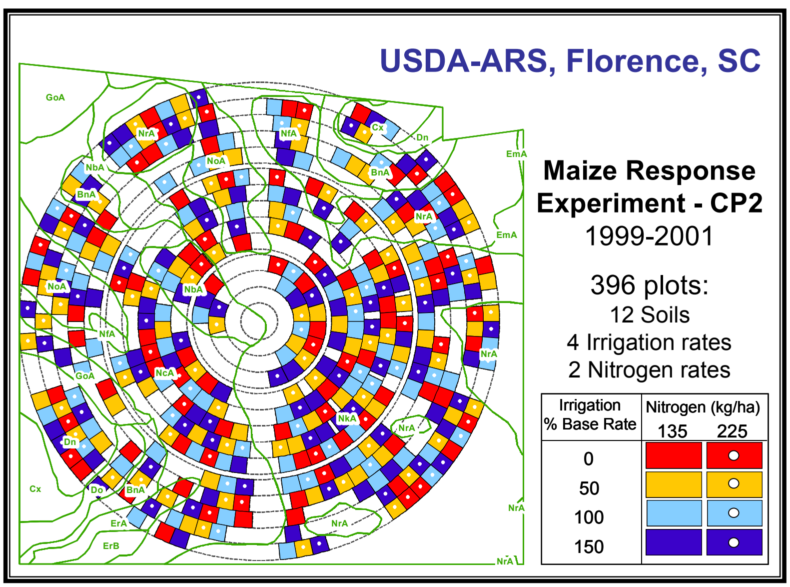

Figure 2. Experimental design for CP2 experiment on corn during 1999-2001.

nitrogen fertilization (50%, 75%, 100%, and 125% of recommendations), 3 levels of irrigation (0%, 75%, and 125% of the hypothetical normal amount to replace ET), 3 antecedent cropping conditions at the initiation of the experiment (corn in a corn-soybean rotation, soybean in a corn-soybean rotation, and continuous corn), and 4 replications. The recommended nitrogen fertilizer amount depended on irrigation because the value for rainfed was 135 kg/ha, corresponding to 6 Mg/ha target yield, and the value for the two irrigated treatments was 225 kg/ha, corresponding to 10 Mg/ha target yield. Application of the variable fertilizer, which was UAN 24S (24% urea ammonium nitrate with sulphur), was achieved through variable irrigation with a small irrigation amount. The cultivation was a conservation tillage system that retained surface residue, but tilled the subsoil under the row to a depth of 40 cm. Corn was planted in 76-cm rows around the circle. Cultural operations followed regional extension guidelines. Corn was harvested using a plot combine in 2-row swaths 6 m in length from the center 6x6-m control area of the plots. Yields were stated at 15.5% moisture.

Under CP2, which was on quite variable soils, the focus of the experimental design was to examine whether irrigation production functions for corn were different among soil map units (Fig. 2). The soil map units were determined on a 1:1200 scale by USDA-SCS in 1984 (Karlen et al., 1990). The Norfolk loamy sand mentioned above is designated NkA and can be seen to be the prevalent soil under CP2. In the orientation shown in the figures, ‘up’ is almost directly northeast. Center pivot 2 is sited directly NE of CP1.

An innovative 396-plot design combined 2x4 factorial randomized complete blocks where there was sufficient area within a soil map unit and randomized incomplete blocks where there was not. The factors were irrigation amount (0%, 50%, 100%, and 150% of normal, which replaced ET according to tensiometers in selected 100% plots) and nitrogen fertilizer (135 kg/ha and 225 kg/ha, which are the recommendations for rainfed and irrigated corn and correspond to target yields of 6 and 10 Mg/ha). Conventional surface tillage was used, including disking of the surface. Corn was planted in 76-cm rows around the circle with in-row subsoiling to 40 cm to break up a dense eluviated horizon. Cultural operations followed regional extension guidelines. Corn was harvested using a plot combine in 2-row swaths 6 m in length from the center 6x6-m control area of the plots. Yields were stated at 15.5% moisture.

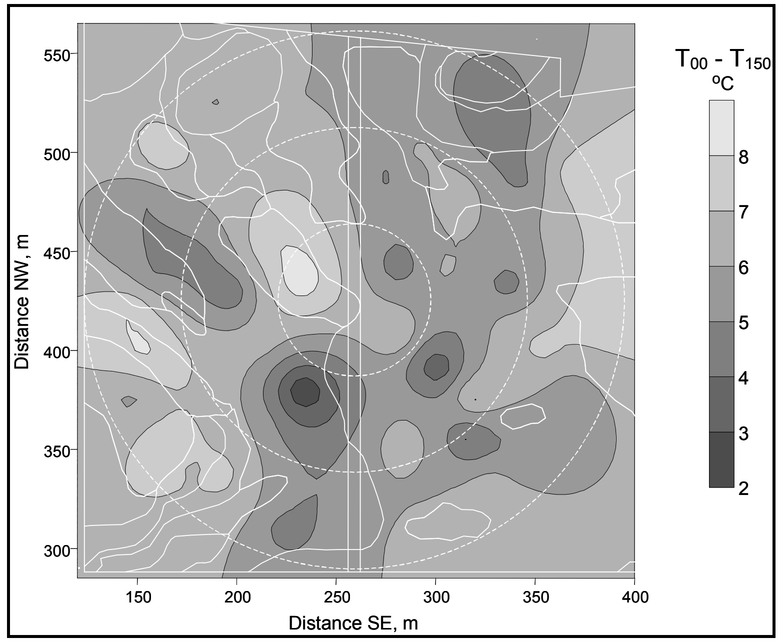

Figure 3. Canopy temperature of water stressed plots minus canopy temperature of well-watered plots of corn on July 23, 1999 for CP2.

Results and Discussion

Canopy temperature appears to be the most-sensitive indicator to illustrate the varied response of corn to the physical characteristics of the soil as they varied across the field. Sadler et al. (2002a) presented a map of the canopy temperature of rainfed (stressed) plots minus the canopy temperature of irrigated (well-watered) plots under center pivot 2 (Fig. 3). These temperatures were measured with an array of infrared thermometers mounted on the boom as it moved around the field during the period ~1130-1500 hrs LST. The range of this difference extends from about 2 to about 8 °C, which comprises radically different conditions for a corn plant. This shows the extreme variation in crop water stress caused by the typically varied soils within this representative Coastal Plain field.

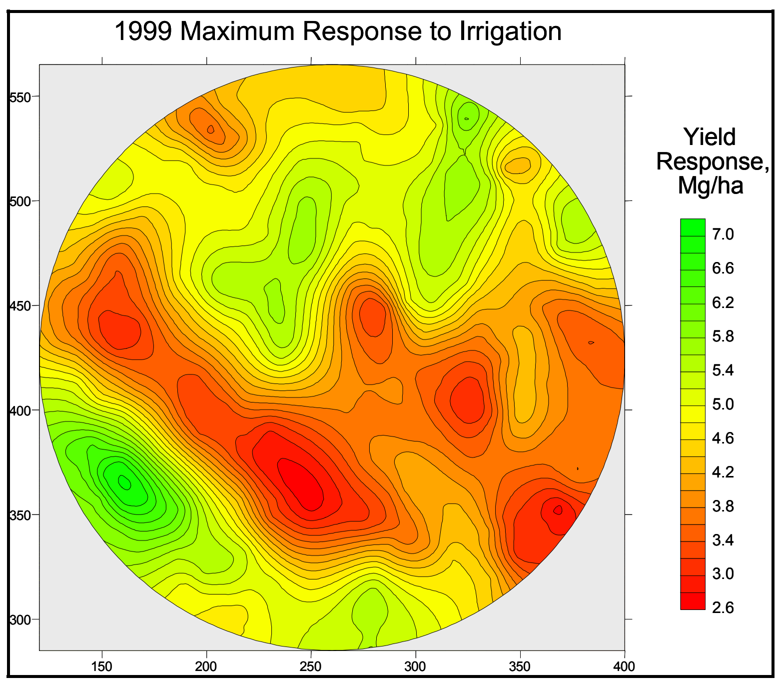

Figure 4. Maximum irrigation response for corn in 1999 for CP2.

The maximum corn yield response to irrigation was examined by Sadler et al. (2002b) and is shown in Fig. 4 for 1999. In this dry year (seasonal rainfall was 288 mm, compared to 410 normally during April-July), the spatial patterns of irrigation response were quite marked. This resulted from distinct spatial patterns in both rainfed yield and also in maximum irrigated yield (neither shown here). Furthermore, these patterns were neither similar nor complementary, resulting in the third spatial pattern of irrigation response, which is shown in Fig. 4. The diagonal low-response area across the lower-left corresponds to the highest yielding area in the field for unirrigated corn, but other patterns in this field are different from either the rainfed yield or the maximum irrigated yield. The maximum response to irrigation ranged from about 2.5 to 7.0 Mg/ha, corresponding to a range from $243.50 to $681.80/ha at local corn prices ($97.4/Mg on 8/28/02).

The amount of irrigation that produced the maximum yield is of considerable interest to irrigation system designers and managers. The greatest amount must be considered in designing the total irrigation capacity of a system, and the spatial variation in the amount needed must be considered in both the design and management. The value obtained in the same 1999 season for which we have seen the maximum irrigation response is shown in Fig. 5. There are two patterns seen. One is spatially variable and covers about half the center pivot. The other is exactly the maximum irrigation amount applied during 1999, which means that approximately half the center pivot's area did not receive enough irrigation to reach a plateau - the production function was still climbing at the maximum irrigation amount. This occurred despite the irrigation management to achieve constant soil water content as measured by tensiometers in selected plots. Clearly, the tensiometer placement did not represent some of these sub-optimal areas. It is also surprising for a second reason, in that these tensiometers were placed in the 100% irrigated plots. One would think that the plots in the experiment that were irrigated at 150% of normal would have made up for the spatial variability, but apparently not. The implications of these findings will be discussed by Camp et al. (2002) in the companion paper.

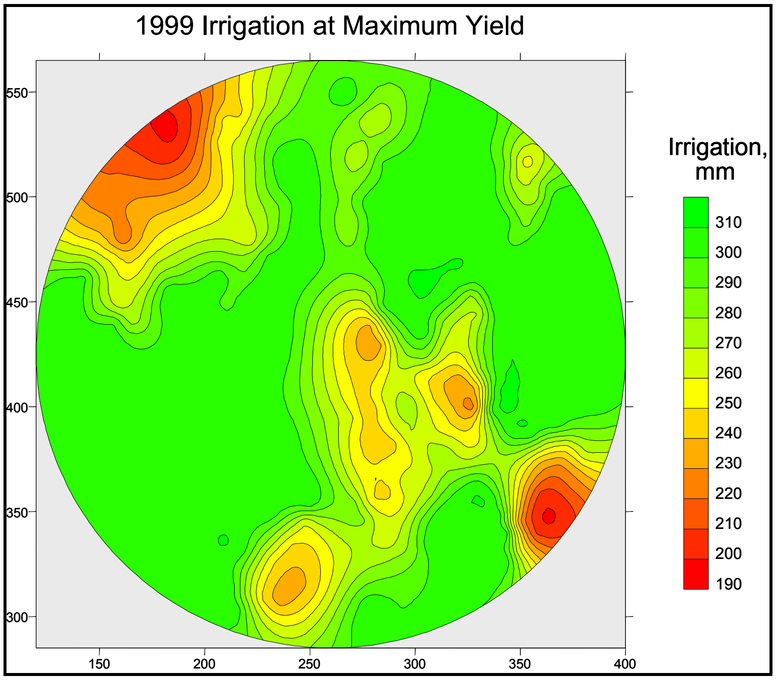

Figure 5. The irrigation amount that produced the maximum corn yield in 1999 for CP2.

The ratio of the maximum irrigation response shown in Fig. 4 to the irrigation amount that produced it shown in Fig. 5 is the corresponding irrigation water use efficiency. It is shown in Fig. 6 stated in terms of kg/ha yield per mm applied water. This generally corresponds to the maximum response to irrigation (Fig. 4), except in locations needing less than the maximum irrigation amount (Fig. 5). The irrigation water use efficiency ranged from 8 to 23 kg/ha yield per mm applied water. This corresponded to $0.78 to $2.24 increase in return per mm of applied irrigation water. The irrigation water use efficiency was similar for 2000, when seasonal rainfall was 371 mm (not shown here.)

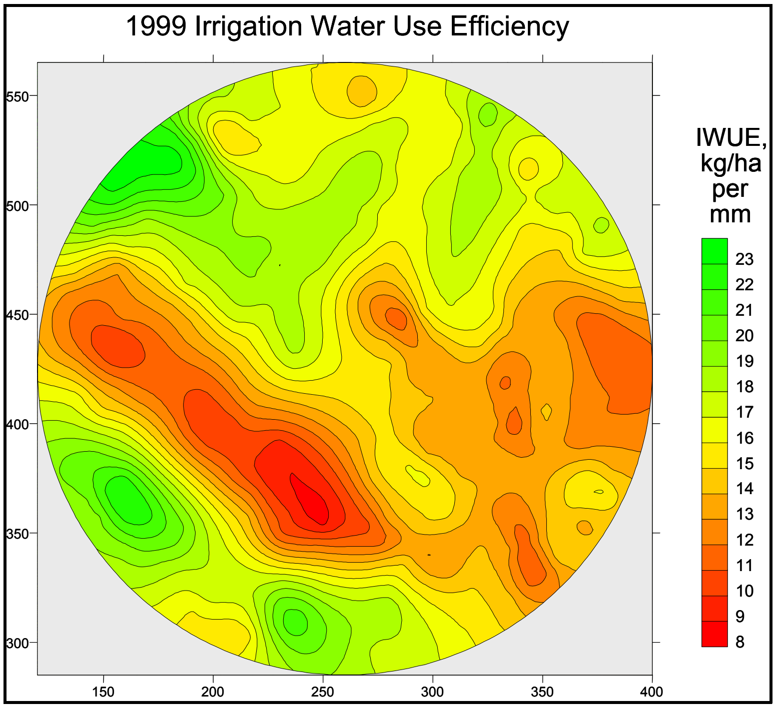

Figure 6. Irrigation water use efficiency at the point of maximum yield for corn in 1999 for CP2.

The maximum response to irrigation for 2001 was quite different, ranging from essentially zero to only 3 Mg/ha. The irrigation amount that produced the maximum yield ranged from near zero to about 280 mm. Therefore, the irrigation water use efficiency varied from near zero to about 16 kg/ha yield per mm applied water (Fig. 7). This upper limit represented a marginal benefit to irrigation of $1.56 per mm applied. The differences appear to be related to rainfall distribution. The seasonal rainfall of 334 mm was intermediate between 1999's 288 mm and 2000's 371 mm, and all were below the 410 mm normal rainfall for April-July. However, the in-season distribution for 2001 was much more favorable than 1999 and 2000, as reflected in county-average corn yields (4.4, 5.3, and 6.8 Mg/ha in the 3 years).

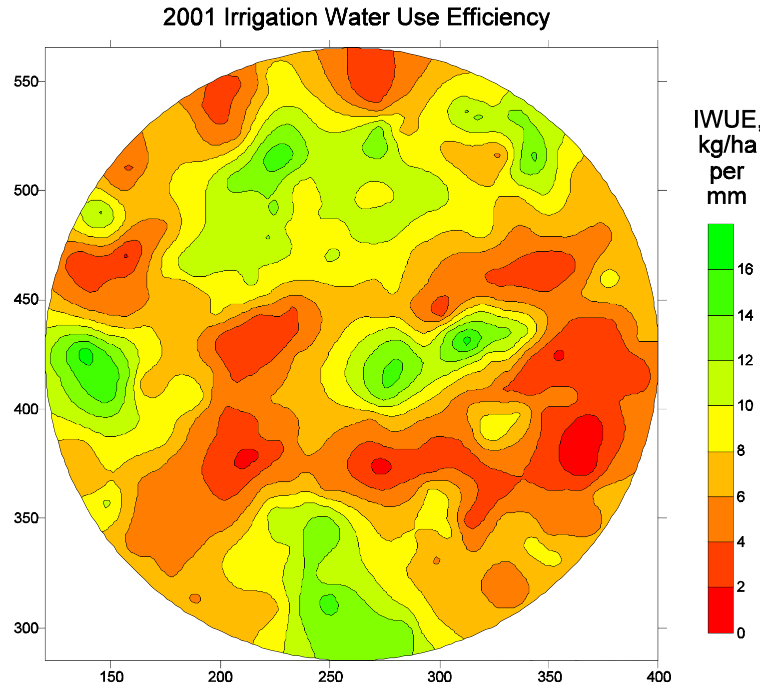

Figure 7. Irrigation water use efficiency during 2001 for CP2, expressed as kg/ha yield per mm irrigation water applied.

Summary and conclusions

The preceding discussion and selected results from the series of experiments conducted at the Florence USDA-ARS center were intended to provide the basis with which to examine the managerial implications of irrigation of corn in the humid southeastern coastal plain. This will be done in the companion paper, Camp et al. (2002), following this in the program and proceedings.

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Spatial Variation in Crop Response: II. Implications for Water and Nitrogen Management

Carl R. Camp, Yao-chi Lu, E. John Sadler[1]

Abstract

For agricultural fields with considerable spatial variation, it is almost impossible to manage water and fertilizer inputs in an optimum manner using conventional equipment with uniform applications. Site-specific applications can be made to zones as small as 83 m^2 (9.1 m by 9.1 m.) using modified center pivot systems. Two modified center pivot irrigation systems in Florence, SC, were used to apply variable water and N-fertilizer amounts to corn during a three-year period. Corn grain yields varied for a range of water and N fertilizer inputs during the period, but yield responses were not equal for all years. Yield response to these inputs also varied with soil map unit, demonstrating that yields increased more with increased input for some soils than for others. The differential response to variable input was analyzed to determine economic response. With these data, it should be possible to ultimately develop a management tool to maximize profit and/or optimize resource allocation or utilization.

Introduction

During the last 10-15 years, reasonably-priced technology to measure spatially-indexed crop yields and to apply fertilizers at spatially-variable rates has stimulated increased interest in site-specific farming. Technology to apply irrigation at spatially-variable rates is not commercially available, having lagged fertilizer application. However, it is generally agreed that water and fertilizer are the most important inputs for determining yield and profit. While moving irrigation systems, if modified, could offer great potential for site-specific application of water and nutrients, little is known of crop yield response to these inputs, or the economic implications. Both yield responses and the associated economic implications must be known before optimum dynamic management can be achieved. Availability of commercial equipment for variable-rate applications of water and nutrients to small management areas will accelerate the need for these crop response functions.

A brief summary of the two-decade history of spatial variability and irrigation management research at USDA-ARS, Florence, SC, and the development of two site-specific center pivot irrigation systems was provided by Sadler and Camp (2002, this proceedings). If not already familiar, the reader is strongly encouraged to review that paper for important background and equipment descriptions to fully appreciate this discussion. These center pivot irrigation systems provide a unique capability to determine the crop response functions needed for dynamic management of water and nutrient inputs to a variety of crops. Although corn and soybean were grown in an initial experiment to prove the function of the site-specific center pivot design (1995-1998), corn was selected as the initial crop for determining crop response functions to both water and N fertilizer.

Irrigation production functions were reported by Sadler et al. (2002b) for three years (1999-2001) in an experiment on center pivot #2 (CP2) with typically variable soils. N-fertilizer production functions were

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reported by Camp et al. (2002) for three years (1999-2001) in an experiment on center pivot #1 (CP1) with a relatively uniform soil. Descriptions of both experiments were reported by Sadler and Camp (2002, this proceedings). Sadler et al. (2002b) reported significantly different irrigation production functions for different soil map units. When soil map unit delineations were ignored (Sadler et al., 2002a), they found spatial patterns in both irrigation response and the irrigation amount that produced maximum yield. Camp et al. (2002) reported different N-fertilizer production functions for each irrigation amount and for each of the three years. In an analysis of the corn yield response to water and N-fertilizer for the variable soils on CP2, Lu et al. (2002) reported estimated production functions for water on two N-fertilizer treatments and three years (1999-2001), and calculated the amount of irrigation required for both yield- and profit-maximizing strategies.

Studies during the period 1999-2001 under CP1 and CP2 provide the data used in both the companion paper and this report. The objectives of this paper are to report production functions for both irrigation and N-fertilizer and to discuss implications of these results for the design and management of site-specific applications.

Methods and Materials

The commercial center pivot systems had been modified to make variable-rate irrigation and N-fertilizer applications to individual management zones within the system, each 9.1m by 9.1 m. N fertilizer applications were achieved by injecting UAN 24S into the irrigation stream at a rate to maintain a constant concentration, and variable N-fertilizer rates were obtained by varying the irrigation application. All applications were controlled by a computer interfaced with the commercial pivot control panel and by a PLC control system to control valve operation. Additional details regarding the site-specific center pivot hardware modifications and the control system were reported by Sadler and Camp. (2002) and other reports cited there.

During the period 1999-2001, corn was grown with a range of water and N-fertilizer applications on both site-specific center pivot irrigation systems. Treatments on CP1 were 0, 75%, and 150% of normal irrigation and 50%, 75%, 100%, and 125% of a N-fertilizer base rate, which was 135 kg/ha for rainfed and 225 kg/ha for irrigated. Treatments for CP2 were 0, 50%, 100%, and 150% of normal irrigation, two N-fertilizer rates (135 or 225 kg/ha), and 12 soil map units. More detailed descriptions of these experiments were reported by Sadler and Camp (2002) and other references cited there.

Crop response curves or production functions were determined for both water and N-fertilizer in both experiments by plotting corn grain yield as a function of either total water (rainfall + irrigation) or total N-fertilizer applied. Although the range in treatment variables suggest that water production functions are more reliable for CP2 (four vs. three water rates for CP1) and that N-fertilizer production functions are more reliable for CP1 (four vs. two N-fertilizer rates For CP2), data from both experiments are discussed. Using spatial statistics and disregarding soil map unit classification, quadratic crop response curves were determined for each of 396 plots in CP2 (Sadler et al., 2000a). From these response curves, maximum yield was determined for each plot (derivative of zero or end point). Irrigation amounts at maximum yield for each plot were then mapped.

In a similar manner, the marginal corn yield benefit to an incremental increase in N fertilizer at the 150% irrigation rate was calculated for both pivots in all years. The marginal yield benefit was determined by dividing the corn yield difference at two N-fertilizer rates by the difference in the N-fertilizer rates. The selected N-fertilizer rates on CP1 were 169 and 225 kg/ha, which correspond to the 75% and 100% rates. On CP2, the rates were 134 kg/ha and 225 kg/ha.. Using current prices for N fertilizer and corn grain, the breakeven point is about 5 kg/ha corn grain per 1 kg/ha of N fertilizer.

Results and Discussion

Crop response to irrigation and N fertilizer. In CP2, the irrigation variable was consistently dominant in all three years, even in best rainfall year. Both linear and quadratic forms of the irrigation effect were significant at the 1% level, and deviation from the quadratic form was not significant in any year. Also, variation among soil map units was significant in all years, at the 1% level in 1999 and 5% level in the latter two years. However, the variation within soil map unit was also significant at the 1% level. These results are more easily visualized in a graphical presentation. For example, corn yield response curves to water for 12 soil map units are shown in Fig. 1, averaged across N treatments. It is obvious from the curves that both the means are different and the ranked order of yields under rainfed (0 IBR) and irrigated conditions is quite different for the soil map units. Similar results were obtained each year but the rank order change was most apparent in the first two years. Response to irrigation, as defined by greatest corn grain yield minus rainfed yield, was quite different across the soil map units. In 1999, responses to irrigation varied from 3.9 to 7.2 Mg/ha for the soil map unit means. Responses in 2000 were similar (2.2 to 8.0 Mg/ha) but were much lower in 2001 (1.3 to 4.0 Mg/ha). Measures of variation from the quadratic curve indicated the best fit in 1999 (r^2 values ranged from 0.39 to 0.99) and 2000, and a much lower goodness of fit in 2001, reflecting the smaller range of yields.

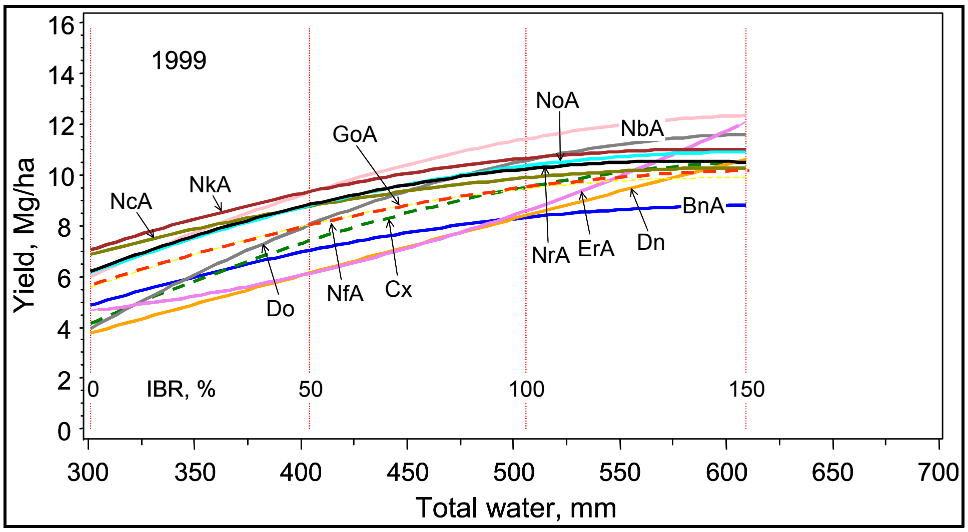

Figure 1. Corn yield response to total water on twelve soils during 1999 under CP2. IBR is irrigation base rate (Sadler et al., 2002b).

While stability of corn response curves would be desirable in order to predict the effect of management, two different types of curves were obtained during this experiment. These can be seen in the mean corn yield response curves for the predominant soil (Norfolk ls, NkA) in all three years (Fig. 2). N treatments were averaged in 1999

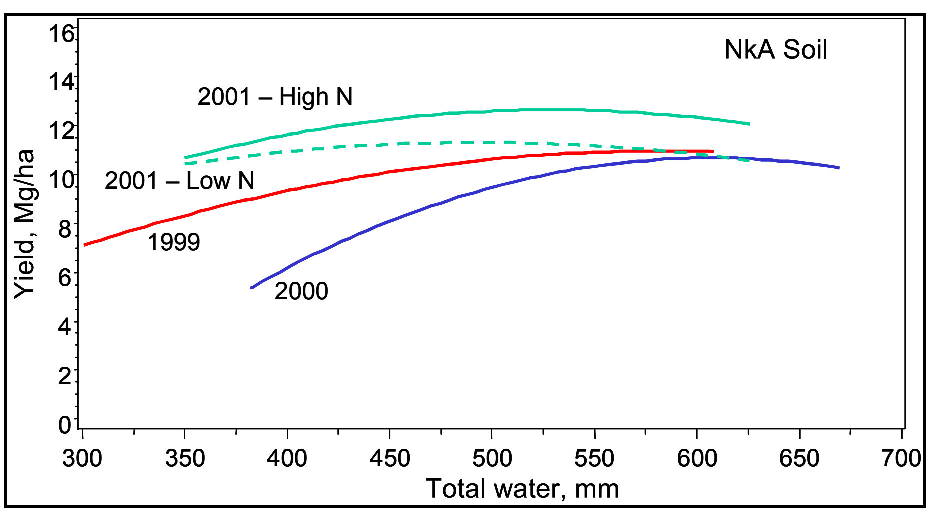

Figure 2. Corn yield response to total water during 1999-2001 for the Norfolk loamy sand (Sadler et al., 2002b).

and 2000 when they were not different. The curves for 1999 and 2000 were similar, rising from a low value with no irrigation to a high, near-plateau value for the greatest irrigation amount. However, in 2001, the corn response for either N treatment was nearly flat across all irrigation treatments. For the NkA soil, r^2 values were 0.73, 0.68, and 0.42 for 1999, 2000, and 2001, respectively.

On CP2 in 2000, the amount of irrigation water that produced the maximum corn yield is shown in Fig. 3. The large areas between 280 and 290 mm indicate that for many locations, a maximum yield (i.e., derivative of equation at zero value) was not obtained within the range of irrigation applied. Extrapolation above the greatest irrigation amount applied (288 mm) is not appropriate. This result is somewhat surprising, especially when the greatest irrigation amount was 150% of normal irrigation. It is also noteworthy that these patterns do not correspond to soil map unit boundaries or any other measured soil property. A similar pattern, but with distinct differences, was obtained in 1999 (See Sadler and Camp, 2002, Fig. 5).

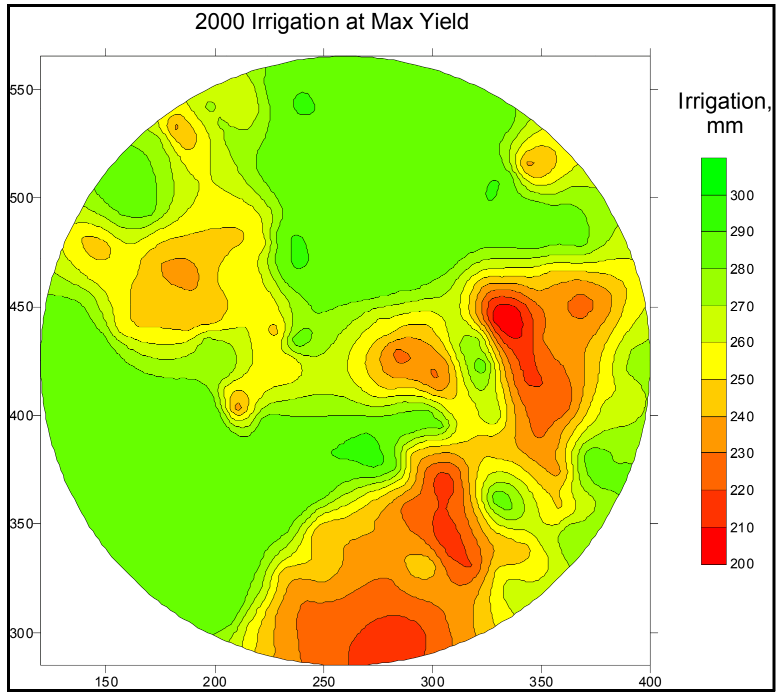

Figure 3. Irrigation amount that produced maximum yield.

Using corn grain yield, irrigation, and N-fertilizer data from the 1999-2001 experiment on CP2, and current prices for water and corn in the south-eastern U. S., Lu et al. (2002) calculated corn production functions for a range of irrigation amounts and two N-fertilizer treatments. All production functions were quadratic in form, were different for each year and for each N-fertilizer treatment, and had r^2 values ranging from 0.51 to 0.65 in 1999 and 2000, and from 0.11 to 0.13 in 2001. They found that profit-maximizing strategies required much less water and produced larger gross margins (total returns minus total variable costs) than yield-maximizing strategies. For example, for the high N-fertilizer rate in 1999, the profit-maximizing strategy required 280 mm of water to produce \$197/ha of gross margins, whereas the yield-maximizing strategy used 351 mm of water to produce only \$173/ha of gross margins. The differences in optimal levels of irrigation water and gross margins between the two strategies become even more significant when the relative water/corn price ratios increase. Finally, they also calculated demand functions and demand elasticities for water, which measures the responsiveness of irrigation water quantity to changes in the price of water. They found that demand for irrigation amount was not very responsive to changes in the price of water at the current price. However, at high water prices, demand for irrigation water became more responsive to changes in water prices.

Corn grain yield responses to N fertilizer for both rainfed and irrigated conditions on CP1 during 1999-2001 are shown in Fig. 4. Irrigated response curves are the means of the two irrigation rates. The linear forms of the N fertilizer effect were significant at the 1% level for both rainfed and irrigated in all years except for irrigated in 1999 (5% level). The quadratic form was also significant for irrigated in 1999 at 5% level and in 2000 at 1%

level. The deviation from quadratic was not significant for any treatment in any year. As with corn response to irrigation, N response curves were different among the three years. Corn response to N fertilizer under irrigation was greatest in 2000, ranging from about 7 Mg/ha to a near-plateau level of about 12 Mg/ha. The response in 2001 was slightly less, ranging from about 8.5 Mg/ha to a maximum of about 12.5 Mg/ha. The response in 1999 was quadratic in form but ranged between 9 and 10 Mg/ha. The low response in 1999 was probably caused, at least in part, by residual soil N from antecedent soybean crops. Corn yields were much lower for rainfed conditions than for irrigated conditions in 1999 and 2000, and increased slightly with N fertilizer, ranging from 5-6 Mg/ha to about 7 Mg/ha. However, in 2001, corn yields for rainfed were similar to those for irrigated because of the favorable rainfall distribution, and sharply increased with N fertilizer, ranging from 7.5 to about 10.5 Mg/ha.

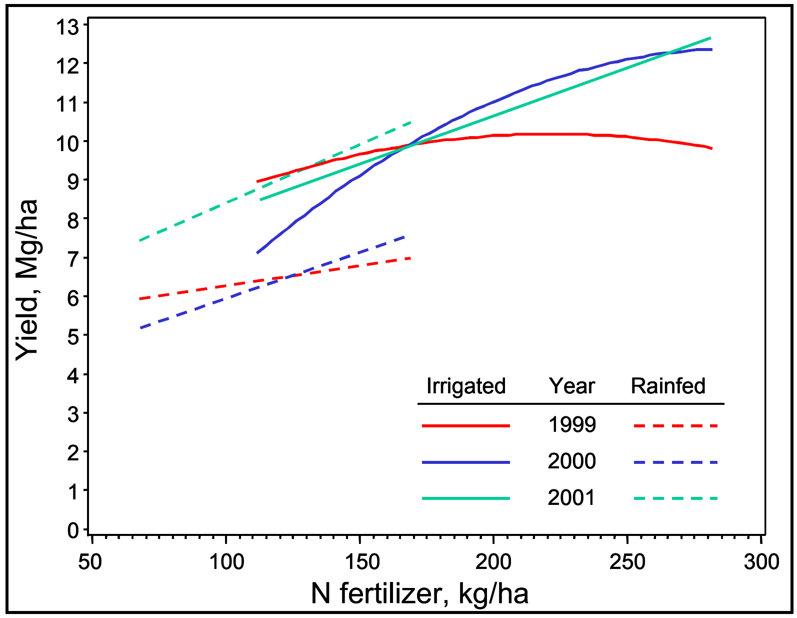

Figure 4. Corn yield response to N fertilizer for both rainfed and irrigated conditions on CP1 during 1999-2001 (Camp et al., 2002).

The marginal corn yield benefit to an incremental increase in N fertilizer at the 150% irrigation rate for CP1 during 2000 and 2001 are shown in graphical form in Figs. 5 and 6. Because the breakeven value is about 5 kg corn/kg N (using current N fertilizer cost and corn grain value), the darker shades of green above that point indicate increasing return while the darker shades of red below that point indicate decreasing return. It is interesting to note that the marginal benefit patterns are distinctly different for the two years and that the

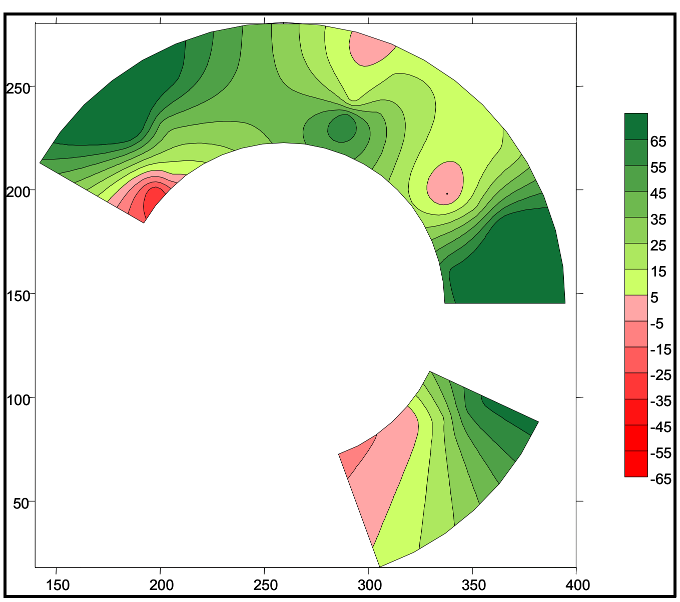

Figure 5. Marginal corn yield benefit from N fertilizer with 150% irrigation on CP1 in 2000 (kg corn/kg N).

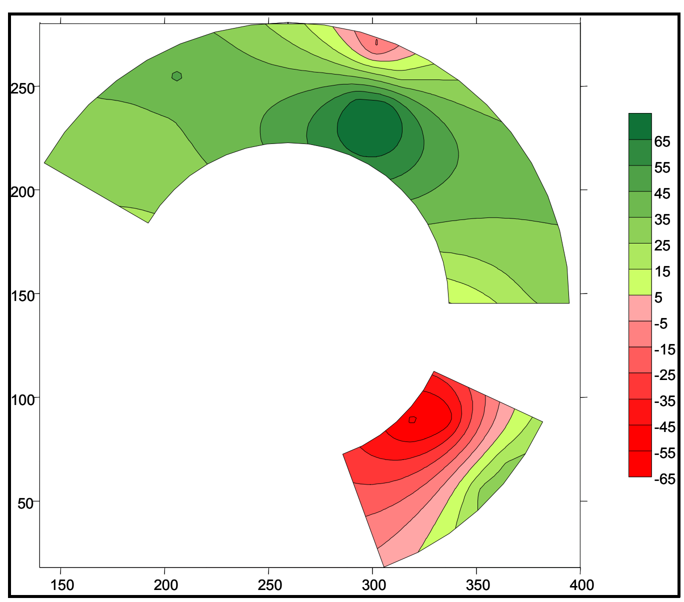

Figure 6. Marginal corn yield benefit from N fertilizer with 150% irrigation on CP1 in 2001 (kg corn/kg N).

patterns do not correspond to soil map unit boundaries or any other known soil property. Since the 150% irrigation treatment was used for this analysis, water should not have been limiting in either year. However, in view of the irrigation deficiency for CP2 discussed previously, it is possible, however remote, that the corn in some portions of this experiment did not receive the optimum amount of water in 2001.

The marginal corn yield benefit to an incremental increase in N fertilizer at the 150% irrigation rate for CP2 during 2000 and 2001 are shown in graphical form in Figs. 7 and 8. The breakeven point and color gradients are the same as in Figs. 5 and 6. In the case of CP2, there were fewer N-fertilizer rates (only two) but many more treatment locations (396 vs. 144), and the entire area within the center pivot was included. Again, the spatial patterns of marginal corn yield benefit were different for the two years although there were some similarities and consistencies, but none of the patterns coincided with any known soil property or map unit boundary. The range of values was less for this experiment than for the experiment on CP1 (-40 to 55 vs. –65 to 65 kg corn/kg N). These results indicate extreme spatial variability in response to N fertilizer, for both relatively uniform (CP1) and variable (CP2) soil map unit classifications.

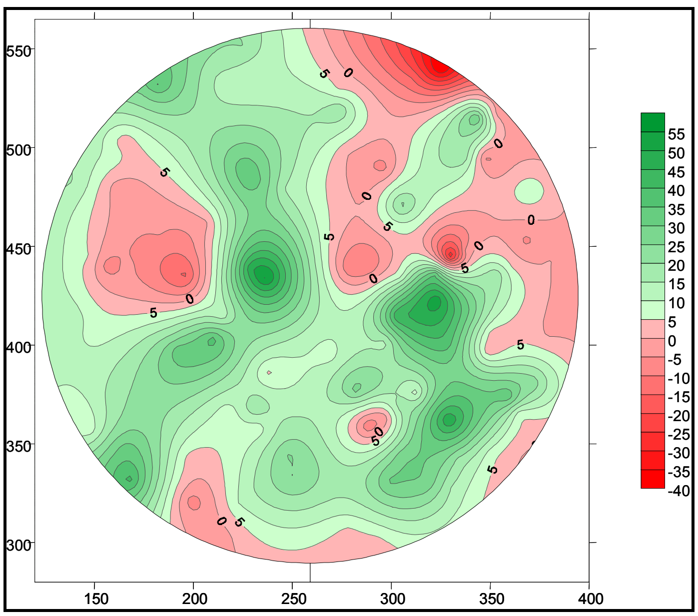

Figure 7. Marginal corn yield benefit to N fertilizer with 150% irrigation on CP2 during 2000 (kg corn/kg N).

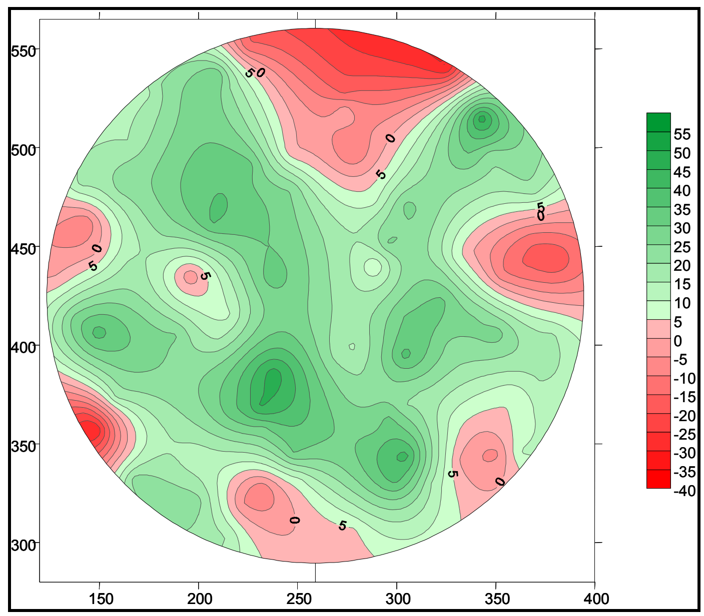

Figure 8. Marginal corn yield benefit to N fertilizer with 150% irrigation on CP2 during 2001 (kg corn/kg N).

Implications for System Design and Management. From the results presented in this and the companion paper, it is obvious that there is considerable spatial variation in corn yield as a result of variable water and N-fertilizer applications as well as other factors. Unfortunately, crop response to these inputs is not constant from year to year, suggesting interactions among the environment, crop, soil, and other factors not yet known. While these results are representative of the southeastern Coastal Plain, spatial variability exists, to a greater or lesser extent, in most all locations. Consequently, site-specific irrigation machines must be designed to accommodate expected conditions.

The first issue to be addressed is determining the management unit size, which is the smallest area within the system to receive independent applications. This depends upon both existing spatial variability and producer preferences. Obviously, the degree and type of spatial variability depend upon the location and region of the

U. S. For example, soil variation may be the greatest source of variation in one location while groundwater recharge zones or obstructions may be the source in other areas. Also, the consequence of improper management can vary from unprofitable management to violation of regulations or statues. Generally, larger areas of similar characteristics can be managed by combining multiple smaller management units.

The range of application rates required within each management unit will also vary considerably with location and region of the country, especially with soil water storage capacity and evaporative demand, e.g. humid vs. arid areas. While current commercial moving irrigation systems have an extensive range of available application rates for water, other considerations such as timeliness of application (total cycle time vs. crop water need) and application efficiency may present constraints. Generally, the range of application rates needed can be addressed by using different sprinkler/nozzle sizes, as it is in current irrigation systems. However, as the management zone size decreases, the selection of acceptable sprinklers/nozzles becomes very limited because of very small wetter diameters, which places a severe constraint on system design. Because variable-rate sprinklers are not yet commercially available, other methods must be used to obtain a range of application rates. To date, three different approaches have been used, including (1) multiple manifolds, each with a different rate and used in various combinations, (2) pulsed water supply to standard sprinkler, with rate depending upon on/off periods, and (3) pulsed variable-orifice sprinkler (rod moving in/out of orifice) to provide application rate of 40 to 100%. For further information on available variable-rate irrigation application see Buchleiter et al. (2000).

Variable-rate applications of chemicals can be accomplished in two different ways. Traditionally, the chemical has been injected into the water supply so that a constant chemical concentration is maintained, and the application rate is determined by the water application. This method is generally acceptable for nutrients such as N fertilizer but is becoming less acceptable for pesticides because of label restrictions and safety concerns. For these chemicals, new commercial application systems are becoming available that have a completely separate supply and delivery system and use the moving irrigation system as a transport device, much like a self-propelled crop sprayer. These systems require less water and can deliver low rates of active ingredient, if needed.

While the design objective in most uniform-rate irrigation systems has been to apply irrigation in the most uniform manner possible, the objective of site-specific irrigation is quite different. Application uniformity is still desired within management units (areas of similar need) but application rates among management units may be quite variable. However, the variable application rates must be predictable and controllable, not random or periodic, and the range must satisfy the crop need for a wide range of conditions.

Once a properly designed site-specific irrigation system is available, it must be managed so that it meets enterprise objectives. Traditional methods for determining the need for irrigation are useful in site-specific management, but the database required will be larger and more complex, and the information must be interpreted differently. The first step is to adopt a management strategy for the enterprise and/or irrigation system. Several options are available, including maximum profit, maximum yield, minimum risk, conserved resources, or limited resource (e.g. water supply, capital). A part of this decision is selection of the crop with considerable attention devoted to the response of the crop to input management. For example, will this crop provide the greatest yield, quality, and/or income increase with the increased water or nutrient input levels for the specific soil, climate, and location? Once these decisions have been made, specific guidelines can be developed for managing these inputs to achieve the management goal. This may require very accurate mechanistic models to augment spatial soil and plant measurements.

The water supply for a variable-rate irrigation system has unique requirements that are often overlooked. The nature of a site-specific irrigation system is such that the water supply flow rate changes continuously, the frequency depending primarily on the severity of spatial variability at the location, unless very sophisticated control algorithms are employed. Generally, the pressurized water supply must be provided by either a variable-flow-rate pump or a group of fixed-flow-rate pumps operated to deliver a range of flow rates. In some cases, water supply volume, flow rate, or quality may be restricted, either temporally or spatially, by either natural, physical, or regulatory means. In all cases, the water supply must be capable of providing the water flow rate during the growing season required to accomplish management objectives and system requirements. Otherwise, alternative or contingency plans must be available.

Summary and Conclusions

Corn crop response functions for variable irrigation and N-fertilizer inputs on southeastern Coastal Plain soils were presented, along with preliminary economic interpretations for the water input. The developed crop response functions varied among the three years making it difficult to select a single function for the crop-location combination. Furthermore, even with 150% normal irrigation in two years, large areas of the irrigation system did not receive adequate water to achieve maximum corn grain yield. These results provide the basis for examination of system design and management considerations for corn in this region. It appears that site-specific irrigation systems must be capable of applying a wide range of irrigation rates, and that the previous irrigation initiation criteria used for these crops and soils probably need to be revised. For maximum economic return, the crop to be grown must be responsive to increased water and nutrient inputs and the enterprise must be managed according to a suitable and sustainable management strategy.

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PRACTICAL UTILITY OF BULK SOIL ELECTRICAL CONDUCTIVITY MAPPING

Hamid J. Farahani and Gerald W. Buchleiter

Abstract

Bulk soil electrical conductivity (EC) measurements are easy and relatively inexpensive to take. A few researchers have investigated the relationship between EC, soil properties, and yield. Even though research results demonstrate a correlation of EC with yield, EC is not a factor that can be managed directly to improve yield. The elusive link necessary to make EC data much more useful to producers, is how to correctly interpret and quantify the various factors affecting EC. A better understanding of the spatial and temporal variability of EC and the relative influence of various soil properties on EC are needed to enhance its utility in site-specific management. Our objective is to summarize the usefulness of EC mapping with examples from our precision agriculture project. We collected EC data from three center-pivot irrigated fields in northeastern Colorado for 1998 to 2002 that were analyzed to identify EC patterns. In these non-saline fields, the patterns in EC maps are highly stable over time and soil EC correlates strongly with texture (clay content), organic matter, and soil water. These findings strengthen the idea of using EC maps to evaluate the potential of EC-based zones for varying agricultural inputs.

Introduction

In-situ bulk soil electrical conductivity (EC) measuring devices provide by far the simplest and least expensive soil variability measurement. Electrical conductivity is a measure of the bulk soil ability to carry electric current, which is mostly dictated by the chemistry of and amount of soil water. Researchers in the field of soil salinity have capitalized on the relationship between EC and soil ionic concentration to infer salinity levels of soils from measurements of EC (Rhoades and Ingvalson, 1971). In non-saline soils, a significant interest is also emerging in using EC to quantify soil spatial variability and develop prescription maps for varying agricultural inputs. The practical utility of EC, however, remains elusive because of the complexity of the interactions between EC and soil physical and chemical properties. For that reason, the ultimate goal of inferring maps of production important soil attributes solely from EC maps may not be fully achieved in the foreseeable future. In spite of that, research has already demonstrated significant utility in using EC to aid producers and consultants evaluate the potential of site-specific management based on the degree of spatial variability reflected in their EC maps. Examples of the most immediate uses of field-scale EC are to: 1) quickly characterize field variability, 2) guide smart (or direct) soil sampling as opposed to grid sampling, and 3) develop potential management zones for variable rate seeding and chemical application.

With the advances in and availability of EC mapping devices, many attempts have been made to infer the relationship of EC and soil attributes. Although results are site-specific and empirical in nature, interesting findings are emerging. Research shows that in the absence of salinity, bulk soil electrical conductivity responds well to soil texture and particularly clay content (Williams and Hoey, 1987; Buchleiter, 2000; Johnson et al., 2001), water content (Sheets and Hendrickx, 1995; Kachanoski el al., 1988), soil organic carbon (Jaynes et al., 1994), and cation exchange capacity (McBride et al., 1990). Since these parameters equally influence field productivity, EC has been found to relate to yield (Sudduth et al., 1995; Lund et al., 1999; Johnson, et al., 2001; Heermann et al., 2002). The fact that EC synthesizes the presence of many soil attributes in a single number that is related to field productivity has prompted some people to delineate EC classes for purposes of management or productivity zone development. In the absence of other complimentary soil information, EC-based management zones prompt the immediate, but mostly unanswered question of “what to manage?” That question is not easily answered and requires careful analysis of the causes of observed variations in EC and yield between delineated zones. Our objective is to summarize some usefulness of EC mapping with examples from our precision agriculture project. For the benefit of the reader, cautionary notes are given regarding the difficulties encountered in classification and interpolation of spatial point data.

Methods and Materials

The study reported herein is part of a larger multi-disciplinary precision farming research study, established in 1997 among a group of USDA-ARS Water Management Research (Fort Collins) and Colorado State University (Fort Collins) scientists on farmer-owned and operated production fields in eastern Colorado. The overall objective of the broader study is to evaluate the technical and economic feasibility of precision farming, by analyzing data from two center pivot irrigated fields near the town of Wiggins, Colorado (called Wiggins1 and Wiggins2) and one near Yuma, Colorado (called Yuma). Fields Wiggins1 and Wiggins2 are 71 and 52 ha and are a few miles apart, with soils including Bijou and Truckton loamy sand and Valentine sand. The Yuma field includes soils Haxtun loamy sand, Albinas loam and Ascalon fine sandy loam. Measurements of bulk soil electrical conductivity were all taken between 1998 and 2002 using the Veris 3100 Soil Mapping System (Veris Technologies, Salina, Kansas). The Veris unit has a total of six coulter electrodes mounted on an implement that is pulled by a pickup truck. It provides simultaneous readings of EC for shallow (0-0.3 m) and deep (0-0.9 m) soil layers. For simplicity, we will use the terms “Shallow” and “Deep” to refer to these readings. A parallel swather (Trimble, Sunnyvale, CA) mounted inside the truck guided parallel passes through the field at 12 to 18 m swath widths with a Trimble GPS unit providing spatial coordinates for each EC measurement.

Results and Discussions

Use of EC to Characterize Field Variability

The quickest representation of the degree of soil variability across a field is given by EC measurements. To create continuous surfaces (i.e., maps) from the EC point data, various geostatistical software and methods are available. Because of the high density of the EC data points per unit area (a few hundred points per hectare), simple interpolation techniques such as Inverse-Distance-Weighting (IDW) have resulted in maps similar to the more elaborate methods of kriging. Figure 1 presents plots of raw EC data and the interpolated surface (using IDW) for Wiggin2. The most obvious observation from these maps is the level of variability in the field as highlighted by different shades for EC ranges. Such maps provide an excellent starting point for producers interested in site-specific management.

For the period 1998 to present, a summary of pre-planting and/or post-harvest EC measurements resulted in mean Shallow EC values of 14.3, 19.0 and 27.5 mS/m (milli Siemen per meter) and Deep EC values of 22.9, 22.7 and 33.3 mS/m for Wiggins1, Wiggins2, and Yuma, respectively. The EC data in these irrigated fields ranged from 5 to 79 mS/m. EC readings of a few hundred mS/m or greater would be required to indicate salinity, a condition not encountered in these fields. The magnitude of the yearly mean EC values were only slightly different even though soil water and temperature, at the least, were most likely different at each measurement day.

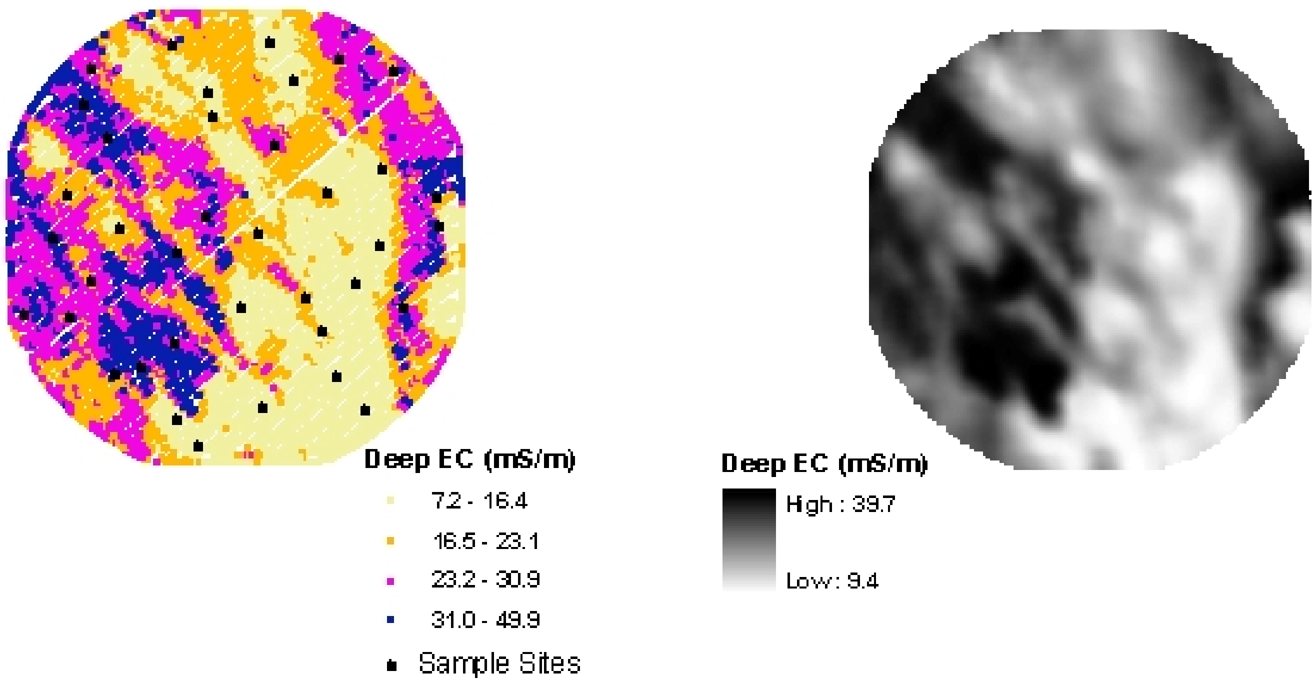

Fig. 1. The 1999 EC measurements (left) and interpolated surface (right) for field Wiggins2.

In regard to the relative behavior of location-specific Shallow versus Deep EC readings, we found a positive correlation between the two with calculated ratios of Shallow to Deep readings mostly below unity. In uniform profiles, higher Deep readings are generally expected to prevail because of mostly higher water content in the soil sub-layer than the top surface layer. In practice and upon repeated mapping, field areas with any observed reversal in the ratio of Shallow to Deep readings or significant changes in EC may warrant closer examination for possible undesirable planting environments and/or unusual accumulation or leaching of chemicals.

In an effort to compare the magnitude of EC data between two seasonal measurements, we placed a 15m by 15m grid surface over the field map and obtained mean EC values for each grid, thus effectively smoothing the data and its directional bias. Figure 2 presents a comparison of the Shallow and Deep readings between 1998 and 2002 measurements in Wiggins1. It is obvious that variability and temporal change are more pronounced in the Shallow (Fig. 2 left) than Deep readings (Fig. 2 right). This is explained by the fact that the surface soil layer is subjected to a more dynamic environment and disturbing agricultural implements than the subsurface soil. The implications are that for purposes of zone development, the Deep EC readings seem to be more stable over time than Shallow readings. For processes that relate to near surface soil properties, such as pesticide binding and bioactivities, delineating zones based on the Shallow readings may be more appropriate while yield and water holding capacity for example may best more appropriately explained by whole profile characteristics or the Deep EC readings.

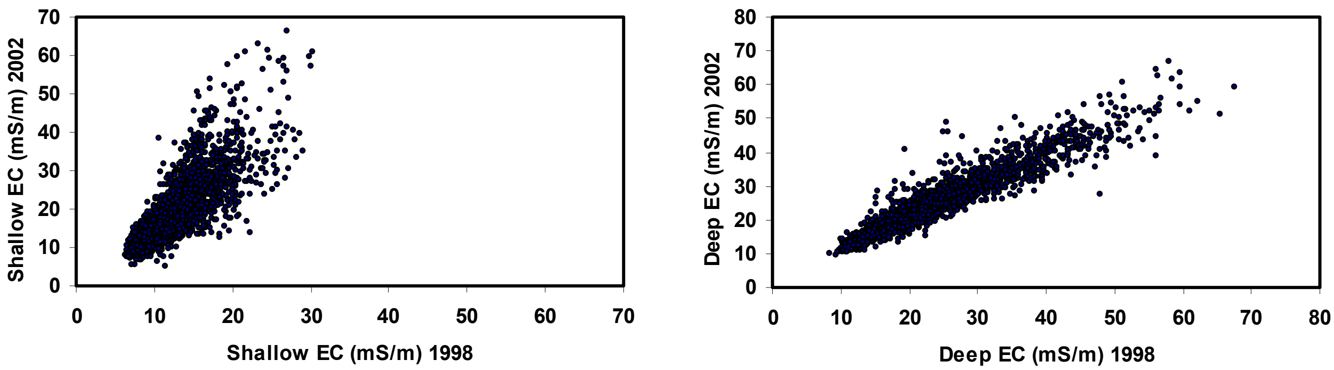

Fig.2. Comparison of Shallow and Deep EC (mean of 15m grid) between 1998 and 2002 readings at Wiggins1.

Use of EC to Guide Smart (or direct) Soil Sampling

A second important use of an EC map is to guide smart (or direct) soil sampling as opposed to grid sampling. With the current lack of knowledge of converting EC maps to soil properties maps, this step of relating the spatial variability of EC to soil properties is essential. In doing so, we used the 1999 EC data and selected a total of 20 to 40 sample sites from each field for purposes of sampling. An example of the selected sampling sites was previously given in Fig. 1 for Wiggins2 where four to six random sample sites were selected from each distinct EC class. Soil profile cores were obtained and analyzed for texture and organic matter.

Results from the soil sampling are summarized in Table 1 along with mean EC values from each field. As given, fields Wiggins1 and Wiggins2 seem to be exceptionally similar in their textural characteristics. The Yuma field is higher in clay and organic matter than the other two fields, a result reflected in its higher Shallow and Deep EC values. For each field, we found a strong correlation between EC and clay and organic matter and water contents. Figure 3 presents percent clay versus Deep EC in the top 0.9 m soil profile for the combined data from all fields, showing a strong coefficient of determination (R^2) of 0.85. That finding indicates that in these non-saline soils, EC is not only a reflection of soil texture, but also independent of field location. The correlation between EC and organic matter and water contents (data not shown) were equally strong. Identifying the characteristics of EC classes enhances the utility of EC maps and will improve understanding of location-specific relationships between EC, yield, and possibly other important properties such as water holding capacity.

Table 1. Mean EC, texture, and organic matter (OM) for two soil depths at the Wiggins and Yuma fields.

	Shallow Soil Profile (0 – 0.3 m)					Deep Soil Profile (0 – 0.9 m)				
	EC	Sand	Silt	Clay	OM	EC	Sand	Silt	Clay	OM
Site	(mS/m)		(%)			(mS/m)		(%)		
Wiggins1	14.3	87	5	7	0.9	22.9	82	8	9	0.8
Wiggins2	19.0	81	10	8	0.9	22.7	82	10	9	0.7
Yuma	27.5	57	29	14	1.6	33.3	54	30	16	1.5

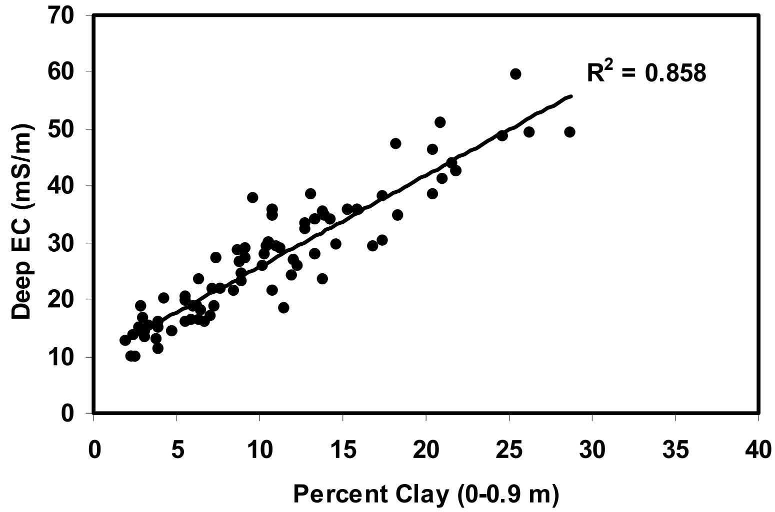

Fig. 3. Deep EC versus percent clay for the 0.9 m soil layer at the three sites in Wiggins and Yuma.

EC Map Creation and Classification (or Zoning)

Generally speaking, EC classification involves more art than science. Various geostatistical packages have been used to create classified maps from a distribution of EC point data, ranging from sophisticated methods such as fuzzy clustering to simple methods such as quantiles. Regardless of the method used, the critical issue is that one must specify the number of desired classes of EC, a priori. In the case of EC data from Veris with two readings per location, the additional difficulty is "which EC layers, Shallow or Deep or a combination of both, are to be used for classification? Depending on the shape of the distribution of data, different methods of classification could yield different patterns and thus classes for the same field. An example is given in Fig. 4 for Wiggins1, in which we used the method of Equal Interval to produce three classes in Fig. 4(left) and used the method of Quantiles to produce similar number of classes in Fig. 4(right). Obviously the two patterns of classes are different. This was caused by the skewed distribution of the EC data at Wiggins1. For a normally distributed data like Yuma, similar class patterns were found regardless of the classification method. The above example cautions against blind classifications without careful examination of data distribution. EC based classes must be soil sampled to quantify the intra-heterogeneity in EC and soil properties of interest. By definition, a class or zone must exhibit the least intra-class and the most between-class heterogeneity.

Temporal Stability of EC and Yield and Their Relationship

While the spatial variability of EC and yield and their relations to soil physical and chemical properties are of significant importance in site-specific management, understanding their temporal variability is equally important. That is particularly true if spatial classes (or zones) developed based on EC, yield, and/or a combination of both are to be used to vary agricultural inputs across the field and over years. Lack of temporal stability in such maps would dictate repeated mappings. Obviously absolute magnitudes of location-specific EC measurements are to exhibit some time-of-measurement dependencies because of the varying transient properties of soil temperature, water content, and ionic concentration. The effects of the stable properties of texture and organic matter on EC maps (or patterns) are, however, expected to remain independent of time. Yield is, however, influenced by more than just soil properties and thus expected to be temporally less stable.

In an effort to determine whether the imposed cultural and cropping practices alter the temporal stability of EC patterns over years, we created maps from EC point data using IDW and employed the method of Natural Breaks (jenks) to produce 3 EC classes for each data set. Although we have conducted quantitative comparison of EC maps for 1998 to 2002 and substantiated that EC maps remain highly stable over time, we rely on a simple visual comparison (see Fig. 5 for Wiggins2) to convey that message of temporal stability. For yield, however, we classified the data into two classes of above and below mean for simplicity. The resulting yield patterns are presented in Fig. 6 for 1997 and 1998 corn harvests. Visual examination of Figs. 5 and 6 reveal that a strong stability is reflected by EC over a span of 4 years while yield patterns failed to hold from one year to the next. The year 1997 was exceptionally wet which apparently removed any effects of varying soil water on yield. Yields for 1999 to 2001 more resemble the 1998 data than the 1997, but the stability in pattern was never as strong as EC. These observations were not surprising as yield is influenced by climatic and management input practices that may not significantly influence EC.

The interesting observation from these figures is the striking similarity between EC and yield patterns in 1998. EC is found to not only reflect the more stable soil properties but also important properties affecting field productivity. While literature reported EC versus yield relationships are promising findings, such relationships are only expected when same soil variables influence both location-specific yield and EC. That condition was apparently met in 1998 but not in 1997 as yield patterns changed. For that reason, EC versus yield relations could exhibit seasonal dependencies. If the 1997 yield map were used for management zone, then those zones would have changed in 1998. This confounds any analysis about the effect of variable management on yield.

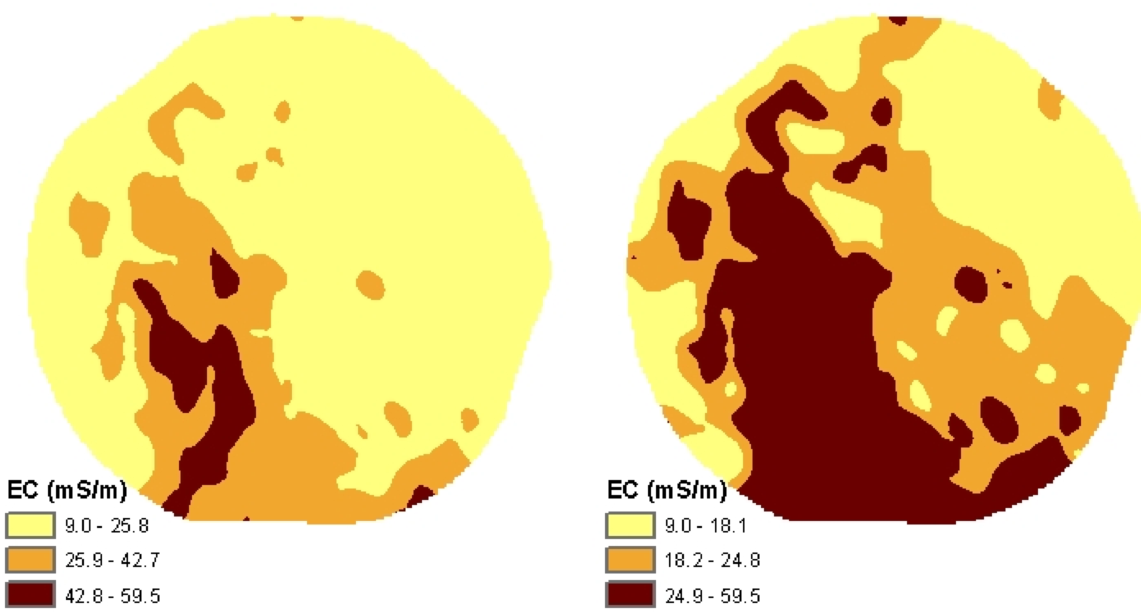

Fig. 4. Maps of EC created using the methods of Equal Intervals (left) and Quantiles (right) for Wiggins1.

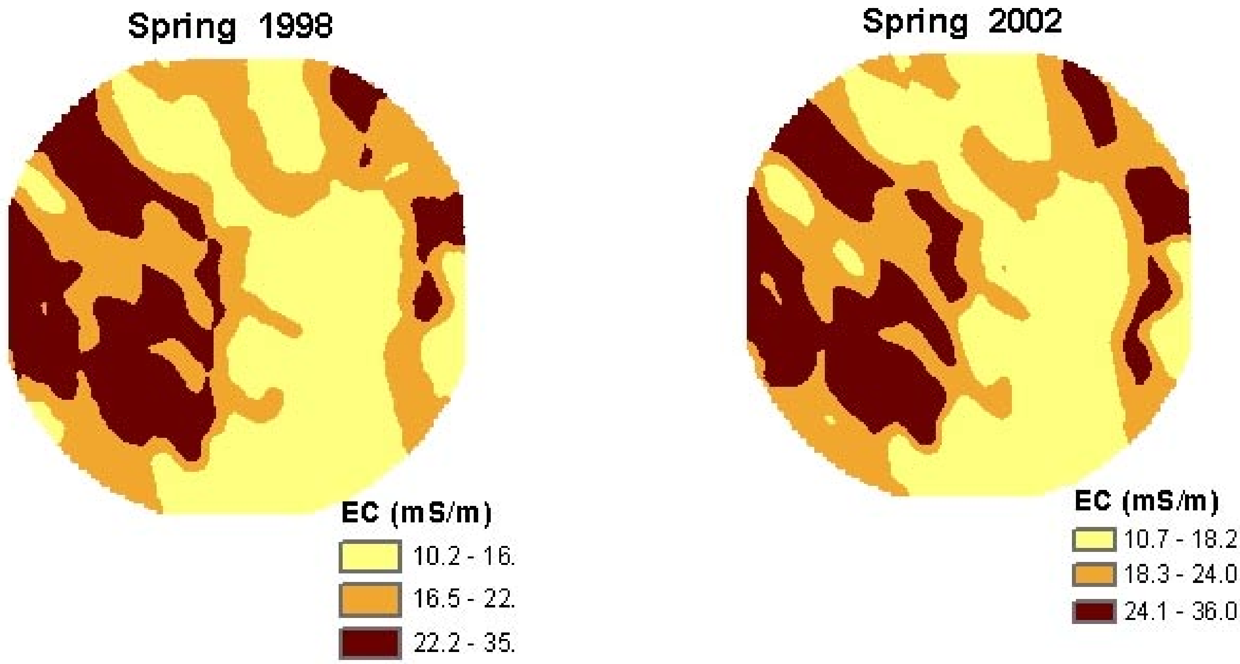

Fig. 5. Maps of EC from Wiggins2 as measured in 1998 (left) and 2002 (right).

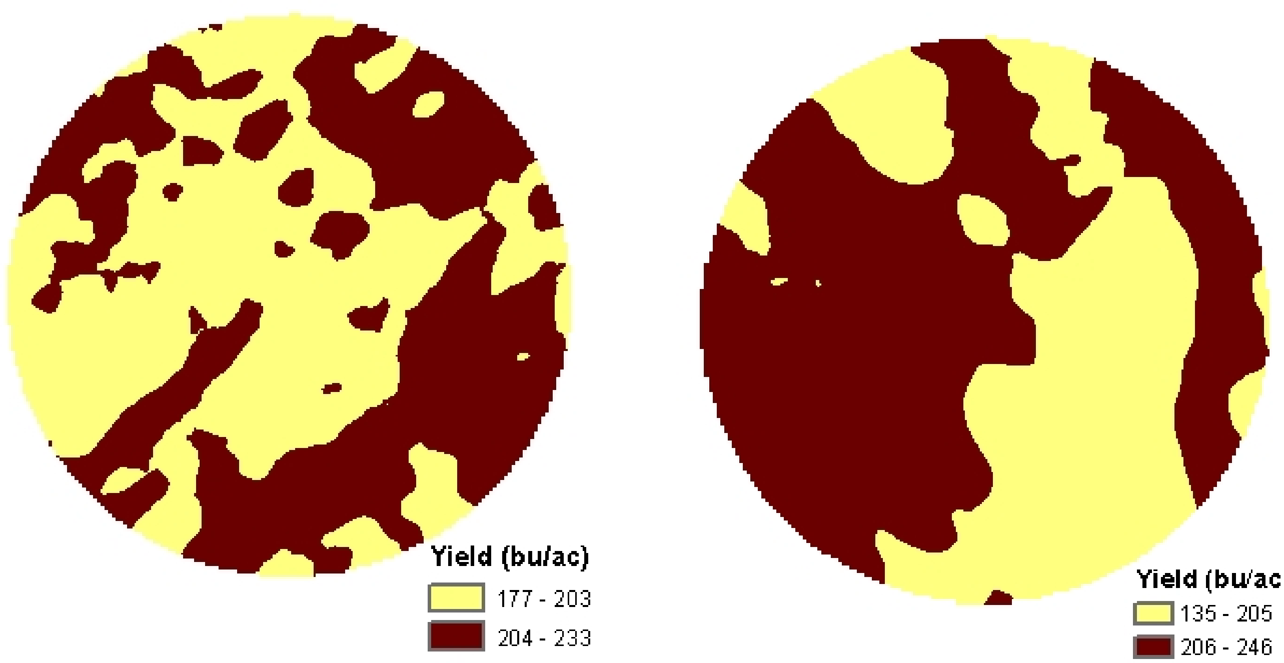

Fig. 6. Maps of yield from Wiggins2 as measured in 1997(left) and 1998 (right).

Summary and Conclusions

The advantages of EC maps over the more costly and labor intensive grid based sampling techniques will be improved significantly once EC maps can be translated to maps of soil attributes that are important in delineating zones of yield potentials, fertility, chemical leaching, and water holding capacity. Yield and EC maps were compared over several years to see if patterns were temporally stable. Results show that in non-saline soils, spatial patterns of EC are reflections of stable soil properties such as clay content and organic matter and thus any measured heterogeneity (or patterns) in EC is expected to remain stable over time. Only significant land modifications (such as leveling) could alter soil stable properties and thus EC patterns. Even though soil water and temperature will most likely differ at different measurement times, these transitory variables are only expected to affect the absolute magnitudes of EC values and not the inherent heterogeneity. Yield is influenced by more than just soil properties and thus found to be temporally less stable.

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Valuable Agricultural Water Saved in Federal Drought Area of Northern California

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and
William A. Johnson, CGCS

Abstract

The Tulelake Irrigation District (TID) is one of 18 districts in the U.S. Bureau of Reclamation Klamath Project which is one of the oldest irrigation projects in the Western United States. The irrigation district supplies valuable agricultural water to otherwise dry but fertile lands in northern California and southern Oregon.

Historically, the TID has faced loss of deliverable water due to high seepage rates in unlined canals and laterals, approaching 50 percent in some cases. This, in addition to the drought conditions here and in other western and southwestern irrigation districts, has prompted the federal government to initiate a program for the selection and installation of low cost, low tech synthetic canal lining systems.

This paper will focus on the selection, cost, installation methods and effectiveness of EPDM rubber canal lining systems as used in the TID emergency seepage control program and as approved by the Federal Government.

Introduction

Historically, one of the major uses for flexible membrane liners or geomembranes has been in the waterproofing of canals and laterals used in water distribution for agricultural irrigation and their use has been documented as early as the 1940's. Early lining systems included bitumen coated burlap and eventually thermoset elastomeric liners such as Butyl Rubber (IR) and Ethylene Propylene Diene Monomer (EPDM). According to Staff (1984), rubber linings were even used prior to the 1930's for the containment of water and Polyvinyl Chloride (PVC) was used in the 1950's. In the 1960's, both thin PVC and Low Density Polyethylene (LDPE) sheeting found their way into lower cost canal lining applications replacing spray applied bitumen, bentonite and thin concrete. However, the thin 0.2 to 0.25 mm (8 to 10 mil) plastic materials were easily damaged during installation and required a minimum of 300 mm (12 in.) of soil cover for protection from UV exposure and mechanical damage.

The agricultural industry in the United States and other countries have historically been faced with the efficient storage and conveyance of water, especially in the arid lands such as the western United States. Government agencies and national committees in many countries were formed to investigate and implement improved canal lining materials. The Department of Agriculture and the U.S. Bureau of Reclamation were pioneers in the development of early research into materials and methods used in the waterproofing of water distribution systems and in the development of specifications and guidelines for the lining of canals (Comer, et.al., 1999).

There are over 26,000 km (16,000 miles) of main canals and over 43,000 km (27,000 miles) of secondary's or laterals in the arid western United States alone (Comer, et.al., 1999). Many of these original water distribution structures were simply excavated in the native soils (or rock) to provide water distribution. The U.S. Bureau of Reclamation began investigating plastic and other "alternative" lining materials for seepage control in the 1940's. to reduce known seepage in many of the canals and laterals under their control. An "alternative" lining material is a material other than conventional concrete or compacted earth linings for use in areas of limited right of way (steep side slopes), northern climates (freeze/thaw) and areas where clay materials were not available. Early work with various canal lining materials is summarized in Bureau of Reclamation (1963), Hickey (1969) and Morrison and Starbuck (1984).

In response to the growing need to reduce seepage and conserve dwindling water supplies in drought areas, the U.S. Bureau of Reclamation has recently completed a canal lining demonstration project where 27 "alternative" canal lining test sections have been constructed. These test sections are being used to assess durability, installation costs, benefit/cost (B/C) ratios, maintenance costs and seepage control effectiveness over severe rocky and highly porous soils. The test sections are predominately located in Oregon, Montana and Oklahoma and are described in Swihart et.al. (1994). Installation of additional test sections and a 7 year durability report was published by Swihart and Haynes (1999) with an updated 10 year report due out in 2002. Based on this and other work, the U.S. Bureau of Reclamation is assisting western irrigation districts in the design and installation of geomembranes for use in saving valuable and increasingly limited agricultural water.

The Tulelake Irrigation District Project

The U.S. Bureau of Reclamation Klamath Project is one of the oldest irrigation projects in the Western United States. As one of the original 18 irrigation districts, the Tulelake Irrigation District (TID) supplies valuable agricultural water to the over 25,500 hectares (63,000 acres) of otherwise dry but fertile lands of the northern California counties of Siskiyou and Modoc as well as Klamath County, Oregon. Irrigation water has always flowed to the approximately 800 farms using a vast network of over 390 km (242 miles) of main canals, laterals and ditches, some of which date back to the turn of the century.

In April, 2001, the U.S. Bureau of Reclamation drastically reduced the flow of irrigation water to the Klamath and Tulelake irrigation districts of northern California and southern Oregon citing environmental considerations in the already drought-affected area. This action caused many farms to go out of business due to lack of irrigation water. The area has been designated a federal drought area eligible for federal aid and funds have been made available for implementing emergency drought relief measures which include the rehabilitation of old earth lined delivery channels.

Historically, the irrigation district has also faced loss of deliverable water due to high seepage rates in unlined canals and laterals of over 30 percent and approaching 50 percent in rocky reaches. The high seepage rates in unlined canals and laterals as well as the drought conditions here and in other irrigation districts, has prompted the federal government to initiate a program for the lining of distribution channels. Part of this program includes the selection and installation of low cost, low tech lining systems that can be 100 percent installed and maintained by the irrigation district personnel without the need for specialized installers or contractors. Materials must be capable of being installed in harsh, rough soil or rocky conditions, resist animal traffic, be repairable by the irrigation district and must be designed for being left exposed in excess of 20 years.

Federal Government Requests Proposals for Lining Systems

In June of 2001, the U.S. Bureau of Reclamation, Mid Pacific Region, issued a Request for Proposals (RFP) to supply a geomembrane system and associated geotextiles (where required) to line the M-2 lateral of the Tulelake Irrigation District from sta 0 + 00 to sta 121 + 92 or approximately 3.7 km (2.3 miles). The request specified an exposed geomembrane system that could be installed, seamed, repaired and maintained by irrigation district personnel. The maximum panel size was limited to 9.14 m x 61 m (30 ft x 200 ft) with a minimum thickness of 1.14 mm (45 mils). The geotextile required for extreme rocky outcroppings was a minimum 340 gm/sq m (10 oz/sq yd) nonwoven protection fabric. The government required that a review panel select the geomembrane system based on the following evaluation criteria:

1. Technical Capability
   a. Ease of Installation (Delivery, Placement, Seaming by TID)
   b. Damage Resistance (During Placement and Operation)
   c. Ease of Repair (Repair by TID over life of the lining)
   d. Expected Life (Manufacturer warranty for exposed conditions)
   e. Seepage control (Effective barrier material)
   f. Descriptive Literature addressing the above

2. Past History and Performance

3. Price

The final selection of a supplier was based primarily on technical merit, installation by TID personnel using their equipment and characteristics of the geomembrane material as well as cost considerations. Thus, the lowest bid price was not the principal determining factor in the final selection of the system.

The canal section to be lined was an original earth-lined canal built in 1942 with some rocky reaches and known high seepage loss in excess of 30 percent. The original section and right of way necessitated use of an exposed geomembrane material due to excessively steep slopes (no soil cover could be placed due to stability considerations). Technical characteristics included the following:

Q = 2 cms (72 cfs)
V = 0.4 m/s (1.32 fps)
D = 1.22 m (4.0 ft)
S = .00015

Side slopes were an average of 1.5H : 1V and base width varied between 1.8 m and 2.4 m (6 - 8 ft). Total width of the section including flat runout anchors at top of slope was 9.14 m (30 ft). Thus, geomembrane panels delivered to the site were required to have a 9.14 m (30 ft) width with no longitudinal seams. Seaming in the field was to be at panel ends only and across the width of the canal section with no horizontal seams on slopes or longitudinal seams on the invert of the canal.

EPDM Chosen for Superior Technical Characteristics and Low Cost

The U.S. Bureau of Reclamation, Mid Pacific Region awarded the project to a material supplier of 1.14 mm (45 mil) thick Ethylene-Propylene-Diene-Monomer (EPDM) rubber geomembrane based on the above technical evaluation factors and low cost. EPDM geomembranes have been in use worldwide for over 40 years in a wide variety of containment applications including large and small irrigation canals. Most recently, EPDM was chosen for the Ochoco and Talent Irrigation Districts in Oregon to line canal sections with extreme water seepage. Both of these projects utilized the irrigation district crews for soils preparation, EPDM installation, seaming and connections to structures.

EPDM rubber geomembranes are considered a superior choice for use in the rehabilitation of old canals and laterals of western irrigation districts for the following reasons:

- Minimal preparation of the channel section using district equipment and personnel
- User friendly ease of panel installation with district equipment and personnel
- User friendly low tech seaming and repair methods by district personnel
- Mechanical properties to resist installation and operation stress in an exposed environment (puncture/impact resistance, working strain to over 500 percent)
- Attachment to concrete and steel structures (gates, turnouts, pipes, etc.) using special waterproof adhesive systems
- Lay flat (soil friction and unit weight) characteristics to resist wind uplift/displacement
- High UV and weathering resistance backed by decades of exposed installations
- Repair and maintenance by irrigation district using simple low tech seaming techniques and repair kits
- Custom panel sizes for differing channel sections
- Installation and seaming in cold winter weather conditions (usually off-season October to March)
- Resistant to animal traffic including deer and elk in remote areas

EPDM Geomembrane Placement by the Tulelake Irrigation District

EPDM factory panels were manufactured and custom-sized for the TID by Firestone Building Products Company. The panels were sized to 9.14 m (30 ft.) in width by 61 m (200 ft.) in length, folded along the length and then rolled for delivery and handling on site. Once the rolls of panels were delivered to the site, the TID deployed the panels using their own equipment and 8 person crew. District personnel fabricated a custom lifting bar which was suspended by cable from the bucket of an XL4100 Gradall. The rolls of EPDM were lifted from a flatbed truck, positioned in the channel bottom and unrolled along the channel by advancing the XL4100 Gradall along the channel access road.

Once the panels were unrolled and unfolded up the side slopes, they were positioned and placed into the anchor benches on both sides of the channel section. The ends of the panels were then overlapped a minimum of 150 mm (6 in.) and the overlap area was cleaned and primed with Firestone QuickPrime Plus. The overlap area was then tacked without wrinkles and Firestone QuickSeam tape, an adhesive tape seam system, was applied by the TID crew. The field fabricated seams were composed of prefabricated 150 mm (6 in.) wide rolls of partially vulcanized Firestone cover strips with adhesive backing. Once the strip was placed and centered on the overlap, it was pressed down onto the two adjacent panels with constant hand roller pressure to ensure complete adhesion. Advantages of using the patented tape seam system include the following:

- Designed for remote areas and can be installed in cold temperatures.
- No specialized welding equipment, hot air guns or supporting electric generator equipment is required.
- Components are simple and can be stored at irrigation district shops for future use.
- Seaming requires no specialized training (TID crew received 15 minutes of instruction).
- Resultant seam is a continuous 75 mm (3 in.) bond to panel edge with high peel and shear strength. Seam area will resist movement under load to over 300 percent strain without affecting the waterproof integrity.
- The same seam methods are used for repair patches by TID maintenance crews.

During the placement of panels, it was noted that the EPDM sheet material was not susceptible to wind uplift even by high winds which are a frequent occurance at this site. The EPDM rubber sheet conforms readily to the subgrade, lays flat and adheres to the soil due to surface friction, unit weight and flexibility (conformance to subgrade).

Once the panels were in place and seamed, the TID crew placed soil cover on the anchor benches and compacted the material at top of slope with dozer or motor grader wheel loading. It was noted that during soil placement and grading on the top of the channel that some large angular rocks in excess of 34 kg (75 lbs) were displaced and rolled down the EPDM slopes. No puncture damage or marks were noted on the EPDM due to rock fall. Although there is no requirement for soil cover on the bottom of the channel, sediment, upper slope soils and wind blown soils will accumulate over time providing a deposited soil cover.

Summary

The TID successfully installed an exposed EPDM geomembrane system using custom manufactured panels, TID personnel for installation and seaming and TID equipment for the soils preparation and backfilling. The combination of low cost and user friendly materials that can be installed by irrigation district personnel with minimal training and no specialized equipment is an outstanding low cost alternative to other systems.

The installed cost of the exposed EPDM system at Tulelake was approximately $0.40 per square foot including preparation of the channel section, material and installation/seaming. As a comparison, the U.S. Bureau of Reclamation estimates of installed costs for lining systems range from a low of $0.76 to a high of $4.33 per square foot (Swihart et.al., 2000).

Since the initial installation and success through the first irrigation season, the TID has purchased additional EPDM panels for installation in 2.2 km (1.3 miles) of additional channel rehabilitation starting in October of 2002.

The TID is typical of many irrigation districts in the western United States where conveyance channels are unlined with many losing between 30 and 50 percent of the deliverable water to seepage during the irrigation season (April - October). With water costs increasing and available water in short supply (especially during dry years or federally mandated allocation restrictions), irrigation canals and laterals are being evaluated for lining with exposed geomembrane systems. There are over 26,000 km (16,000 miles) of main canals and over 43,500 km (27,000 miles) of laterals in the western United States alone. Of these, only approximately 15 percent are lined. Although all reaches of canals or laterals do not need lining, the potential of those that will need lining to save valuable irrigation water is indeed large.

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Experiences with the UGA EASY Evaporation Pan for Irrigation of Cotton Grown in Midsouth Clay Soils

by

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Introduction

A novel, yet simple, device was developed by Thomas et al. (2002) to provide farmers with a visible indication of evaporation, which can be related to crop water use. The UGA EASY evaporation pan consists of a washtub with a float connected to an adjustable rod that is hinged to allow it to swivel (figure 1). The rod is connected to a pointer, which indicates crop water status against a back plate that can be seen from the road. The back plate has a black line that indicates field capacity and a red line that signals to the observer when to irrigate. The rod can be adjusted back and forth according to soil/crop combination and period of the season. For example, high frequency irrigation in sand might require high sensitivity (the rod with a shorter travel), while lower frequency irrigation in clay soils might require the rod to be extended. This study presents preliminary data on our experiences using the UGA EASY Pan irrigation scheduler for cotton grown in a Sharkey clay soil. Soil-water potential was monitored simultaneously at three depths to provide some indication (other than visual) of crop water stress and give an idea of the zone of root activity.

Procedures

The EASY Pan was installed in a grass lane between two semicircular field sections (hereafter called field 13) planted in cotton and irrigated by a single-tower center pivot. This location provided easy access and good visibility. The predominant soil was Sharkey clay, which had been subsoiled with a Paratill subsoiler the previous fall. Watermark Model 200SS soil water sensors were installed at 9, 18, and 27 inches depths, in four quadrants of the field. Sensors were read periodically in the morning using the Watermark 30 KTCD-NL meter. Soil temperatures at the 12-inch depth were measured using a thermocouple at the end of a long probe. These readings were used to compensate Watermark readings at all depths for temperature, using equations modified from those presented in Thomson and Armstrong (1987) for the Watermark Model 200 sensor. Insects and weeds were controlled using standard practices and the crop was irrigated according to the field manager's best "guess" and observation of the crop. Thus, the EASY Pan was simply monitored and used as a passive device.

Results

Figure 2 illustrates the seasonal trend of evaporation and water replenishment as registered by the EASY pan, retrofitted with a numbered gauge. The black line of the pan's back plate corresponded to a gauge reading of 4, and the red line (signal to irrigate) corresponded to a reading of 0.5. Differences in a scale reading had an approximate 1:1 relationship with differences in pan water level, at the rod's fully extended position.

In no case did the pan signal for irrigation, although the crop's visual condition clearly indicated a need for water before some rainfall or irrigation events. As indicated, travel on the float rod was set to fully extended position, to accommodate lower frequency irrigation customary for crops grown in clay soils. A simple adjustment of the float rod for shorter travel would have allowed pan readings to more closely match water requirements. For the pan we used, the indicator would also need to be offset downward, as all readings were above the range of field capacity and irrigation. In our case, a reading of 6.3 corresponded to saturated conditions, which was past the black line (scale reading of 4).

Cotton growth in field 13 has always lagged behind cotton grown in other fields, even with subsoiling. We have found that more frequent water application is usually necessary in this field to replenish a shallow rooted crop. Another cotton field (hereafter called field 4), planted in Tunica Clay was monitored simultaneously with another EASY pan. This field was furrow-irrigated, so water was not added to the pan by irrigation. Soil conditions in this field are very good for cotton growth, and soil moisture sensors indicated strong uptake deep in the root zone (data not shown). Spot checks on pan readings indicated that a slightly shorter travel of the float rod might still have been needed to indicate irrigation for this field, although visible stress was never observed before an irrigation or rain event.

Figures 3 and 4 indicate corresponding soil moisture readings during the season for our field. Two stations (Stations 9 and 10) were chosen to illustrate differences. The figures illustrate strong uptake in the shallow zone, but little uptake in the 18-inch zone until late in the season. By contrast, strong water uptake was observed deep in the root zone (down to 24 inches) in field 4 (data not shown). Differences between sensor readings at the two stations illustrate variability in vigor, soil differences, and probable proximity of sensors to active roots.

Interesting sensor trends can be seen in figure 5. Plots of soil water tension from the 9-inch depth showed an expected correlation with water uptake as registered by the EASY pan across dates, past July 2, 2002 (day 183). However, there is a distinct dividing line between sensor data before and after day 183. The cotton was beginning to show visible stress early in the season, but readings from the 9-inch sensors did not climb to values one might expect, or values observed at sensor stations in other experimental cotton fields. Soils were cracking around the sensors in field 13, possibly reducing contact and keeping readings depressed. A very heavy rain of 4.5 inches occurred for two days before day 183 and we suspect that this caused the soil to swell around the sensors, re-establishing good soil-sensor contact. This is evidenced by higher sensor readings and definable trends after day 183 (figure 5).

Conclusions and Observations

The EASY pan can be a good scheduling tool for crops grown in clay soils. We feel there is ample adjustment of the float rod for irrigation of crops grown in clay soils. We did notice some lack of consistency and quality control in construction of the pans, however. Two EASY pans were ordered at different times, and we noticed that lines on the back plate corresponded to different points of vertical travel for the float rod. For example, both pans could be filled to overflow and the pointers would rest at different points relative to the two lines. In our case, neither pointer rested close to the black line. The pointer could be bent to indicate properly, but a better method is needed. Thomas et al. (2002) suggested using a slotted and moveable back plate to allow shifting the two lines for proper alignment. An extension of this idea might be to allow both lines to be moveable independently by taping them to strips of metal and pivoting them at the bottom of the plate. Although the float rod can be moved to adjust the device's sensitivity, the ability to move each line might be an added convenience for practical use. Whatever modifications are chosen, simplicity of design and use should always be kept in mind.

As has been stated, we used the EASY pan as a passive instrument this year, and did not use it to schedule irrigation. Observed trends with both the EASY Pan and Watermark soil moisture sensors indicated how we might use this pan to modify irrigation schedules in the future. Although better guidelines for irrigation of cotton need to be developed, we have been irrigating to replenish 1.5 to 2 inches on all cotton fields during periods of high water use. Looking at sensor readings and observing the crop, it appears that another irrigation may have been warranted between day 196 (July 15) and day 205 (July 24) for field 13. The crop was showing signs of visible stress for three days before the 2-inch rain came before day 205. It was clear that each soil environment/crop combination had a different characteristic, as the cotton in field 4 showed no signs of visible stress before irrigation.

The pan could be used for furrow irrigation, but an estimate of water applied would have to be made so the proper amount could be added to the pan. The amount applied can only be estimated based on flowrate and duration of application, but this may be sufficient. Responses to wetting from soil water sensors may be used to judge uniformity of water application using furrow irrigation.

Disclaimer

Mention of a trade name, proprietary product, or specific equipment does not constitute a guarantee or warranty by the U.S. Department of Agriculture and does not imply approval of the product to the exclusion of others that may be available.

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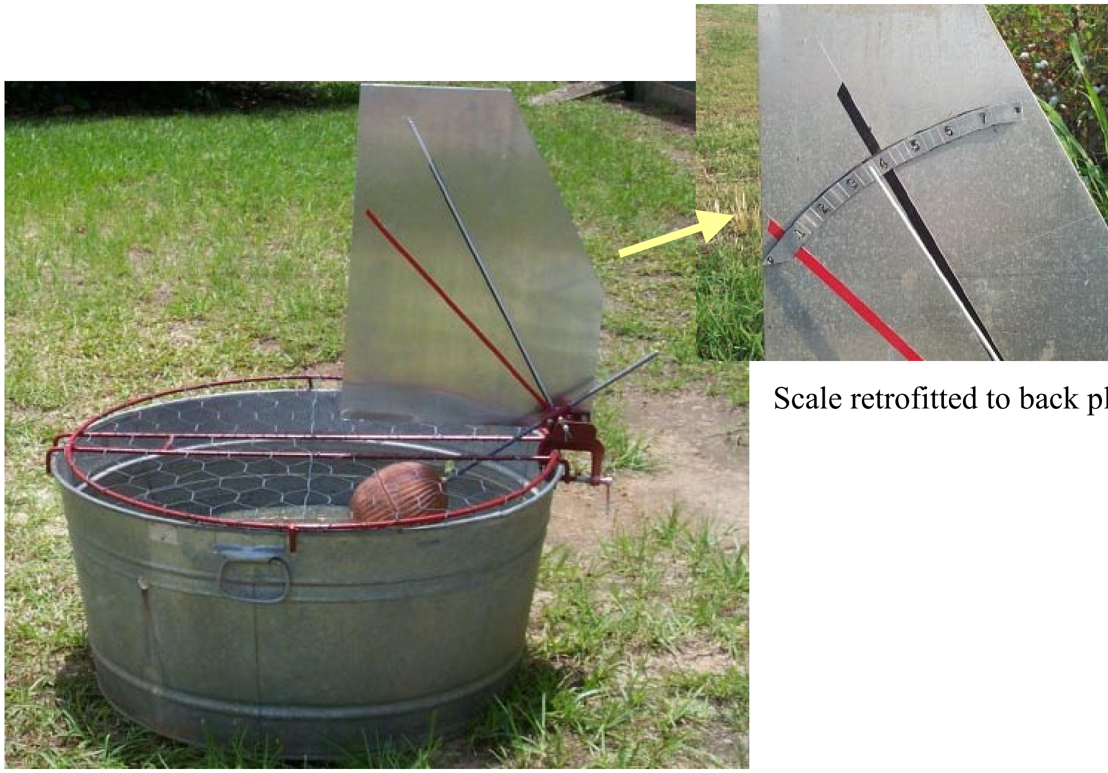


Figure 1. UGA EASY pan irrigation scheduler (from Harrison and Thomas, 2001)

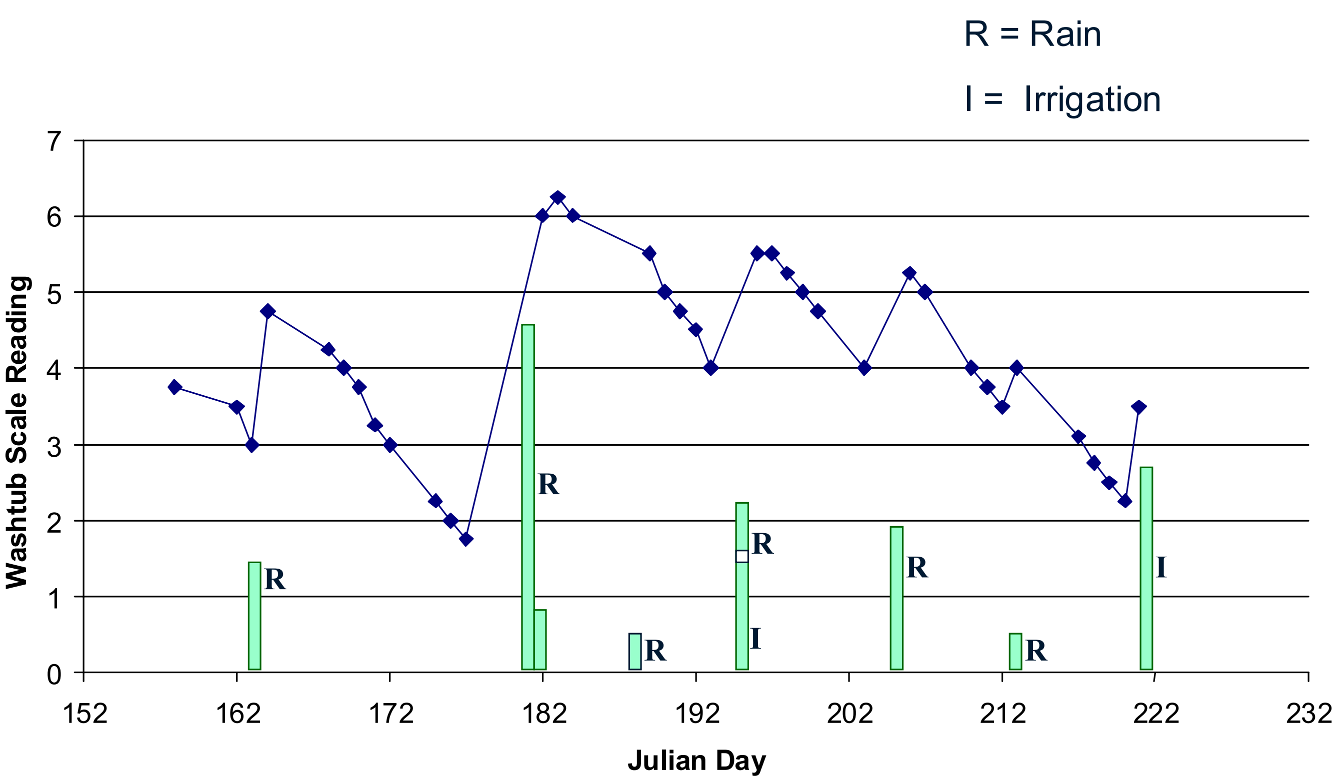


Figure 2. Plot of scale readings from the EASY pan showing rain and irrigation events. Y-axis represents washtub scale reading or inches applied by irrigation or rainfall

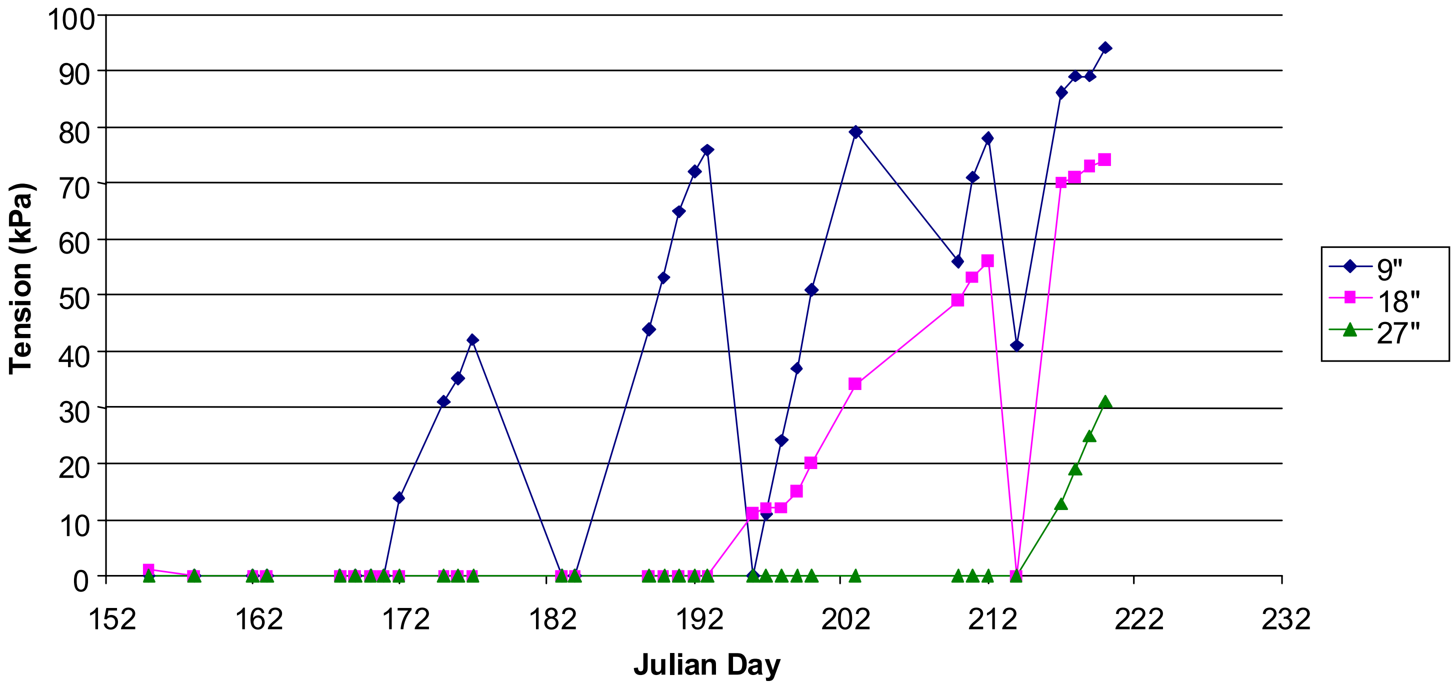


Figure 3. Watermark sensor readings (Station 10)

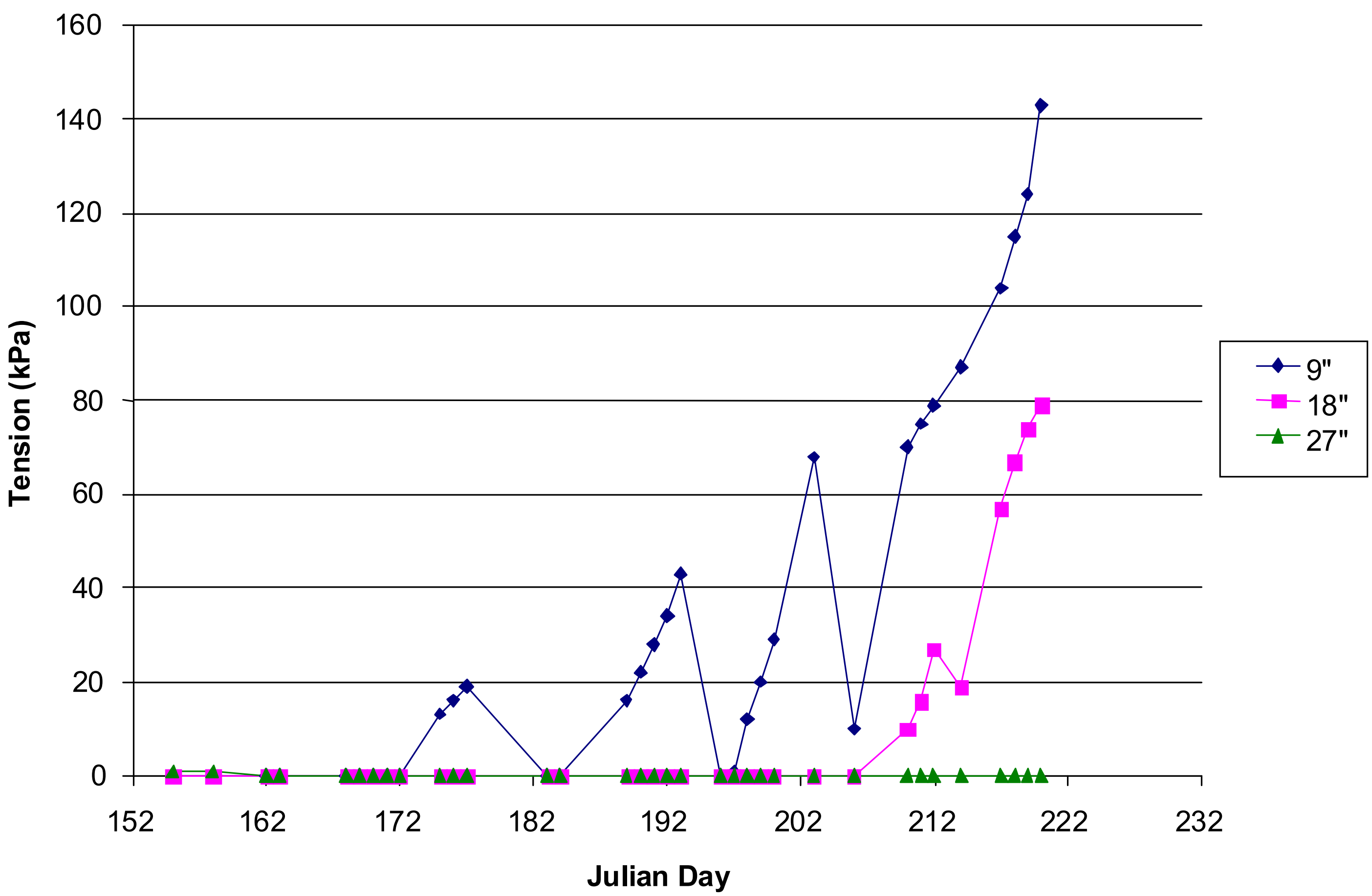


Figure 4. Watermark sensor readings (Station 9)

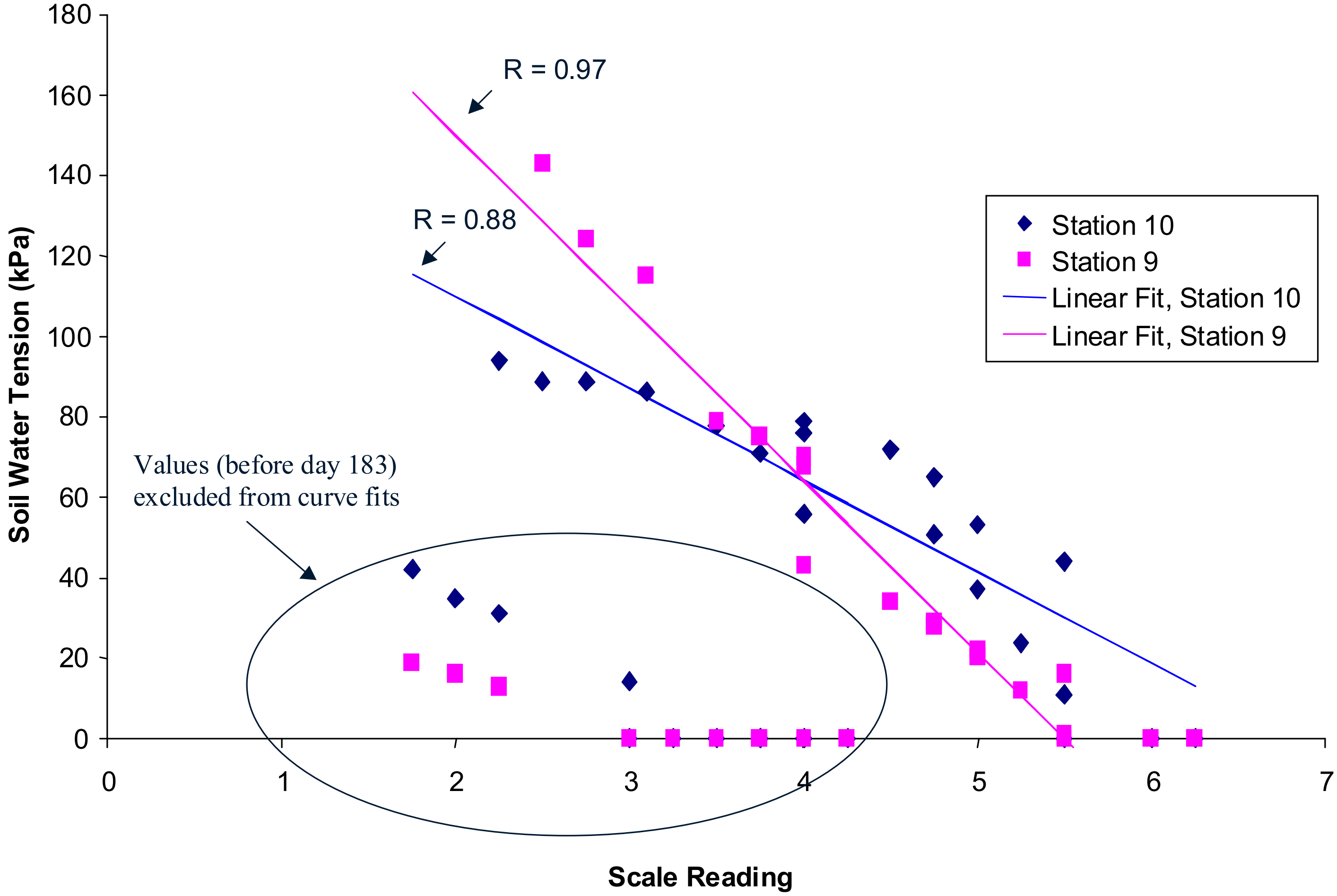


Figure 5. Scale readings from EASY pan vs. Watermark sensor readings.

Software Programs Currently Available for Irrigation Scheduling

Joe Henggeler, University of Missouri

I. Irrigation Scheduling Programs (Real-Time Weather)

1.-- The ***Michiana Irrigation Scheduler*** program is available free from the Internet. It schedules irrigation for a variety of crops. Some of the notable features are as follows. Based on the Stress Day Index concept, one is able to view estimated final yield throughout the season (yields are reduced from an inputted maximum yield value) as the soil becomes too dry. The associated soil moisture status (status can go saturated) is presented both numerically and graphically, through quantities of "+" or "-". Historical weather sets for various latitudes of Michigan and Indiana are included. Real weather (only maximum and minimum temperature) is compared to averages to show deviation from norm. Software is compact (562 K), but does a good job and is easy to use. One toggles between the two main input screens "Field, Crop & Soil Data" and "Weather & Irrigation Data" (Fig. 1.1) to input the data. Hitting the "CALC" button allows the program to calculate and present data. One problem is that summary data (total deficit, days until 1-in of deficit occurs, current ET_c) is only visible for a single date (which was chosen back on the input screens).

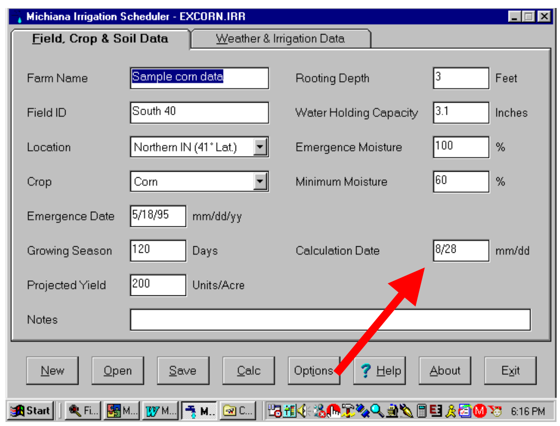


Fig. 1.1 - The main menu page for the *Michiana Scheduler*, tabbed over to show "Field, Crop & Soil Data" side. The date shown on this page (red arrow) will have its summary data shown; the program will forecast 7 days beyond this point.

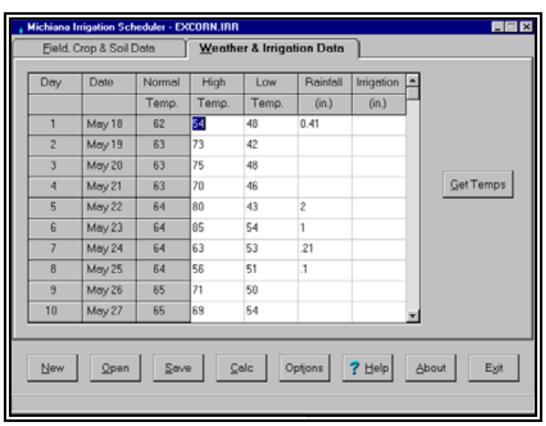


Fig. 1.2 - The "Weather & Irrigation Data" side of the main menu page for the *Michiana Scheduler*. High & low temps are shown; historic is used until actual data is supplied. "Options" selection will give user the choice of using average, rather then max/min temperature. One can get weather data from another file by using "Get Temps."

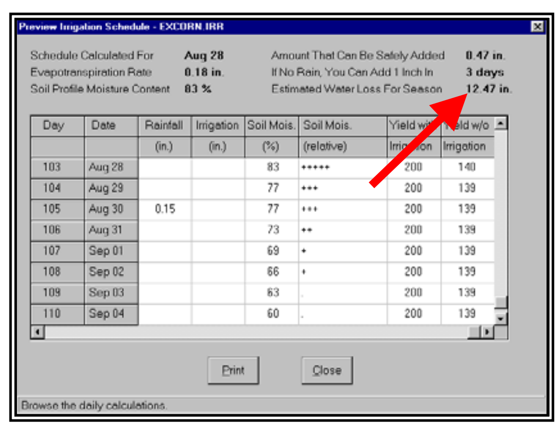


Fig. 1.3 - The page showing resulting data (after choosing "Calc" from main menu page). All the data at the top of the mast is just for the single date previously chosen on the main menu. The *Michiana Scheduler* is predicting final yield to be 139 bu/acre based on the seasonal stress endured by the crop. Note it also provides estimates of water loss to deep percolation (red arrow); this might be a useable tool to make fertigation decisions with . Not shown in the figure is the deviation from historic daily temperatures.

2.-- The ***Arkansas Scheduler*** is a computer program that has been around since 1980. It is developed and strongly supported by the University of Arkansas. The University's innovated ***Verification Program*** is partially responsible for its widespread use in Arkansas and other states in the mid-South. The Verification Program is a pseudo-consulting effort by the University, in which only a couple of producers per commodity (corn, soybeans, rice, and wheat) in a county are chosen to be worked with. These producers provide a field to follow University BMPs and a check field. The yield results are outstanding. Participants point to weed control and irrigation as the two areas they alter the most. One of the BMPs for irrigation is using the ***Arkansas Scheduler***. Thus the impact of irrigation scheduling over a significant number of years and a large number of locations can be seen. One of the most controversial aspects of using the ***Arkansas Scheduler*** regards whether to irrigate on the date it calls for if a rain is forecast. The university-endorsed protocol is to irrigate anyway, as many showers never materialize. The advice appears to be beneficial, as growers in the program continue to experience good yields. The program is free from the Internet. The day to day use of it is fairly easy, but many growers have a hard time getting the files initially set up, which is done by choosing option 4 "Alter or Initialize Irrigation File" in the main menu, which is shown in Figure 2.1.

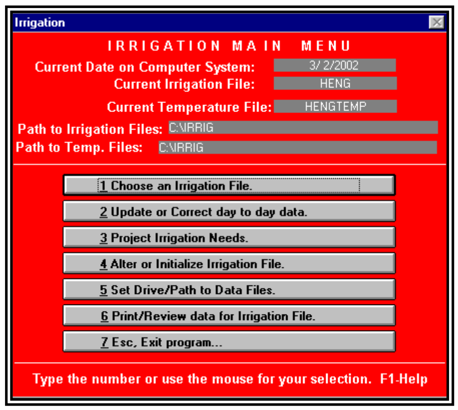


Fig 2.1 - The main menu for the *Arkansas Scheduler*.

The set up takes place in the menu shown in Figure 2.2. One of the greatest innovations in the ***Arkansas Scheduler*** is that it suggests the <u>irrigation deficit</u> based on crop and soil, and to a degree, irrigation method. The suggested deficit values will appear in a pop-up text box when the user is in the "Start Irrig. Deficit" column (Fig. 2.2). Thus, users does not have to toy with crop rooting depths, soil water holding capacities, and MADs. The suggested deficits have been empirically derived. Growers, however, can alter these deficits if they desire to. Once the original set-up data is saved and stored, one does not need to deal with this screen again. From the main menu, choose option 2 "Update or Correct day to day data" to input weather data (only max temperature is needed) and irrigation and rainfall amounts. Choice 3, "Project Irrigation Needs", will go through several screens that show current moisture status (Fig. 2.3) and project when to irrigate.

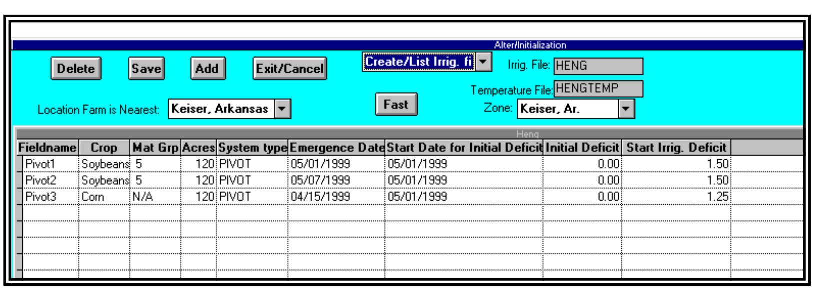


Fig. 2.2 - The set up page for *Arkansas Scheduler*. Up to 16 separate fields can be set up. The irrigation deficit values at which to trigger watering are suggested as BMPs. The starting moisture condition can occur before, on, or after actual emergence date of the crop. The program suggests using an ample rainfall event sometime around emergence as a starting point, in which case the deficit is known to be 0.0 inches.

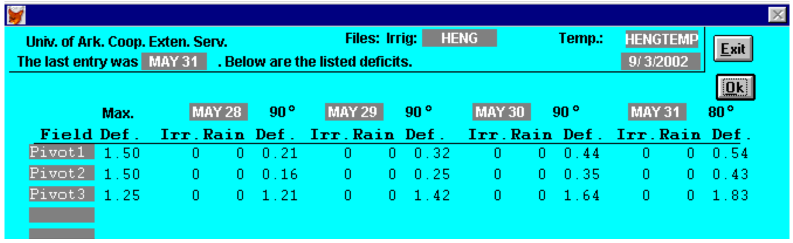


Fig. 2.3 - Recent moisture status conditions is shown.

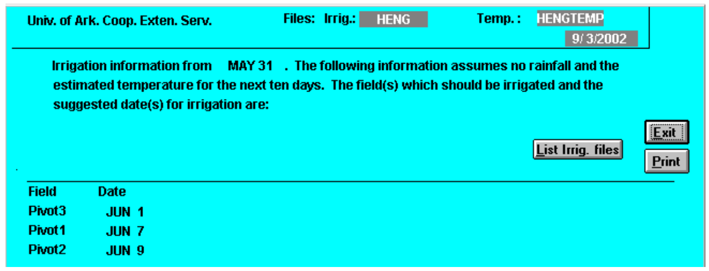


Fig. 2.4 - Final viewed page lists the fields that need to be irrigated and the dates on which to apply the irrigation. Clearly delineating the date irrigation will occur ahead of time is an important aspect of any good irrigation scheduling program.

3.-- The ***KanSched*** program began life as ***Kiscorn,*** a spreadsheet scheduling program. Kansas State University developed the program. It is very nice looking, which, it is felt, has aided in grower adoption. The program does not use raw weather data, but instead needs ET_o or ET_r data. Kansas has a network of weather stations and ET is available on the Internet. Unfortunately, these data must be hand input at this time. The program's main operations work out of a single page (Fig 3.1) that makes things handy. It displays soil moisture deficit when clicking on "Soil Water Chart". However, the required 16 data input fields are too cumbersome, and seek information that most farmers would not have readily available (e.g., four separate dates regarding maturity stage of the crop [including the date when canopy covers 70-80% of the field]). Fortunately, a help screen is available in which you merely choose season length (and with the already-inputted emergence date) which then provides best estimates for the four required dates. A help screen is also available that will allow one to choose one of the eleven major soil textural groups, rather then having to input what the Permanent Wilting Point and soil available water holding capacity values are.

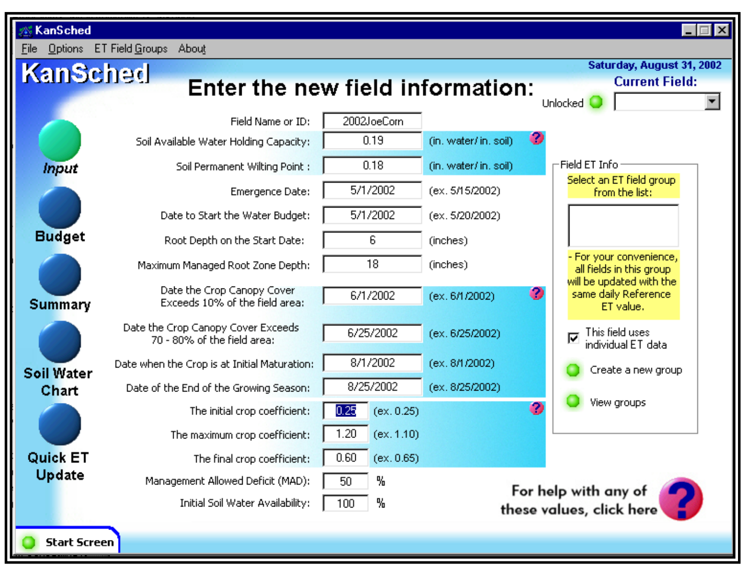


Fig. 3.1 - Main page for *KanSched*. Data can be input from here and options moved on to from here. This centralization makes the program easy to use.

4.-- NDSU's ***Computerized Irrigation Scheduling by the Checkbook Method.*** North Dakota State University has been a leader in developing Internet irrigation scheduling tools. Water use of various crops (with various emergence dates) is graphical displayed in beautiful JPG images showing the statewide 1-, 3-, 7-, and 14-day consumptive use. A companion tool is the ***Computerized Irrigation Scheduling by the Checkbook Method*** developed by them (and the University of Minnesota) based on an earlier bulletin on checkbook irrigation scheduling. The program is a compiled spreadsheet that tracks soil moisture depletion. While the program has little visual impact, it performs what needs to be done. As a spreadsheet, it allows for cut-and-paste insertion of weather data or crop water use, a feature that many of the database irrigation scheduling programs lack (Fig. 4.1). This functionality may explain why NDSU's server has more hits on its tabular ET data then its handsome graphically presented data. Some other special features include soil moisture depletion functions, easy-to-use root zone soil moisture calculators, and minimal weather data requirements (only maximum temperature). Each field can have two portions and is saved in a separate compiled spreadsheet at 2 1/2 meg each, so multiple locations could add up to large storage needs.

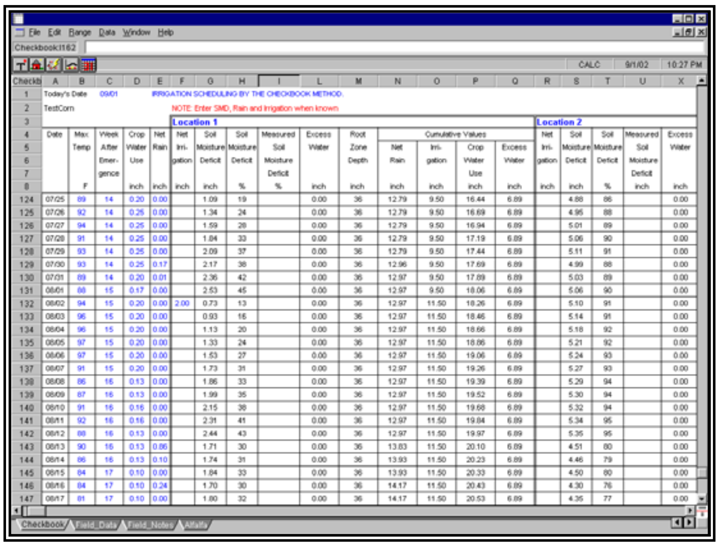


Fig. 4.1 - The program creates a spreadsheet screen for each field being scheduled. Data is input and results are viewed on the "Checkbook" tab, being displayed here. The initialization for each field is done under the "Field Data" tab.

5.--The ***AZSched*** program of the University of Arizona had an earlier life as a DOS-based program. It has some outstanding features, one of which is the large number of irrigated crops it supports. The crop coefficients are Heat Unit-driven, which is nice. However, they use a day-long integrated heat unit that is not exactly like the normal base heat unit that most places do. Therefore, some care should be taken in transporting these data to other locales, especially those that normally experience cloud cover. The program is built upon the excellent UA-run weather network, and current weather can be downloaded from about two dozen stations. Data from previous years is also available. The soil moisture content query pages can painlessly extract lots of detailed information on soil parameters (Fig. 5.1). One of the nice features of the program is that it clearly displays the moisture status of the fields being audited, so that dangerous depletion levels should not creep up on the user. A single page report with dates to irrigate can be ordered, also.

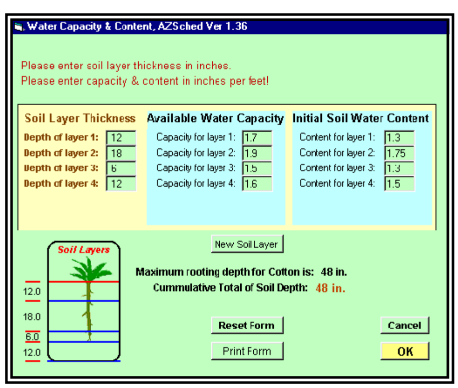


Fig. 5.1 - *AZSched* has nice input screen for inputting information about soil moisture holding data.

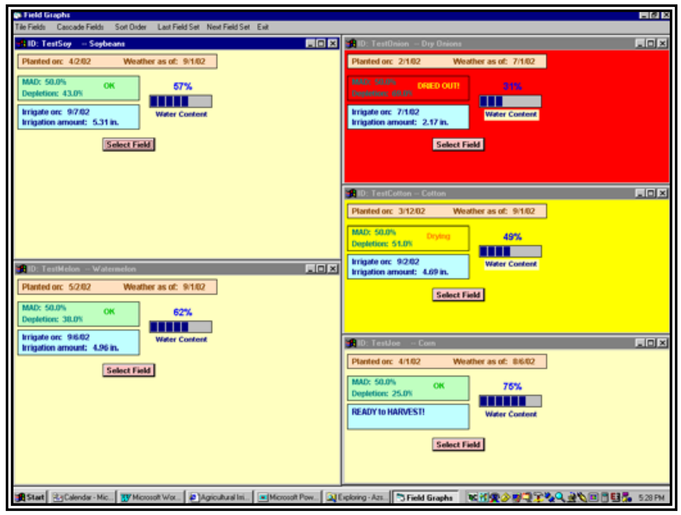
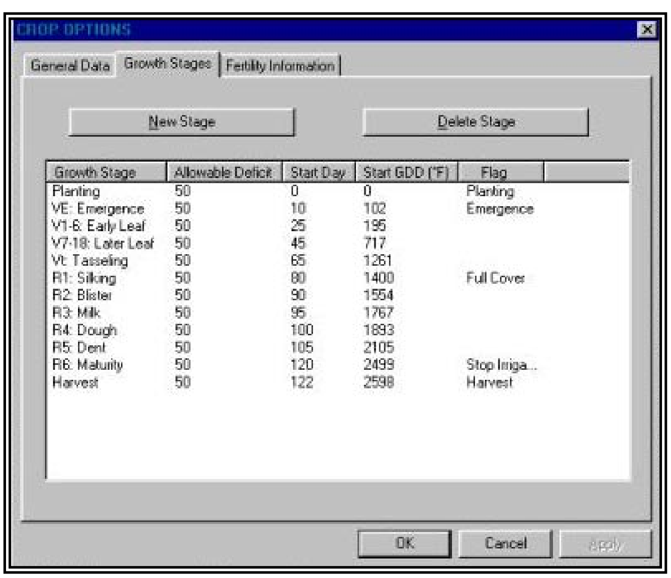
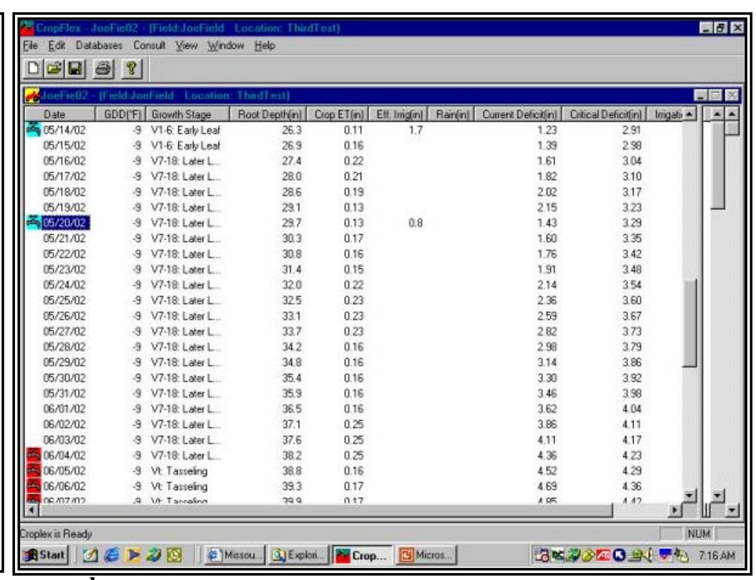


Fig. 5.2 - ***AZSched*** **has a special page where the current status of all fields being monitored is displayed together. Backgrounds are color-coded based on how dry they are. Dates and amounts for next irrigation are shown.**

6.--The ***Cropflex 2000*** program is Colorado State University's effort at managing both fertility and irrigation. The fertility management is impressive and very detailed (e.g., it not only asks for things like soil test data, but queries whether you trust the results!) The irrigation details get partially lost in the shuffle. The program imports weather text files in the CSU, KSU or USDA format; it is fortunate to be able to do this, as the manual inputting goes very slow. Generic crop data could be used (the file would still have to be made for it), but hybrid-specific files are possible. Multiple stages could be created that would have stage name, MAD, days to reach, heat units to reach, and message to display (Fig. 6.1a). These crops would also need values for the polynomial of Kc (before and after full cover). The multi-stage MAD is a worthwhile characteristic. The irrigation status is shown in a tabular form by date after planting and lists information on root depth, ETc, irrigations, rainfall, and deficits. Green-background icons on the line indicate an irrigation occurred that day. Red of the same indicates irrigation is needed (Fig. 6.1b).



a.



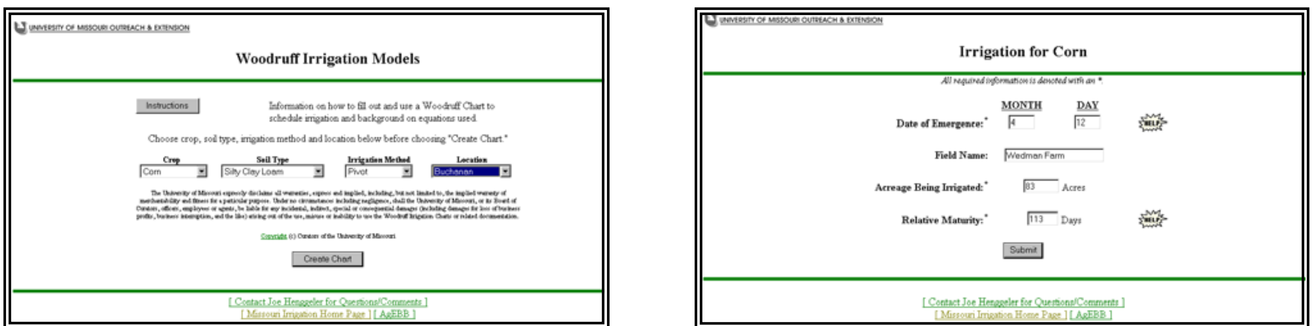
b.

Fig. 6.1(a) - ***Cropflex 2000*****'s growth stage screen where the physiology of a crop can be entered; tab to the "General Data" to enter the values of the polynomial describing Kc. (b) Information on the daily status of soil moisture, rooting depth, etc. can be seen. Icons allow one to easily see important dates.**

II. Irrigation Scheduling Programs (Historic Weather)

7.-- ***The Woodruff Chart maker.*** One very unique tool for scheduling is the Woodruff chart. The web-based program from the University of Missouri uses historical weather data to develop an accumulative water use curve for the crop, emergence date, and weather file in question.. This curve serves as a graphical tool for timing irrigations. Figure 7.1a queries the user for the initial needed information; choosing the county selects the 30-year weather average for that county. The next screen (Fig. 7.1b) queries for additional information. The Relative Maturity (RM) value of the corn hybrid or the Maturity Group (MG) of the soybean variety is input. RM information tied to emergence date and the county-associated weather file will predict black layer for the corn. MG information along with emergence date and county-based latitude allows the date of full maturity of soybeans to be predicted. Thus, this program does a very good job in predicting how long in the season to irrigate.

The concept of the Woodruff site was to keep it very simple. Growers do not have to enter root depth, water holding capacity or MAD to develop an irrigation depth per application. The program chooses this based on the crop and soil chosen. The Internet site constructs the appropriate graph and the user prints it off. From then on scheduling is done with a pencil. Figure 7.2 shows a Woodruff graph.



a.　　　　b.

Fig. 7.1 (a) - The opening query menu for the University of Missouri's Woodruff Chart maker (which resides on the Internet). (b) Fig. 7.1 (b) - The next WWW level query screen interrogates for additional information.

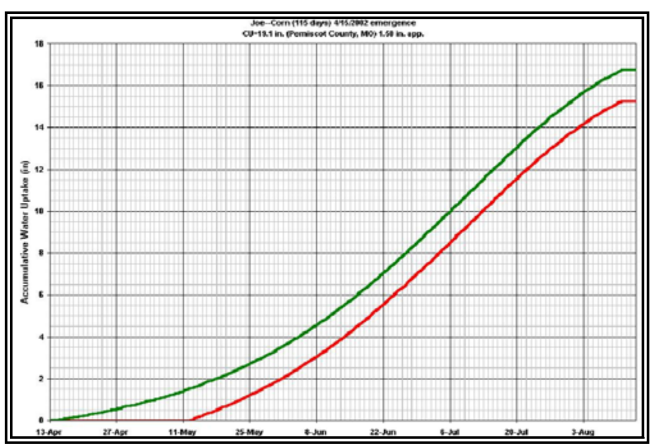


Fig. 7.2 – A customized Woodruff irrigation as it is delivered off the Internet. The green line is accumulative water use; the red line is drought region. A farmer pencils in the rains and irrigations, so as to stay between the two lines.

8. – **Wateright** is basically an irrigation scheduling tutorial developed by the Center for Irrigation Technology. It is built around the CIMIS weather network, plus the weather stations in WA, OR, ID and MN. It gathers current weather data and uses archived data for future periods. This (and the arid climate it is associated with) allows a reasonable estimate of when to apply irrigation. However, the program does not allow for any input (such as actual rainfall and irrigation), so it remains hampered as a real scheduling tool. The fields that you create are kept as “cookies”, and when you log back on the Wateright Internet site, they are still there.

Two tables follow with more detail on these eight irrigation scheduling programs.

Name	Crops	ET referenced	Type of K_c	Init. [A]	Method that weather data is input	Wet [B]	Pre [C]	Graph [D]	Root [E]	Projects crop ending point	Irrigation amount dictated by	Predicts irrigation data?	How is rainfall handled?	How is irrigation system efficiencies handled?	How are soil parameters handled?
Arkansas Scheduler [1] Ver. 1.0 (1999)	corn cotton soybeans milo	potential ET or potential ET estimated from Max Temp	time-based	e	hand input within program; historic data supplied; some sites have real-time WWW files	yes	yes	no	no	soft prediction	desired deficit	yes (10-day forecast)	hand input; if it exceeds 1.0 inches, user is queried re: effective rain	automatically subtracts out 10% of what is applied by sprinkler; nothing for flood	uses soil type & crop to suggest deficit to use; no calculations
Michiana Irrigation Scheduler [2] Ver. 1.0 (1997	corn soybeans alfalfa dry bean potato	accepts hi/low temps; possibly Hargreaves-Samani	unknown	e	hand input within program; historic data supplied	no	no	pseudo	no	user indicates	desired soil moisture %	yes (7-day forecast)	hand input	no	user inputs root zone storage amount and MAD value
KanSched [3] Ver. 1.1 (2002)	corn soybeans milo cotton	ET_r or ET_o	derived from value inputted at various % of canopy closure & other items	e	hand input either ET_r or ET_o	no	no	yes	yes	user indicates	choosing what ever % depletion desired (50% is default)	if future ET_o was input, one could use graph to eyeball when	hand input; tally of deep percolation occurs	choose value	place available to input water % at Permanent Wilting & available storage %. AS times input rooting depth gives total water; this times MAD is irrigation trigger point
NDSU's Computerized Irrigation Scheduling by the Checkbook Method [4] Ver. 2.01 (2001)	corn wheat barley soybeans sunflower potato pintobeans sugar beet alfalfa	potential ET estimated from Max Temp	weeks post emergence	e	hand input or cut-and-paste (only max T needed)	no	no	yes	yes	program picks end date	choosing whatever % depletion desired	yes	hand input or cut-and-paste	user is suppose to put in net	choosing soil type by 6-inch layers gives holding capacity; 36-inch max or less for some crops
AZSched [5] Ver. 1.36 (2002)	alfalfa barley 2 melons corn cotton grn. chiles potato safflower soybeans wheat 9 veggies 3 grapes	ET_r	heat-unit based	p	can download text files for about 25 AZ weather stations (current & past); can also hand input	no	no	no	yes	program chooses	based on % of depletion Also tells amount needed to fill deficit	as a report and as a screen flag	hand input	hand input	very nicely; rooting depth chosen by computer; user inputs soil layer info in terms of in/ft based on layers chosen
Woodruff Irrigation Chart Maker [6]	corn cotton soybeans	historic Blaney-Criddle	HU-based (% of seasonal HUs)	e	internal; all MO counties included	no	no	no	no	model prediction	desired deficit	yes (rainfall must be used to adjust)	users pencil it in on the chart	Assumes net amount applied	uses soil type & crop to suggest deficit to use; no calculations
Cropflex 2000 [7]	many possible	ET_r uses Kimberly Penman, Jensen-Haise or Hargreaves	Heat Unit or Days	p	can load text files from three formats (CSU, KSU, and USDA)	no	no	no	yes	user supplies	critical deficit in inches (or can be converted to %)	yes	from inputted file or manually	efficiencies vary with method; not readily changeable	current rooting depth times soil's AWHC times a MAD that can change over crop stage
WATERIGHT [8] Evaluated on-line 2/2002	many	ET_r	5-point time method; can be adjusted	p	internal; all cooperating weather station real-time data from CA (also, WA, OR, ID, MT)	yes	no	no	yes	user indicates	desired deficit; set interval	average date of irrigations (deviations in rainfall amounts & ETmust be used to adjust)	Within the pulled-down data file (other data can't be entered)	user inputc	Selecting soil type chooses holding cap.; user inputs rooting depth & MAD

[A] Init. = "Initial Readings from" where "e" is emergence and "p" is planting
[B] Wet = "Wet surface evaporation feature available?"
[C] Pre = "Pre-season moisture balance equations made?"
[D] Graph = "Graphical representation of soil moisture deficit available?"
[E] Root = "Changing root depth?"

[1] University of Arkansas; available for downloading from: http://www.aragriculture.org/computer/schedule/default.asp
[2] Purdue Research Foundation; available for downloading from: http://www.agry.purdue.edu/hua/inhua.htm
[3] Kansas State University; available for download from: http://www.oznet.ksu.edu/mil (choose "downloads" then "MIL Toolkit download")
[4] North Dakota State University or University of Minnesota ; available for purchase at $35.00.
[5] University of Arizona
[6] University of Missouri; available from interactive web site at: http://agebb.missouri.edu/irrigate/woodruff/
[7] Colorado State University; available for download from: http://ulysses.atmos.colostate.edu/~crop/
[8] Center for Irrigation Technology at California State University, Fresno; available from interactive web site at: http://www.wateright.org/

Name	Computer Space Required	Cost	Designed For	Contains Soil Stress Function	Other notes
Arkansas Scheduler	3.1 megs	free	AR, TN, MS, LA, MO	no	New version will be out for 2003 that will work off the Internet; pioneer in using empirical research to determine ideal deficit, so as to avoid the root depth X holding capacity X MAD
Michiana Irrigation Scheduler	0.5 megs	free	MI, IN, KY	yes	Gives temp deviation; indicates soil moisture (can go to saturated conditions); graphically shows good or bad soil moisture condition by how many "+" or "-" are printed out; shows daily and accumulative yield loss coming from soil moisture stress (user inputs expected maximum); summary data (total deficit, days until 1-in of deficit occurs, current ET_c) is shown only for the single date selected to be viewed
KanSched	1.7 megs	free	KS (but could be universal)	no	Nice presentation; compact—works off a central page; fields can be grouped, so as not to have to re-apply ET info; weather data not needed, only ET data; ET data can not be put in automatically; having both ET_r or ET_o and separate K_c values could lead to confusion
NDSU's Computerized Irrigation Scheduling by the Checkbook Method	2.6 megs, plus 2.3 megs for each field	$ 35	ND, MN	yes	A compiled spreadsheet; one can adjust predicted values of soil moisture deficit by putting in data from hand sampling; alfalfa handled differently then the other crops; lots of weather files from locations in ND & MN are built-in; each field can have 2 locations; every field will be a separate spreadsheet (@ 2 megs)
AZSched	8.5 meg	free	AZ	yes	Nice display; large selection of crops; easy to learn; lots of weather data resources are available
Woodruff Chart Maker	0 megs	free	MO	no	Chart is printed at beginning of the season and penciled in; good user support
Cropflex 2000	0.8 megs	free	CO, KS	no	An excellent fertility management program; new crop data would need an expert to initialize; might be an excellent scheduling tool for a seed company; can use SI units
WATERIGHT	0 megs	free	CA (also, WA, OR, ID, MT)	no	A lot there, but not really a checkbook method as actual irrigation amounts/dates and rainfall can't be entered; keeps "cookies" of your files, so you don't have to re-enter

WEATHER DATA COLLECTION FOR IRRIGATION MANAGEMENT

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Abstract
Advances in information technology have provided managers with alternate options for irrigation management. With water becoming a limiting resource, managers depend on these new technologies to determine optimal irrigation management schemes. Weather variables play a key role in these decisions. The College of Agricultural and Environmental Sciences of the University of Georgia has developed a network of automated weather stations that has grown from three stations in 1991 to 45 stations in 2001. It is expected that more than 50 stations will be operational by the end of 2002. These stations have mainly been installed in unique ecological regions where agriculture is important. Weather variables that are observed include air temperature, relative humidity, wind speed and direction, solar radiation, precipitation, soil temperature at different depths and soil moisture. These variables are summarized every 15 minutes and at midnight daily summaries and extremes are determined. Using dedicated telephone lines and modems, the data are transmitted to a central location in Griffin. After processing, the data are made available via the web site www.Georgiaweather.net. Besides obtaining the summarized data, users have also access to calculators that determine potential evapotranspiration and rainfall. This information can then be used as a guideline for irrigation management. It is expected that more advanced irrigation schedulers will be added to the system in the near future.

Introduction
The existence of irrigation companies is largely due to the variability of our weather and climate, especially rainfall. If rainfall amounts and events were evenly spread across the year, there would be no need for farmers, growers, homeowners and others to irrigate. Fortunately or unfortunately, depending on your business perspective, weather is variable and possibly unreliable. There is therefore a need to supplement the natural precipitation with supplemental irrigation to maintain healthy crops, gardens and lawns. Although in the past water was an unlimited resource, recently it has become more restricted. For instance in the greater Atlanta metropolitan areas, outdoor watering is now limited due to lack of sufficient water for irrigation. The recent drought in the southeast that started in 1998 and has continued through 2002, has been the major cause for this restriction. With limited or restricted water resources, there is a need to schedule irrigation based on the actual needs of a crop or a plant. Weather plays a critical role in irrigation scheduling and to be able to schedule irrigation, accurate weather information is required.

Figure 1. Traditional rain gauge operated by the National Weather Service (left).

Background
Traditionally the National Weather Service (NWS) has been responsible for weather observations. Most of the weather observations are made at major airports, due to the need to forecast local weather conditions for

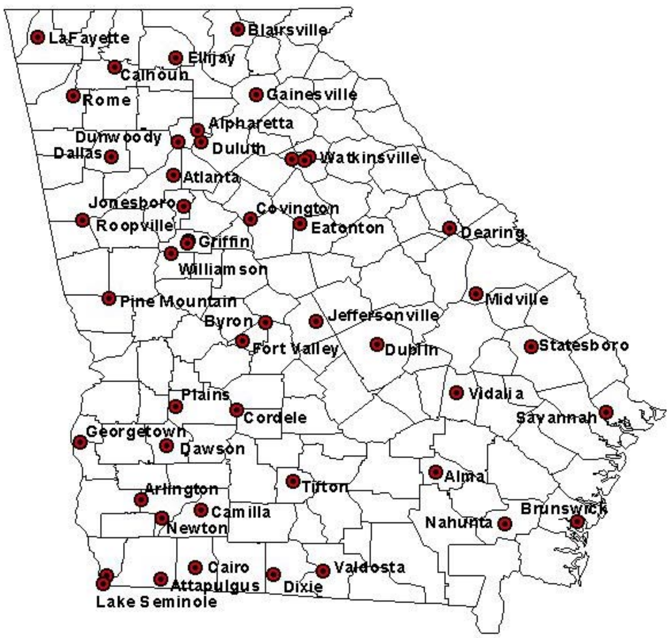

Figure 2. Locations of the weather stations of the Georgia Automated Environmental Monitoring Network.

aviation. The NWS also operates a Cooperative Observer Network, in which volunteers record local weather conditions. These observations are normally made once a day at 8.00 am and include maximum and minimum temperature and rainfall (Figure 1). However, this information is inadequate for irrigation scheduling as the variables that are being collected are limited, the access to the data is difficult and the availability of data is not timely. Therefore several Land-grant universities have developed automated weather station networks to collect weather data in a timely manner and make the data available to the general public. One of the larger networks is the Mesonet in Oklahoma, where at least one weather station is operational in each county. Large networks also exist in California, Washington, Arizona, Nebraska, North Dakota, Texas, Florida and several other states.

The Georgia Automated Environmental Monitoring Network (AEMN) was developed by the College of Agricultural and Environmental Sciences of the University of Georgia. The first weather station was installed in 1991 and currently 49 weather stations are in operation. Most of these weather stations have been installed at sites that relate to agriculture. Examples include experimental research stations in Blairsville, Plains, Midville, Tifton, Griffin and Watkinsville; USDA research laboratories in Plains, Byron and Watkinsville; nurseries in Dearing and Cairo, row crop farms in Georgetown, Cordele, Arlington, and Vidalia; fruit orchards in Ellijay, Alma, Cleveland and Nahunta; educational facilities in Covington, Fort Valley, Dallas, and Jeffersonville, and golf courses in Duluth, Dunwoody, Alpharetta, and Pinemountain. The stations are located across the state and are representative for regional weather conditions. The current locations of the weather stations can be found in Figure 2.

Figure 3. Tipping bucket rain gauge.

Operation

The automated weather stations of the AEMN are based on Campbell Scientific units. The control and monitoring unit is based on a Campbell Scientific CR10 and CR10X data logger, which has 128K memory and can store up to 62,000 data points. The data logger has 12 single-ended or six differential analog inputs, two pulse counters, three switched excitation channels and eight digital I/O ports. A basic configured station records precipitation, air temperature and relative humidity, wind speed and wind direction, solar radiation, soil temperature at three different depths, barometric pressure and soil moisture. The sensors that are currently being used are listed in Table 1. Rainfall is measured with a tipping bucket rain gauge as shown in Figure 3. Each “bucket” holds 0.01 inch of rain; once the

Figure 4. Weather station at the Atlanta Athletic Golf Club in Duluth, Georgia.

bucket is full it tips and a pulse signal is sent to the data logger. The data logger then converts the number of pulses to total rainfall by the data logger. Each data logger is programmed to scan all sensors at a one-second frequency and data are summarized every 15 minutes. At midnight daily extremes and daily totals are calculated. The system is battery operated, which is recharged with a solar panel during daytime hours. Communications are handled through a modem and a dedicated telephone line to each station or a cellular phone system. An example of a complete operational weather station is shown in Figure 4 for the Atlanta Athletic Golf Club.

Data are downloaded to a centrally located computer at the College of Agricultural and Environmental Sciences Campus in Griffin. Data are downloaded every 12 hours for all stations. In addition, the detailed data from the stations located in the greater Atlanta area are downloaded every 15 minutes as soon as the data loggers have been updated. Several stations are called at least hourly to download the most recent weather data. Once the data have been downloaded from the web, they are processed and pushed to data and web servers.

Data Dissemination

A special web page has been developed for distribution of the weather data collected by all stations and dissemination of weather-based information for application in agriculture, engineering and other disciplines, including irrigation management. The web page is located at www.Georgiaweather.net. The main page displays a map similar to the one shown in Figure 2. Each point is clickable and once a site has been selected, the user is presented with 12 different options as shown in Figure 5. Data that can be retrieved include current conditions for some of the sites as discussed previously, yesterday's data, data for the last 30 days, historical data recorded by the station, long-term climate data and a link to the local weather forecast page provided by the NWS. The AEMN is not a position to provide forecasts for local weather data, as this is the main responsibility of NWS.

Table 1. Weather variables and sensors of the Georgia Automated Environmental Monitoring Network.

Variable	Sensor
Air temperature	HMP-45C Vaisala Temperature and RH Probe
Relative humidity	HMP-45C Vaisala Temperature and Relative Humidity Probe
Precipitation	TE525 Texas Electronics Tipping Bucket Rain Gage
Wind Speed	034A Met One Wind Set
Wind Direction	034A Met One Wind Set
Solar Radiation	LI200X Li-Cor Silicon Pyranometer
Soil Temperature @ 2, 4 and 8 inches	CS-107 Water/Soil Temperature Probe
Barometric Pressure	CS-105 Vaisala PTB101B Barometric Pressure Sensor
Soil Moisture	CS-615 Water Content Reflectometer

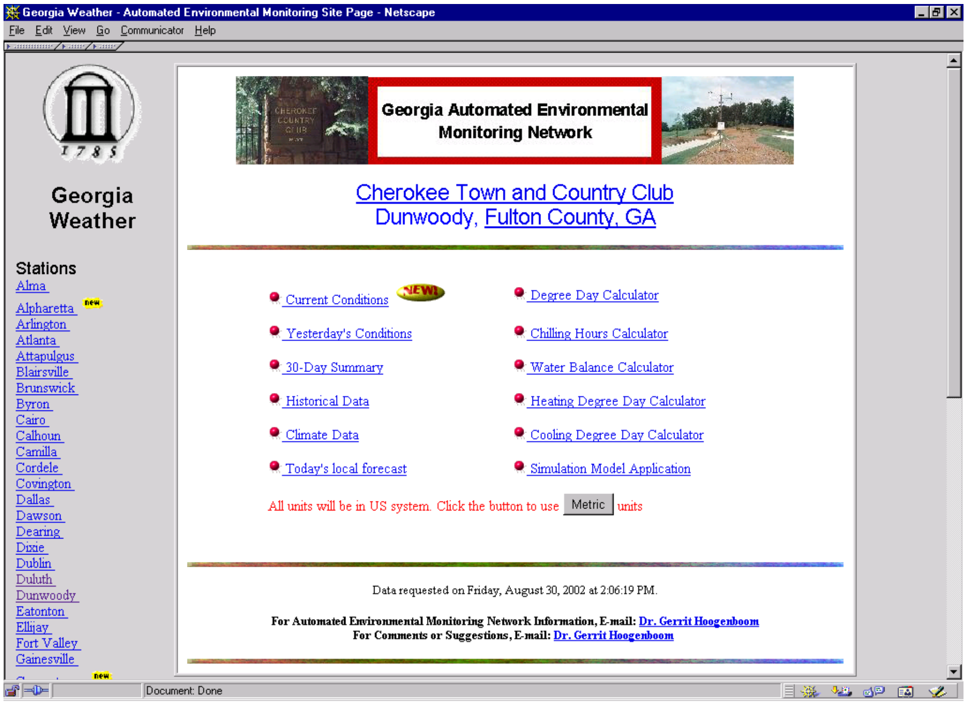

Figure 5. Main menu for weather data retrieval and applications. Example shown is for the Cherokee Town and Country Club in Dunwoody, Georgia.

Weather Data Applications

A second set of information is based on applications of the weather data. This includes the calculation of chilling hours and degree-days for agricultural crops, vegetables, fruits and ornamentals. Plant growth and development is a function of temperature and with these calculators users can obtain an indication about rates of growth and development for various plants as a function of local conditions. A similar set of calculators include the cooling degree-day and heating degree-day calculators, which are used extensively by the heating and air conditioning industry as well as agricultural industries associated with confined spaces such as greenhouses.

The water balance calculator is most directly associated with irrigation. It provides the user with an indication of cumulative rainfall for a defined period, as well as potential water loss. Cumulative rainfall is based on local rainfall observed by the weather station, while cumulative water loss is calculated using a potential evapotranspiration equation that has local temperature and solar radiation as input. The difference between these two calculations, i.e. cumulative rainfall and evapotranspiration, provides the user with an indication of local water needs and supplemental irrigation. In figure 6 an example is shown for Callaway Gardens in Pine Mountain. Cumulative rainfall for this year is 26.9 inches, while cumulative evapotranspiration is 33.8 inches. There is a deficit of 6.9 inches. Note that the cumulative normal rainfall is 38.8 inches. Current rainfall is therefore 11.9 inches below normal.

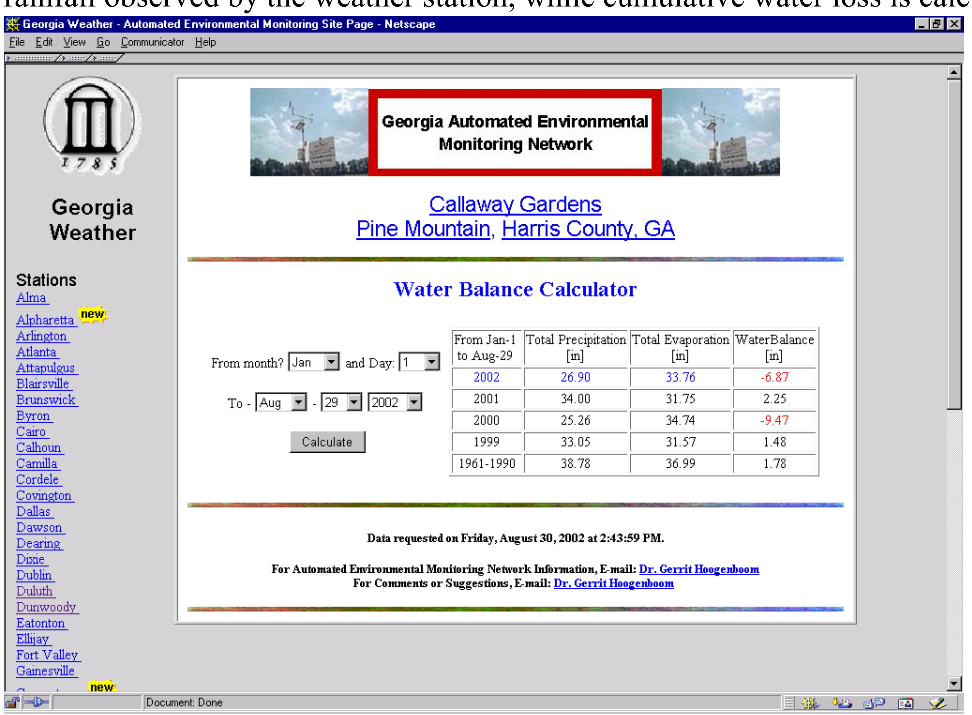

Figure 6. Water balance for Callaway Gardens, Pine Mountain, Georgia for January 1 through August 29, 2002.

Future

The water balance calculator shown in Figure 6 is rather simple. More advanced decision support systems and computer tools are needed to help users decide when to irrigate and how much water to apply. Factors that should be taken into consideration include effective rainfall, water holding capacity of the soil, date of last irrigation or rainfall, type and stage of the crop, and the local weather forecasts. With this type of information users can apply water more selectively, while maintaining optimum growing conditions. At the same time water use will be reduced. A prototype of this type of irrigation scheduling system has been designed for peaches. Hopefully it can be expanded to include other crops to benefit all irrigation applicators.

Predicting Water Demand for Irrigation under Varying Soil and Weather Conditions

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Abstract

Recent issues that affect water resources in the state of Georgia include the tri-state (Alabama, Florida and Georgia) water dispute, the continuing drought in the southeastern USA, and the rapidly increasing water use by agriculture through irrigation. An understanding of water needs by agriculture is critical to ensure the availability of water for future users. The objective of this study was to evaluate crop yield response to irrigation for different soil and weather conditions using the EPIC crop model. Yield predictions showed the highest variation for rainfed conditions, while the annual yield variability was greatly reduced when irrigation was applied. Rainfed yield was lowest for the Troup loamy sand and was highest for the Dothan loamy sand. For maximum yields under non-stress conditions, the Fuquay sand had the highest irrigation demand while the Dothan loamy sand had the lowest irrigation demand. Cotton yield showed a linear increase with an increase in total irrigation until maximum yield was reached under non-stress conditions. The Troup loamy sand and Fuquay sand showed the greatest range in yield response to an increase in total irrigation. For the Dothan loamy sand, there was little increase in yield with an increase in total irrigation. This study showed that the EPIC model can be a useful tool for determining water demand for irrigation at a farm level for different soil and weather conditions. Future efforts will focus on using the model for regional estimation of water use for irrigation in Georgia.

Introduction

Recent issues that affect water resources in the state of Georgia include the tri-state water dispute between Alabama, Florida and Georgia, the continuing drought in the southeastern USA, and the rapidly increasing water use in agriculture through irrigation. An understanding of water needs by agriculture is critical to ensure the availability of water for future users. In Georgia, agricultural irrigators are required to have a permit, but they are not required to report their water use. Over 20,000 permits have been issued, and nearly 2,000 new applications are pending in the Flint River basin alone. Approval of these new applications depends on a better understanding of water use for irrigation, outcomes of the tri-state negotiations for a water allocation formula, and effects of the current drought and pumping on river flows (Thomas et al., 2000). Unfortunately, how much water is required and how much is actually being used for irrigation is currently unknown. The Georgia Department of Natural Resources, Environmental Protection Division, the designated state regulatory agency, therefore has to rely on estimates of water needs by agriculture for its water management decisions.

Computer simulation models have been developed to predict yield and water use under different irrigation and other management practices for specific sites where soil and weather information are available. With this predictive ability, water management decisions can be evaluated at a field level. In addition the impacts of plans and policies on regional agricultural water needs and production can also be determined. The objective of this study was to demonstrate the use of a computer simulation model for evaluating crop yield response to irrigation for different soil and weather conditions.

Environmental Policy Integrated Climate model

The Environmental Policy Integrated Climate (EPIC) model is a computer simulation model that can be used to determine the effect of management strategies on agricultural production and soil and water resources. The drainage area considered by EPIC ranges from a field to about 100 ha area, where weather, soils, and management systems are assumed to be homogeneous. EPIC has a single crop model that handles multiple crops and components to simulate the soil and plant water and nitrogen and phosphorus balance, and crop and soil management. (Williams et al., 1989; Meinardus et al., 1998). Inputs for EPIC include data on weather variables, crop parameters, soil parameters, and crop and soil management practices. EPIC is driven by observed and/or simulated daily weather inputs that include total solar radiation, maximum and minimum air temperature, total precipitation, average relative humidity, and average wind speed. An option to simulate rainfed or irrigated conditions is provided in EPIC. Irrigation may be scheduled by the user or can be conducted automatically by the model. With the automatic option, the model decides when and how much water to apply based on a set of thresholds defined by the user. Required inputs for the automatic version include a signal to trigger water applications and the maximum amount per application. The three options to trigger automatic irrigation are plant water stress level, plow layer soil water tension in kPa, and rootzone soil water deficit in mm. For the plant water stress level option, automatic irrigation is triggered whenever the crop water stress factor reaches a predetermined value between 0 and 1, with 1 representing no stress and 0 indicating complete cessation of transpiration.

Methods

Tifton, Georgia was selected as the study site, with 22 years (1980-2001) of long-term historical weather data. Observed solar radiation, maximum and minimum air temperature, and precipitation were collected from the weather station that is located in the Coastal Plain Experiment Station. This weather station is part of the Georgia Automated Environmental Monitoring Network (www.Georgiaweather.net; Hoogenboom, 2001). The remaining weather inputs were generated using monthly weather statistics for the closest weather station available in the EPIC weather generator parameter database. Five soils, representative of the sandy and loamy sandy soils of the Coastal Plain region, were used to define the soil inputs. Values for various soil parameters at different depths were obtained from the soil survey report of the Georgia Agricultural Experiment Stations (Perkins et al., 1986). The amount of water in the soil that can be extracted by the plant depends on soil physical characteristics as well as rooting depth. For the selected soils, total extractable soil water varied from 3.1 inches for the Troup loamy sand to 5.3 inches for the Carnegie loamy coarse sand (Table 1). Among the five soils, the Troup loamy sand had the highest hydraulic conductivity, followed by the Fuquay sand. The Carnegie loamy coarse sand, Dothan loamy sand, and Tifton loamy sand had very low hydraulic conductivity in the lower part of the subsoil. Cotton, one of the most important crops in Georgia with a harvested area of about 3.46 million acres for the year 2000 (www.nass.usda.gov/ga), was selected for this study. Crop and soil management practices, which include land preparation, planting and harvesting dates and fertilizer application, were obtained from the variety trial reports of the Georgia Agricultural Experiment Stations (Day et al., 1999; Day et al., 2000; Day et al., 2001; Day et al., 2002; Raymer et al., 1991; 1992; Raymer et al., 1993; 1994; Raymer et al., 1995; 1996; Raymer et al., 1997; Raymer et al., 1998).

The simulation was set at one year and was initiated on January 1. Initial soil water content was estimated automatically by the model based on average annual rainfall. The plant water stress level option was selected to trigger automatic irrigation. Threshold values for triggering irrigation varied from 0.1 to 1, with 1 corresponding to fully irrigated (non-stress) conditions. Maximum amount per application was set to 1.18 inches. A sprinkler irrigation efficiency of 75% was assumed. Crop yield for rainfed conditions was also evaluated.

Table 1. Total extractable soil water and saturated hydraulic conductivity for the five soils.

Soil	Total Depth (inches)	Extractable Soil Water (inches)	Depth Below Soil Surface (inches)	Saturated Hydraulic Conductivity (inches/hour)
Carnegie Loamy Coarse Sand	83.9	5.3	5-17 32-45	0.8-3.9 0
Dothan Loamy Sand	83.9	3.9	5-17 32-45	1.1-7.0 0.1-0.2
Fuquay Sand	83.9	4.4	5-17 32-45	5.4-7.1 1.6-7.1
Tifton Loamy Sand	83.9	4.1	5-17 32-45	1.9-5.6 0.0-0.4
Troup Loamy Sand	94.1	3.1	5-17 32-45	6.4-12.8 8.6-12.1

Results

Crop yield is determined by numerous interacting factors. One of the main causes for yield variability of rainfed crops is the annual variation in precipitation. In this study, the total rainfall during the growing season (April-October) ranged from 7.5 inches in 1997 to 38.1 inches in 1994. The average rainfall was 18.5 inches and the standard deviation was 5.9 inches. Figure 1 shows that for rainfed cotton, the highest yield was obtained in 1994, the growing season with the highest total rainfall. The lowest yield was obtained in 1997, the growing season with the lowest total rainfall. The simulated yields for rainfed cotton were highly variable for all soils except the Dothan loamy sand (Figure 1). In contrast, for fully irrigated (non-stress) cotton, EPIC predicted a fairly stable yield from 1980 to 2001 for all soils (Figure 2).

Yields for rainfed cotton were between 188 and 580 lb/acre less when compared with fully irrigated (non-stress) conditions (Table 2). Rainfed yield was lowest for the Troup loamy sand; the soil with the lowest extractable soil water and the highest hydraulic conductivity. Rainfed yield was highest for the Dothan loamy sand. For all soils, yield predictions showed a higher deviation from the mean for the rainfed conditions compared with the irrigated conditions. For maximum yields under non-stress conditions, the Fuquay sand had the highest irrigation demand while the Dothan loamy sand had the lowest irrigation demand.

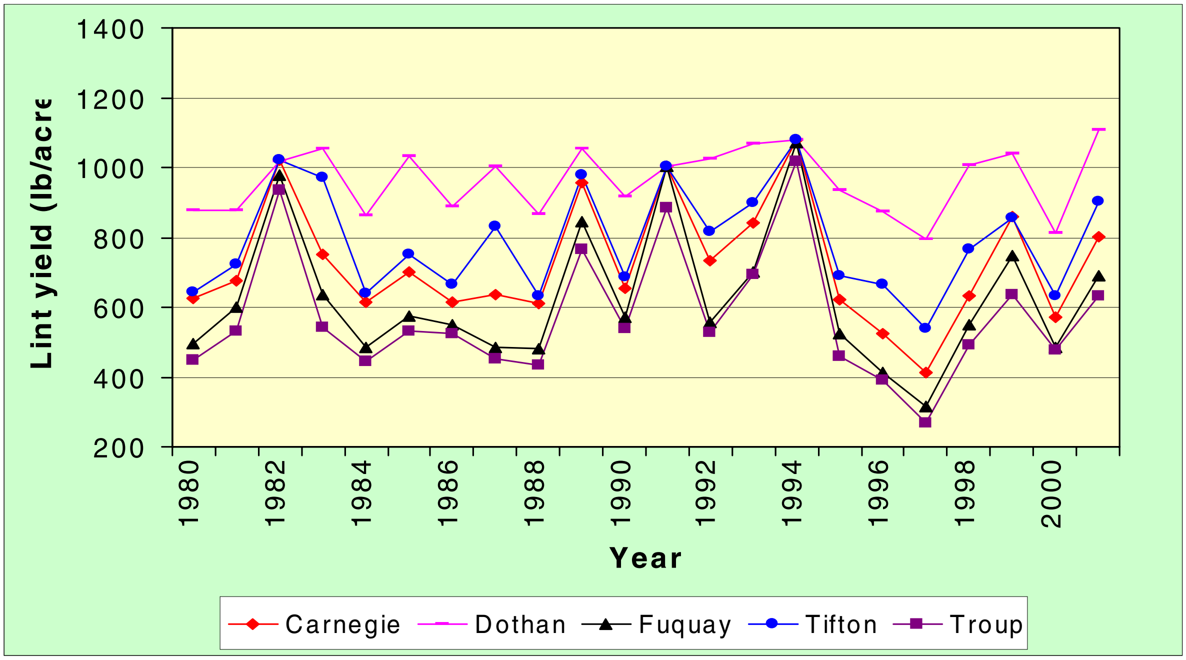

Figure 1. Yield for rainfed cotton for different soils.

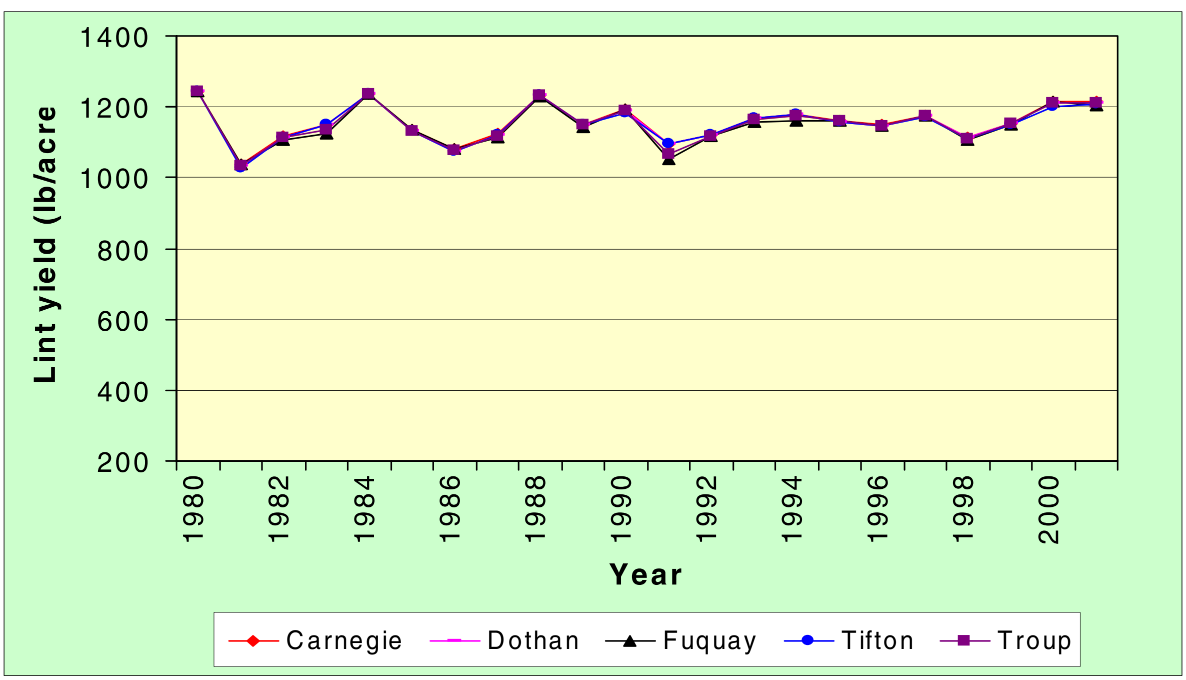

Figure 2. Yield for fully irrigated cotton for different soils.

Table 2. Average yield and water demand for irrigation for cotton (1980-2001).

	Fully Irrigated				**Rainfed**	
	Lint Yield		**Irrigation**		**Lint Yield**	
	mean	sd	mean	sd	mean	sd
	(lb/acre)		(inches)		(lb/acre)	
Carnegie	1160	53.6	17.4	5.4	723	169.7
Dothan	1152	53.6	6.5	4.5	964	89.3
Fuquay	1152	53.6	29.5	3.3	625	196.5
Tifton	1152	53.6	12.0	6.0	786	151.8
Troup	1152	53.6	28.5	3.2	572	187.5

The yield response to an increase in total irrigation for different soils is shown in Figure 3. Cotton yield showed a linear increase with an increase in total irrigation until maximum yield was reached under non-stress conditions. The Troup loamy sand and Fuquay sand, the soils with the highest hydraulic conductivity, showed the greatest range in yield response to an increase in total irrigation. For the Dothan loamy sand, there was little increase in yield with an increase in total irrigation.

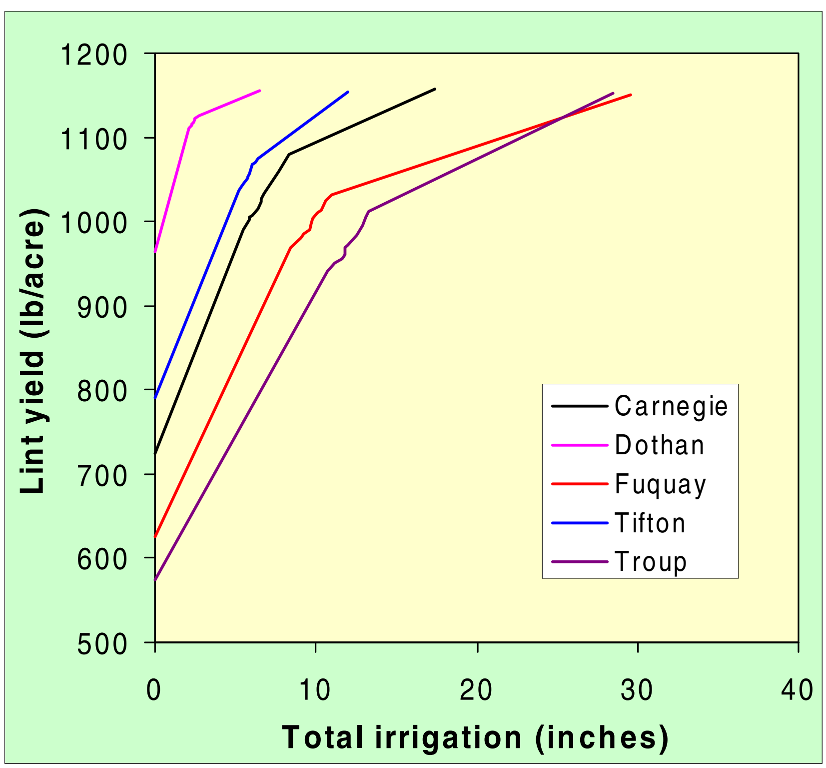

Figure 3. Yield versus total irrigation for different soils.

Conclusions

The EPIC model was used to evaluate crop yield response to irrigation for different soil and weather conditions. Yield predictions showed the highest variation for the rainfed conditions, while the annual yield variability was greatly reduced when irrigation was applied. Rainfed yield was lowest for the Troup loamy sand and was highest for the Dothan loamy sand. For maximum yields under non-stress conditions, the Fuquay sand had the highest irrigation demand while the Dothan loamy sand had the lowest irrigation demand. Cotton yield showed a linear increase with an increase in total irrigation until maximum yield was reached under non-stress conditions. The Troup loamy sand and Fuquay sand showed the greatest range in yield response to an increase in total irrigation. For the Dothan loamy sand, there was little increase in yield with an increase in total irrigation.

This study showed that the EPIC model can be a useful tool for determining water demand for irrigation at a farm level for different soil and weather conditions. With expected limited water availability for agriculture in the near future due to the increasing urban and industrial demands, EPIC can be used to determine minimum irrigation requirements for obtaining acceptable yield levels and to analyze the effects of limiting irrigation amounts on crop yield. Future efforts will focus on using the model for regional estimation of water use for irrigation in Georgia.

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IRRIGATION SCHEDULING FOR COTTON AND SOYBEAN IN NORTHEAST LOUISIANA

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ABSTRACT

Yield response from irrigation varies widely from year to year in Northeast Louisiana for cotton and soybean grown on alluvial soils. Studies were initiated to identify irrigation schedules that optimize yield and water use efficiency. Cotton and soybean experiments were conducted with furrow irrigation systems that compared various regimes derived from the Arkansas Irrigation Scheduler (AIS). Soil moisture depletion as predicted by AIS was also monitored with Watermark soil moisture sensors. The most intensive AIS irrigation schedules promoted the highest yields in cotton and soybean, but often more conservative irrigation approaches were just as effective. At low soil moisture deficits, Watermark sensors and AIS soil moisture values were similar, but as moisture deficits escalated, results from the systems diverged. Irrigation scheduling systems need to account for in-season dynamics of cotton and soybean crops, optimize yield, and eliminate unnecessary irrigation.

Keywords: Irrigation scheduling, Cotton irrigation, Soybean irrigation, Arkansas Irrigation Scheduler, Watermark soil moisture sensor.

INTRODUCTION

Rainfall in Northeast Louisiana can vary greatly from year to year. Devising irrigation schedules for relatively drought tolerant crops such as cotton and soybean grown on soils with a high water holding capacity and for deep root penetration can be very challenging. Escalating fixed costs such as land, equipment, and planting seed, coupled with low cotton and soybean commodity prices have made investment in irrigation a risky proposition. In addition, yield responses from irrigation depends on rainfall patterns during the season. This results in an extended payback period for investment in irrigation infrastructures. Nevertheless, irrigation is a tool that reduces risk of cotton and soybean production in years when rainfall is sporadic and worthy of investigation. Poorly timed irrigation can result in sub-optimal yield performance (Orgaz et al., 1992; Radin et al., 1992) and inferior fiber properties (Boquet et al., 2000). Efficient use of irrigation saves energy and water while reducing damage to the environment and enhancing long-term sustainability (Bosch and Ross, 1990; Raghuwanshi and Wallender, 1998; Howell, 2001).

Irrigation timing should be based on plant or soil water status (Steger et al., 1998). Irrigation regimes that quickly replenish soil-moisture after depletion from evapotranspiration generally are superior to less frequent, high volume irrigation (Phillips, 1980; Pringle et al., 1989; Radin et al., 1992; Orgaz et al., 1992; Bordovsky and Lyle, 1999). Delaying initial irrigation for cotton can retard lint yield potential (Johnson et al., 1989; Steger et al., 1998). Likewise, premature irrigation termination can limit lint yield (Palomo and Godoy, 1998; McConnell et al., 1999). Nevertheless, cotton has considerable compensatory abilities to recover from both early season and late season drought stress and produce acceptable lint yield (Ball et al., 1994; Pace et al., 1999; Wanjura and Upchurch, 1999). In most years on alluvial soil in Northeast Louisiana, soil moisture is plentiful enough to ensure adequate vegetative soybean development. Avoiding stress during reproductive development, especially at or near anthesis, is critical for optimal soybean yields (Board and Harville, 1998; Heatherly, 1983).

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Due to the cost-return ratio of irrigation in this region, most systems generally are low-cost, low-maintenance, and make inefficient use of water. Irrigation scheduling is an imperfect process at best on most farms in Northeast Louisiana. A limited number of producers use AIS software program developed by the University of Arkansas (Cahoon, et al., 1990). The program was not specifically developed for the unique growing conditions in Louisiana and many of the input parameters require a great deal of guesswork. Conditions that confound determination of irrigation scheduling in Northeast Louisiana include availability of moisture deep within soil profiles, transpiration rates affected by high relative humidity, and frequent returns to maximum soil-water holding capacity from rainfall events within a growing season. In most regions throughout the world, water availability is generally the most limiting factor for production; however, in Northeast Louisiana crop damage from insects and weed competition often are the most restrictive forces on yield potential. Information is needed that identifies scenarios in which irrigation and irrigation schedules have the greatest impact with the limited resources that producers are willing to invest in irrigation.

METHODS AND MATERIALS

Cotton

Experiments were established near St. Joseph, LA, on Commerce silt loam and Sharkey clay at Panola Corporation in 2000 and 2001, and on Sharkey clay at the LSU AgCenter-Northeast Research Station (NERS) in 2001 and 2002. Cultivar 'Deltapine NuCOTN 33B' was planted in all tests at the Panola Corporation. Experimental design was a randomized complete block with three replications in 2000 and four replications in 2001. In 2000, plots were 32 rows (97-cm center) x 243 m. In 2001, plots were 24 rows (97-cm center) x 243 m. Treatments were furrow irrigated. The four center rows of each plot were harvested with a four-row spindle type picker. Seed cotton was weighed in a boll buggy modified with a weigh cell. In 2001, cultivar 'Deltapine 458 B/R' was planted at NERS. Experimental design was a randomized complete block with four replications. Plots were 16-rows (102 cm center) x 61 m. Treatments were furrow irrigated. Two center rows of each plot were harvested with a one-row spindle-type picker. Sub-samples were ginned at the LSU AgCenter-Northeast Research Station's ginning laboratory to determine lint fraction. In 2002, the test at NERS was arranged in a split-split plot experimental design with nitrogen rates and cotton varieties as sub-factors; however, only the main effect of irrigation versus no irrigation will be discussed in this manuscript.

AIS requires users to select an allowable soil moisture deficit as defined by the amount of acre-inches of water lost from the soil due to evapotranspiration. As the calculated water budget is exhausted, AIS recommends irrigation. AIS was set at soil moisture deficits of 2-inches (AIS-2.0) and 3-inches (AIS-3.0). Temperature and rainfall data was collected from a weather station located at NERS. Other climate data required for the AIS was obtained from Calhoun, LA. The treatment, in which irrigation was initiated at AIS soil-moisture deficit of 4-inches (AIS-4.0), was switched to a 2-inch soil-moisture deficit after initial irrigation. The 1.5-inch water budget (WB-1.5) method assumed a 56 mm daily water use beginning at first bloom and continuing until two weeks past the first open boll (Hutchinson and Sharpe, 1989). This system assumed all precipitation was held in the soil and later available to plants. Tensiometers were placed at a depth of 10-inches in each plot and irrigation was triggered when analog gauges were at –0.75 bars. Non-irrigated treatments were included in all tests. In 2002 at NERS, Watermark soil moisture sensors were placed at 76-cm depths in all main treatments in three of the four replications. This particular depth was found to be optimal for irrigation predictions based on soil moisture (Boquet, 1989). Irrigated treatments in 2002 were scheduled with AIS-2.0.

Soybean

Experiments were conducted at Louisiana Delta Plantation, near Jonesville, LA, in 2000 on Tensas-Alligator clay, and at NERS in 2001 and 2002 on Sharkey clay. At Louisiana Delta, 'Hartz 5588 RR', a Maturity Group V cultivar was planted. Experimental design was a randomized complete block with four replications. Treatments were AIS set at 2-inch soil moisture deficit (AIS-2.0), AIS at 2.5-inch deficit (AIS-2.5), and a non-irrigated control. Plots were 16 rows (97-cm center) x 182-m. Irrigation treatments were furrow irrigated. Severe insect damage prevented collection of harvest data. At NERS 'Suregrow 489 RR', a late Maturity Group IV cultivar was planted. Experimental design was a randomized complete block with four replications. Treatments included AIS at 1.5-inch deficit (AIS-1.5) and 2.5-inch deficit (AIS-2.5), plus a non-irrigated control. Plots were 16 rows (102-cm center) x 106-m. Irrigation treatments were furrow irrigated. Temperature and precipitation data was collected at NERS. Other climate information for AIS was derived from Calhoun, LA. In 2002, Watermark soil moisture sensors were placed at 76-cm depths in all treatments in three of the four replications, but irrigation was always based upon the AIS system. Two center rows were harvested for yield.

Data were analyzed using the GLM procedures of SAS (SAS Institute, 2001) and LSD was calculated for mean comparisons.

RESULTS

Data from irrigation studies in Northeast Louisiana was affected considerably by rainfall events. The 2000 growing season from June to August was uncharacteristically dry with drought conditions intensifying in July and August (Table 1). Precipitation was more abundant in the 2001 and 2002 growing seasons. Not only did more rain fall during this time but the number of days in which rainfall events occurred increased from the 2000 weather pattern.

Soybean

Yield data in 2000 was not obtained because of severe stinkbug damage. Irrigation frequency was greatest in AIS-2.0 (Table 2). In 2001, the test at NERS resulted in no significant yield differences among irrigation schedules. The test averaged 3,534 kg ha^{-1}. Despite the frequent rainfall, AIS-1.5 received six irrigation applications and AIS-2.5 received three. In 2002, AIS-1.5 required three irrigations and AIS-2.5 received one irrigation. The AIS-1.5 irrigation schedule produced 4,609 kg ha^{-1}, which was significantly higher than AIS-2.5 and non-irrigated treatments.

Cotton

The largest response to cotton irrigation was observed in 2000 (Table 3). Tests at Panola Corporation on both soil types showed significant responses to irrigation with the greatest yield increases on Sharkey clay. In 2001, yield results were confounded by intense losses from boll rot due to frequent rainfall in August and September. Concomitantly, the experiment on Commerce silt loam at Panola Corporation and at NERS on Sharkey clay resulted in no significant yield responses among irrigation schedules. The experiment at Panola Corporation on Sharkey clay did, however, result in AIS-2.0 and WB-1.5 irrigation schedules yielding significantly more than AIS-3.0 and the non-irrigated regime. In 2002, irrigation frequency was limited to two applications due to frequent precipitation. That test has yet to be harvested.

Comparisons between AIS and Watermark soil moisture sensors were made in 2002 at NERS (Figure 1). AIS made a more precise prediction of soil moisture as measured by the Watermark system when soil moisture was relatively high. Correlation between AIS and Watermark values ranged from R^2= 0.4200 for soybean (AIS-1.5) to R^2= 0.1293 soybean non-irrigated.

DISCUSSION

The value of irrigating cotton in Northeast Louisiana was demonstrated in most experiments in this study, but effectiveness of one scheduling system over another was not overwhelming. The compensatory nature of cotton allows plants to continue to thrive even during short periods of drought stress. Frequency of irrigation on these soils with high water holding capacity did not affect yield to a great extent. Soybean are more sensitive to drought than cotton. AIS 1.5 ensured no drought stress occurred; however, such a frequent irrigation regime may waste water and could lead to losses from waterlogging (Linkemer et al., 1998). A more conservative approach with more precision may optimize yield and guard against the squandering of water.

A system that incorporates the positive aspects of AIS, such as irrigation projections that enhance farm management, but allows for in-season adjustments based on crop development (Jackson et al., 1990), and eliminates the guesswork associated with soil variation and crop conditions within fields is needed by cotton and soybean producers in Northeast Louisiana. Watermark soil moisture sensors may fill this need if an accurate and user-friendly system can be developed.

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Table 1. Rainfall events and monthly accumulation at LSU AgCenter's Northeast Research Station, St. Joseph, LA, in June, July, and August 2000-2002.

Year	June		July		August	
	Rain Events (days)	Total (mm)	Rain Events (days)	Total (mm)	Rain Events (days)	Total (mm)
2000	7	70	5	45	2	55
2001	13	156	8	106	10	101
2002	9	99	10	262	12	93

Table 2. Soybean response to irrigation schedules at Louisiana Delta, Jonesville, LA, and LSU AgCenter's Northeast Research Station, St. Joseph, LA, 2000-2002.

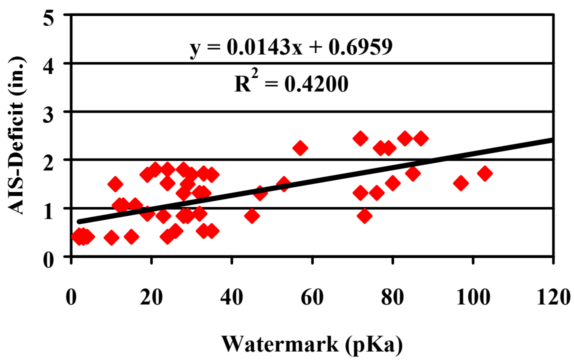
Location and Year	Schedule	kg ha^{-1}	# Irrigation
LA Delta (Tensas-Alligator clay)-2000	AIS-2.0 deficit	n/a	5
	AIS-2.5 deficit	n/a	3
	Non-irrigated	n/a	0
NERS (Sharkey clay)-2001	AIS-1.5 deficit	3,813	6
	AIS-2.5 deficit	3,462	3
	Non-irrigated	3,305	0
	Mean	3,534	
	LSD (0.05)	ns	
NERS (Sharkey clay)-2002	AIS-1.5 deficit	4,609	3
	AIS-2.5 deficit	4,446	1
	Non-irrigated	4,402	0
	Mean	4,484	
	LSD (0.05)	125	

Table 3. Cotton response to irrigation schedules at Panola Corporation and LSU AgCenter's Northeast Research Station, St. Joseph, LA, 2000-2002.

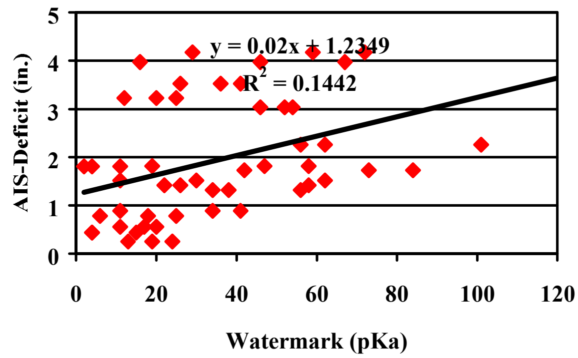
Location and Year	Schedule	Lint (kg ha^{-1})	# Irrigation
Panola (Commerce silt loam)-2000	WB-1.5 deficit	1,557	6
	AIS-2.0 deficit	1,500	5
	AIS-4.0 deficit	1,523	4
	Non-irrigated	1,193	0
	Mean	1,444	
	LSD (0.05)	249	
Panola (Sharkey clay)- 2000	AIS-2.0 deficit	1,525	5
	AIS-3.0 deficit	1,356	4
	WB-1.5 deficit	1,430	3
	Non-irrigated	886	0
	Mean	1,417	
	LSD (0.05)	175	
Panola (Commerce silt loam)-2001	AIS-2.0 deficit	974	3
	Non-irrigated	925	3
	AIS-3.0 deficit	900	2
	WB-1.5	887	0
	Mean	922	
	LSD (0.05)	ns	
Panola (Sharkey clay)- 2001	AIS-2.0 deficit	930	3
	WB-1.5 deficit	900	2
	AIS-3.0 deficit	772	2
	Non-irrigated	763	0
	Mean	841	
	LSD (0.05)	91	
NERS (Sharkey clay)-2001	AIS-2.0 deficit	1,117	3
	Tensiometer (-0.75 mb)	1,068	3
	AIS-3.0 deficit	1,068	3
	Non-irrigated	1,024	0
	Mean	1,070	
	LSD (0.05)	ns	
NERS (Sharkey Clay)-2002	AIS-2.0	n/a	2
	Non-irrigated	n/a	0

Figure 1. Relationship between soil moisture deficits as projected by AIS and indicated by Watermark soil moisture sensors in cotton and soybean at LSU AgCenter's Northeast Research Station, St. Joseph, LA, 2002.

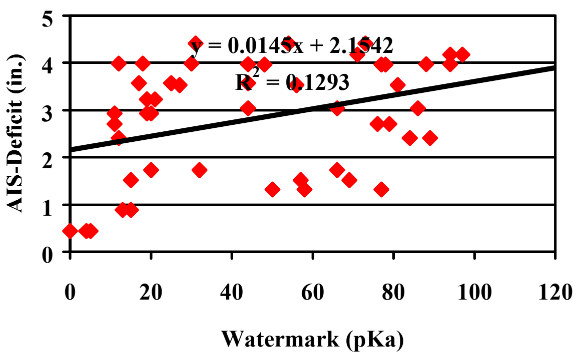
Soybean (AIS-1.5)



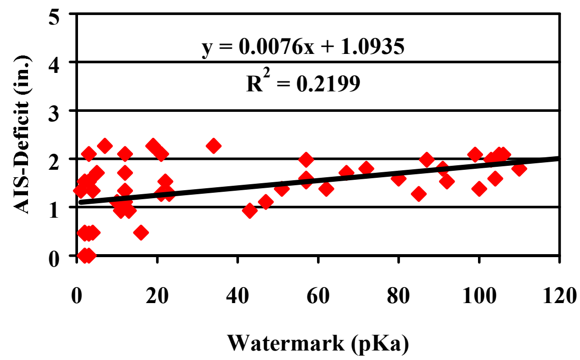
Soybean (AIS-2.5)



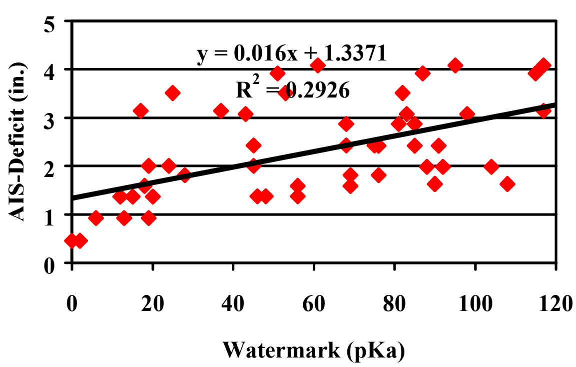
Soybean (non-irrigated)



Cotton (AIS-2.0)



Cotton (non-irrigated)



AGRICULTURAL WATER USE IN GEORGIA:
MONITORING RESULTS FROM AG. WATER PUMPING

D. L. Thomas, K. A. Harrison, J. E. Hook, L. Wheeler, G. Hoogenboom[1]

ABSTRACT

Results from three years of agricultural water use monitoring are presented for the state of Georgia. The Ag. Water Pumping program, with statistically valid sampling of all water withdrawals, indicates that between 10.8 and 5.8 inches of water were applied "on the average" depending on the region of the state and the year (1999 to 2001). Since all three of these years have designated drought distinctions, agricultural water use was not as high as might have been projected.

INTRODUCTION

The following paper presents results (to date) of the Ag. Water PUMPING (Agricultural Water: Potential Use and Management Program IN Georgia, see: www.AgWaterPumping.net) monitoring program. Since Georgia does not currently have a requirement for agricultural water users to report their use, Ag. Water PUMPING was designed to address this shortfall. With over 21,000 permitted withdrawals, it was not feasible five years ago to require all permitted users to report their water use (cost, personnel, and political constraints). Ag. Water PUMPING was instituted to monitor a representative sample (2%) of all agricultural withdrawals. Wheeler et al. (2002) described how this program was developed and the process used to collect data.

METHODS

The methods for this study have also been described by Wheeler et al. (2002). Preliminary data and procedures were discussed by Thomas et al. (2001), Houser et al. (2001), and Thomas et al. (1999). The main goal of this paper is to present and consolidate the results. The partitioning of agricultural region in the state of Georgia has a strong bearing on the way results are to be presented. The current tri-state water war between Georgia, Alabama, and Florida associated with waters within the Chattahoochee, Flint, and Apalachicola Rivers created a "southwestern" division in our data set. Basically, we separated the southwest region based on surface and ground water that is directly associated with the Flint River

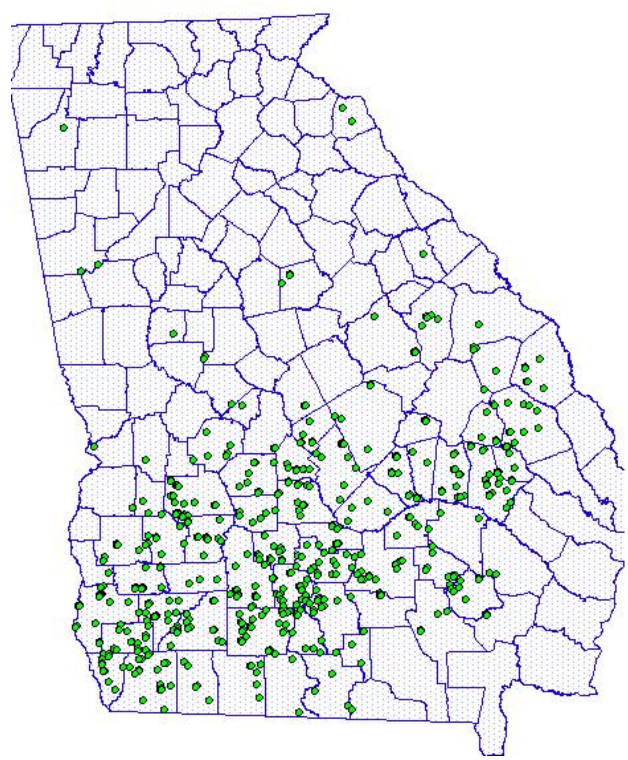


Figure 1. Distribution of monitoring sites within Ag. Water PUMPING.

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(called the Flint Basin). We are also dealing with significant salt water intrusion issues along the coast. A 23 county region was designated (tier 1 to tier 3 counties) to address the salt water intrusion problem. The surface and ground water withdrawals within these counties are associated with the Coastal Zone region of the state. Both of these two regions are currently under a moratorium for new agricultural permits (ground water). Surface water withdrawal permits are still allowed in the coastal region, but most of the easily-accessible (and economical) surface water resource withdrawals are already in place.

The central part of the state is currently not facing moratoriums or lawsuits. This area was the last to be instrumented by our project, and has a greater percentage of surface water withdrawals. This region (everything else in south Georgia) is designated as the Central Coastal Plain (CP) region of Georgia. Additional agricultural withdrawal permits are being monitored in North Georgia, but the total number of permits and the number of monitored sites makes these withdrawals somewhat negligible in the overall analysis.

Presentation of agricultural water use data can be in a variety of different formats. The one chosen for this paper is "inches". Inches of water use implies "acre-inches" or water that has been applied over a particular crop area to that average depth. One of the largest constraints in presenting agricultural water use data in Georgia is the lack of definitive data on exactly how many permitted withdrawals are actually in use, and whether all withdrawals are represented in the permit data base. The Cooperative Extension Service of the University of Georgia has performed an irrigation survey periodically over the past two decades. The most recent irrigation survey (2000) indicated that there were over 1.5 million acres of irrigated acreage in the state of Georgia (Harrison, 2001). At the same time the permit data base indicated over 2.0 million acres of agricultural irrigation, and the National Agricultural Statistics Service (NASS) indicated less than 750,000 irrigated acres in the state of Georgia (Hook et al., 2001) . Choosing the correct irrigated land area has a major bearing on total withdrawals due to agriculture.

RESULTS

General results from monitoring program are described in Table 1 from each of the three basins for the three years of actual monitoring. Installation (*) years are so designated. Only those sites with complete irrigation records were used in the installation years. It is important to note that south Georgia has been in a drought since 1998. Rainfall has been quite a bit less than normal during this period. These results are averaged across all monitoring sites and crops within the particular regions. The total acreage associated with the indicated water use values are also indicated.

Table 1. Average Irrigation Water Use from Ag. Water Pumping.

<u>Total Monitored Irrigation in Year 1999:</u>	
Flint Basin:	10.82* in.
Central CP:	-
Coastal Zone:	7.63* in.
<u>Total Monitored Irrigation in Year 2000:</u>	
Flint Basin:	10.17 in. on 19,920 ac
Central CP:	7.26* in.
Coastal Zone:	7.48 in. on 5,130 ac
<u>Total Monitored Irrigation in Year 2001:</u>	
Flint Basin:	7.51 in. on 19,830 ac
Central CP:	5.80 in. on 16,070 ac
Coastal Zone:	6.56 in. on 5,740 ac

Questions immediately arise as to the "reason" for the differences across the regions of the state. Obviously, the first reason is the differential distribution of rainfall during the growing season. Afternoon thundershowers and frontal systems create localized rainfall patterns with potential for drastic differences in rainfall across the state. Obviously, rainfall variations are likely to be a prime reason for the differing irrigation values. Figure 2 indicates rainfall characteristics for selected months in the year 2000. At least four weather stations within the Georgia Agricultural Environmental Monitoring Network (Hoogenboom, 2001) were used to create the rainfall values in each region of the state. The long-term average values are based on 60+ years of historical records from the Tifton, Georgia weather station. Long-term average rainfall is quite consistent across the southern portion of the state. The rainfall values are "total" rainfall, not "effective" rainfall. In some months, rainfall totals were achieved by a couple of large rainfall events. Much of this rainfall was likely to runoff or go to deep percolation (and not be available for plant use). September was the only month with widely varying rainfall amounts across south Georgia as compared to the other months.

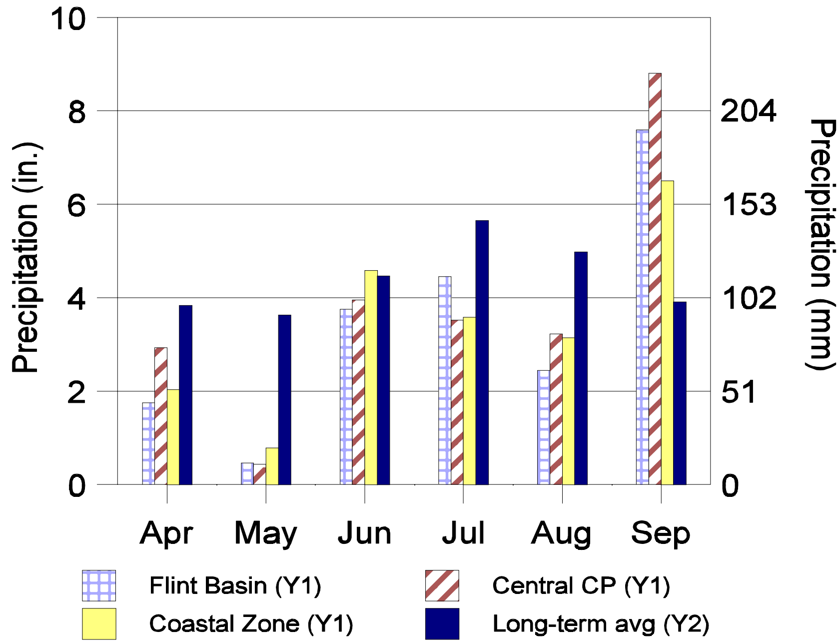

Figure 2. Year 2000 rainfall distribution during the primary growing season for most agricultural crops.

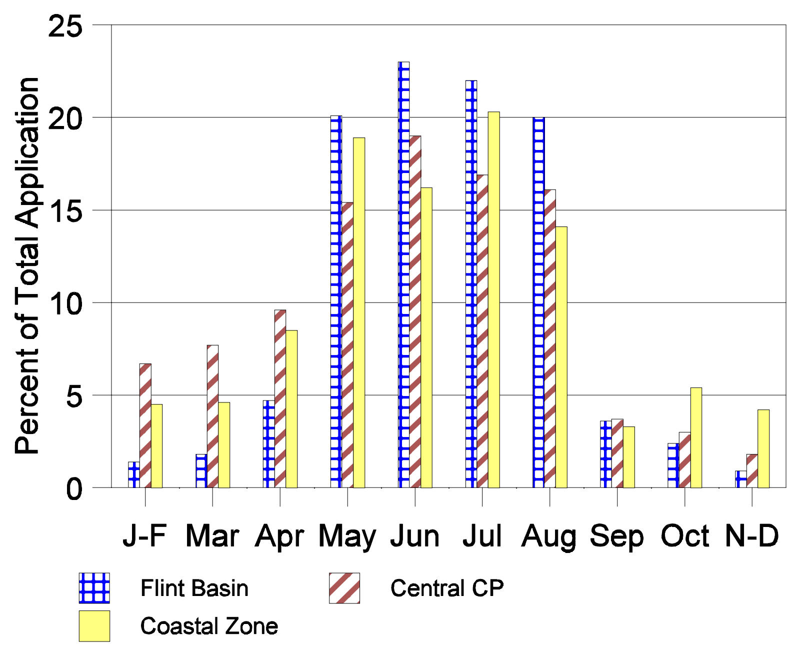

Figure 3. Year 2000 irrigation water use as distributed across the year.

The year 2000 was defined as a drought year. However, only a few months showed evidence of severe drought conditions. Figure 3 illustrates the distribution of the irrigation during 2000. In a typical year, irrigation applications are highest in the months of May through August because most summer crops are being irrigated sometime during those months. The percent of total application indicated in the figure is a representation of when irrigation applications occurred throughout the year. For the Flint Basin, most irrigation was during the summer months. For the other regions, irrigation applications were distributed throughout the year. For the Coastal Zone, the

Vidalia onion season has irrigation applications during the winter months. Based on the information shown in Table 1, more water was applied in the Flint Basin in 2000. This may have been a result of "water availability" rather than "water need".

Figure 4 describes rainfall characteristics in 2001, also described as a drought year. Average rainfall conditions for all locations across South Georgia (based on at least 5 raingages in each region from the Georgia Automated Environmental Monitoring Network (GAEMN; www.Georgiaweather.net) indicated lower than normal rainfall for April, May, July and August. Also, rainfall in the Flint Basin was quite a bit lower than normal and lower than other regions in July.

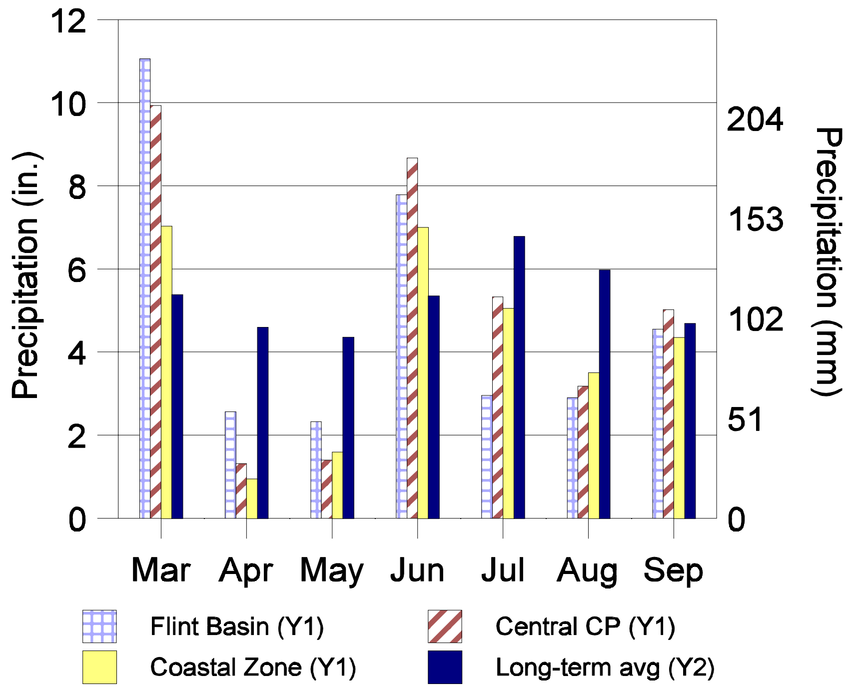

Figure 4. Year 2001 rainfall distributions across the southern portion of Georgia.

Irrigation applications reflected the differences in rainfall. The greatest amount of water was being applied during July in the Flint Basin. July is one month when most major row crops are being irrigated (corn, cotton, and peanut). The year 2001 was also the first year that the installation of monitoring sites was complete for Ag. Water Pumping.

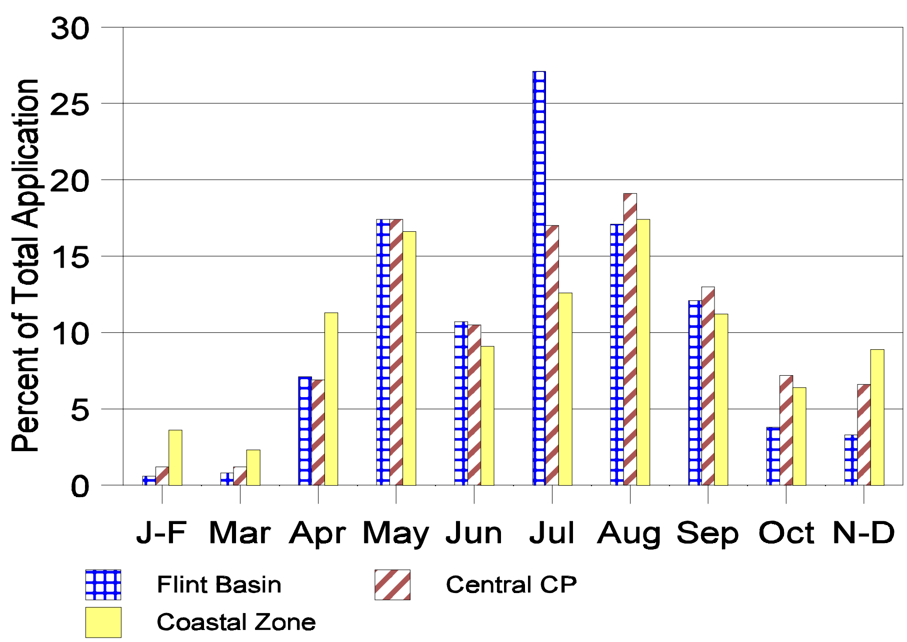

Figure 5. Year 2001 irrigation water use throughout the year.

It is important to realize the impact and benefit of rainfall during the growing season. Although drought conditions were evident, total irrigation amounts were not significantly high. Projections by the Georgia Environmental Protection Division indicate "that during a drought year, farmers could be using more than 17 inches" (Rehis, 2002). That does not seem to be the case in the statistically valid results of the Ag. Water Pumping program.

One other way to describe the irrigation data is to compare results between 2000 to 2001. Consistent trends in irrigation water use can help with general water management decisions. Figures 6-8 describe the 2000 and 2001 irrigation characteristics for the Flint Basin, Central Coastal Plain, and the Coastal Zone, respectively. The Central Coastal Plain and Coastal Zone results indicate that general water use trends cannot be assumed from year to year. In all three areas, more systems were operating in the first part of 2000 as compared to the first part of 2001. In addition, more systems were operating in the later part of 2001 as compared to the later part of 2000. Additional research on effective rainfall, water supply availability, cropping patterns, and the decision process used by farmers when irrigating, is required to fully understand why irrigation patterns differ from year to year. Some of that data is available in the data base associated with the Ag. Water Pumping program, however, we may not be able to answer all questions with the information available.

<u>Why are farmers using less water than may be projected?</u>

There are many factors that may influence the decision by farmers to use less water. One reason is the inability of many irrigation systems to actually apply that much water during a crop growth period (2 to 3 months). Some irrigation systems have limited water supplies (surface withdrawal permits), thus water must be strategically placed during critical crop growth periods for maximum potential benefit. The rate of return on added water (cost of water versus expected crop yield benefits) is another reason

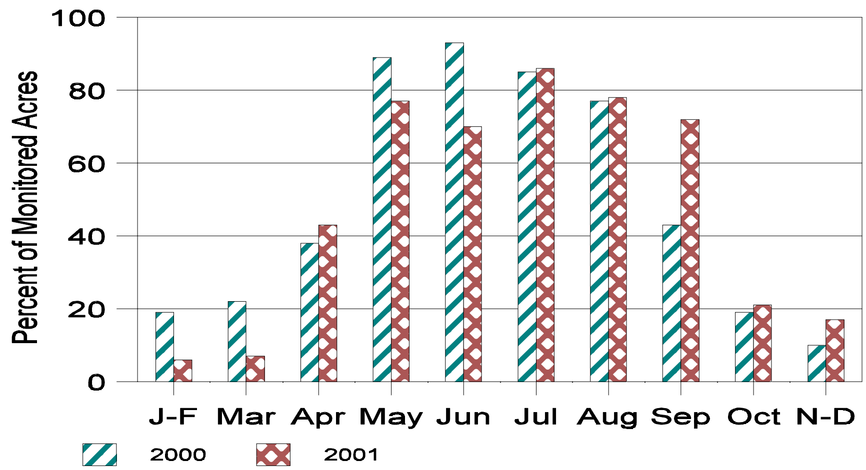

Figure 6. Percentage of monitored acres irrigated in the Flint Basin by month for each year.

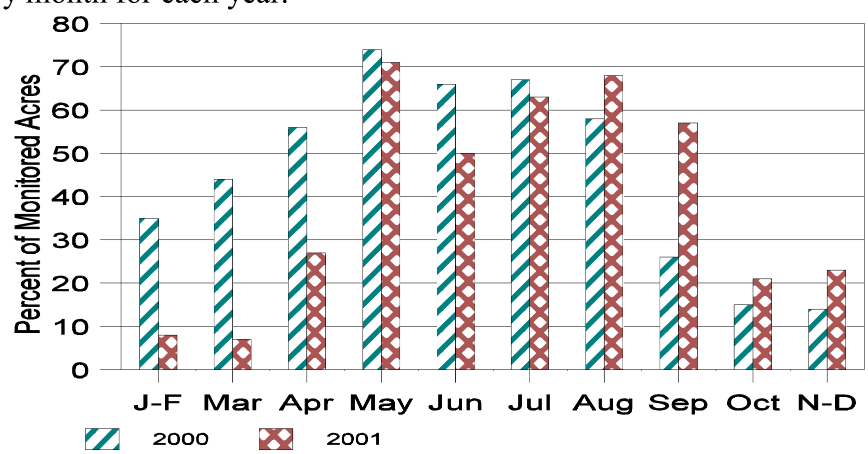

Figure 7. Percentage of monitored acres irrigated in the Central CP by month for each year

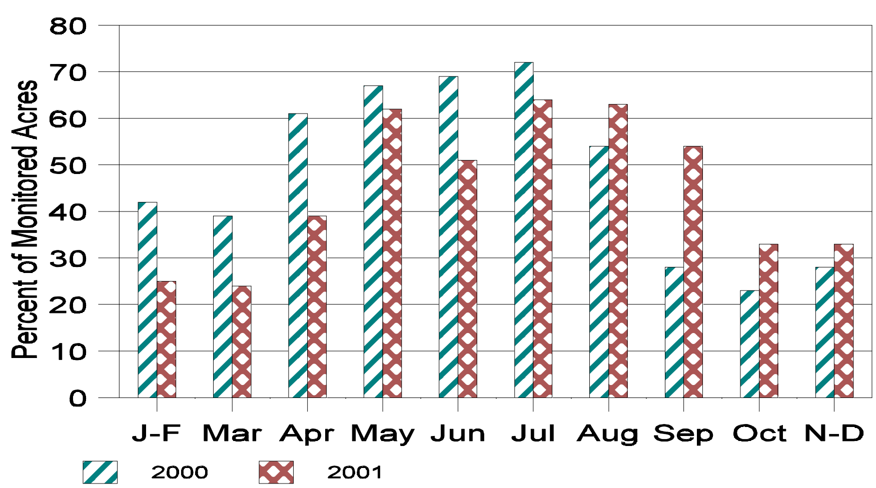

Figure 8. Percentage of monitored acres irrigated in the Coastal Zone by month for each year

why farmers may not be using as much water. One other factor that influences water application amounts is scheduling approaches. Many different approaches have been suggested and encouraged to help farmers determine crop water needs and when to irrigate. Unfortunately, scheduling remains a significant need, especially for cotton. The University of Georgia introduced the EASY Pan as a way to help farmers schedule both cotton and peanut irrigation (Thomas et al, 2001; Thomas et al., 2002). The unit was designed to require little maintenance and time by the farmer during the growing season. Other options that are being evaluated include simple computer models and irrigation decision support systems.

CONCLUSIONS

Farmers are using a significant amount of water for irrigation in Georgia. Using an estimated 1.6 million acres of irrigated land, farmers used on the average between 0.7 and 1.3 bgd (billion gallons per day) from 1999 to 2001, depending on their location in the state (based on the average 5.8 to 10.8 inches applied). Rainfall provides some contribution to the irrigation water needs, however, total rainfall does not explain all variations associated with "when" water is used. The Ag. Water Pumping program is providing a statistically-valid indication of agricultural water use. Since rainfall variability, crop rotations, water supply availability, scheduling approaches, and economic viability all contribute to farmer decisions about irrigation, the need for effective understanding about "why farmers use the water the way they do" is very important. However, agricultural water use during drought years may not be as severe as has been projected by some agencies.

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IDENTIFYING AND RELIEVING SOIL WATER REPELLENCY IN TURFGRASS SYSTEMS

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INTRODUCTION:

Soil water repellency is a challenging water management issue for turfgrass managers. Identifying the extent and subsequent approach to alleviation of soil water repellency through practical surfactant application is often the most prudent approach. Surfactant application delivery via irrigation systems is an intriguing method for routine management of soil water repellency. The objective of this experiment was to determine the efficacy of several surfactants when applied through an irrigation system.

MATERIALS AND METHODS:

On May 24, 2000 the treatments listed below were applied and then re-applied on 7/7, 8/2, and 10/25 using the FLREC's chemigation plots. The research plots were allowed to recover the month of September due to the combined effects of dry down stress and management. Treatments were applied to 4 replications of 4m x 4m bermudagrass plots that can be individually controlled to deliver precise volumes of irrigation mixed with treatment solutions. The experiment consisted of four dry-down periods after treatments were applied and irrigated following irrigation protocol (5/24-6/19, 7/7-7/21, 8/2-8/18 and 10/25-11/15). In between dry-down periods plots were maintained with 1.0lb N/1000ft^2 of 16-4-8 and treated by herbicides. Turfgrass quality (scale of 1-10 with 10=dark green turf, 1=dead/brown turf and 6=minimally acceptable turf), percent localized dry spots (LDS), and soil moisture measurements were taken prior to initiation and for the duration of the study. Soil cores were removed from plots prior to application and through the experiment. Water drop penetration tests were performed on soil cores. All data was subject to statistical analysis and significant means were identified.

TREATMENTS:

1. ACA 1761 @ 2 oz/1000ft^2 with 1/16" irrigation
2. ACA 1761 @ 2 oz/1000ft^2 with 1/8" irrigation
3. InfilTRx @ 0.75 oz/1000ft^2 with 1/8" irrigation
4. BreakThru @ 0.75 oz/1000ft^2 with 1/8" irrigation
5. Control

RESULTS AND DISCUSSION:

The experiment bracketed a period of seasonal and atypical dry weather that allowed for several observation periods favorable for evaluating treatment effects. As a result, significant treatment effects were noted for many of the parameters tested over the experiment (Tables 1–8). Turfgrass quality was improved by surfactant treatment during the typical dry season in May and during unusual droughts in August and late October, and fewer differences were observed during a normal wet season in July (Table 1). Individual treatments received similar ratings with few consistent differences (Table 1). Infiltrx had among the highest ratings on most dates as did 1761applied with 1/16th inch of water (Table 1).

Soil moisture content was significantly affected by treatment on three measurement dates (Table 2). Early on, controls had greater moisture content and later on during a severe dry period in November, the control had significantly lower moisture (Table 2). Since the controls were of lesser quality even in May, this suggests that early on the control could not efficiently take advantage of the moisture in the soil. Later on the treated plots were improved perhaps by the ability to retrieve water more effectively over several stress periods (Table 2).

There were more localized dry spots in the control on Nov. 15 2000 (Table 3). Infiltrx did well on most dates (Table 4). The 1761 1/8th inch irrigation treatment, on some dates, had somewhat more dry spotting (although inconsistent). Water drop penetration time (WDPT) differences were obtained at the surface level (Tables 5 and 8). Generally, treatments had lower WDPT than the control (Tables 5 and 8).

In conclusion, the use of irrigation applied surfactants provided better turf quality during typical and atypical dry periods in south Florida in year 2000.

Table 1. Turfgrass quality ratings for Aquatrols injection study initiated on May 24, 2000.

	-------------------------------------Date-------------------------------------								
Source	5/24[1]	6/7	6/19	7/7[1]	7/21	8/2[1]	8/16	10/25[1]	11/15
BreakTh	7.5ab	7.1	7.4a	5.6	7.1ab	6.8	7.0ab	7.7a	7.8ab
Infiltrx	7.6a	7.0	6.9bc	6.3	7.6a	7.1	7.3a	7.5a	7.4b
1761 1/8”	7.5ab	6.8	6.6c	5.8	6.6b	6.9	7.1ab	7.6a	7.9ab
1761 1/16”	7.8a	7.0	7.1ab	6.0	6.9ab	6.9	6.7b	7.6a	8.1a
Control	7.3b	7.0	6.7c	5.1	6.5b	7.0	7.0ab	6.9b	6.9c
Signif.	+	ns	*	ns	+	ns	+	*	**

+, ns, *, and ** = P<0.10, P>0.10, P<0.05, and P<0.01 respectively.

[1]Treatments applied on these days.

Turfgrass quality ratings based on a 1-10 scale with 10=dark green turf, 1=dead/brown turf, and 6=minimally acceptable turf.

Means with the same letter within a column are not significantly different according to Duncan’s Multiple Range Test.

Table 2. Theta probe readings (moisture content of soil) for Aquatrols injection study initiated on May 24, 2000.

	-------------------------------------Date-------------------------------------								
Source	5/24[1]	6/12	6/16	7/7[1]	7/21	8/2[1]	8/16	10/25[1]	11/15
BreakTh	.337	.243b	.140	.200	.177	.179b	.244	.241	.077a
Infiltrx	.340	.247b	.141	.224	.201	.204ab	.264	.222	.073ab
1761 1/8”	.327	.270a	.140	.206	.175	.209a	.265	.252	.072ab
1761 1/16”	.351	.281a	.143	.231	.190	.214a	.287	.258	.078a
Control	.354	.276a	.154	.230	.199	.213a	.262	.248	.046b
Signif.	ns	**	ns	ns	ns	+	ns	ns	+

+, ns, and ** = P<0.10, P>0.10, and P<0.01 respectively.

[1]Treatments applied on these days.

Means with the same letter within a column are not significantly different according to Duncan’s Multiple Range Test.

Table 3. Percent LDS for Aquatrols injection study initiated on May 24, 2000.

	Date			
Source	6/19	7/18	8/16	11/15
Break-Thru	21.3b	81.3a	17.5b	1.3b
Infiltrx	28.8ab	56.3b	22.5b	5.0b
1761 at 1/8" irrig.	41.3a	82.5a	45.0ab	1.3b
1761 at 1/16" irrig.	23.7ab	70.0ab	38.8ab	0.0b
Control	36.3ab	86.3a	58.8a	13.8a
Significance	+	+	+	**

+ and ** = P<0.10 and P<0.01

Means with the same letter within a column are not significantly different according to Duncan's Multiple Range Test.

Table 4. Water Drop Penetration Time (WDPT) in seconds for Aquatrols injection study soil cores taken on May 24, 2000 (Pre-treatment).

	Depth (cm)						
Source	0	1	2	3	4	5	6
Break-thru	52	13ab	7	0.3	0	0	0
Infiltrx	56.3	21a	9.3	0.5	0.3	0	0
1761 1/8"	64.5	17.5a	8	1.3	0	0	0
1761 1/16	43.5	7.3b	3.5	0	0	0	0
Control	56.7	12.7ab	6	0.8	0.3	0	0
Signif.	ns	+	ns	ns	ns	ns	ns

ns and + = P>0.10 and P<0.05

Means with the same letter within a column are not significantly different according to Duncan's Mulitple Range Test.

Table 5. Water Drop Penetration Time (WDPT) in seconds for Aquatrols injection study soil cores taken on June 13, 2000.

	Depth (cm)						
Source	0	1	2	3	4	5	6
Break-thru	6.3b	1.3	1.3	0.5	0.5	0.3	0.3
Infiltrx	7.0ab	3.3	1.5	1.0	0	0	0.3
1761 1/8"	4.0b	6.0	0.8	0.5	0.5	0.5	0
1761 1/16	2.8b	1.8	0.8	0.5	0.5	0	0
Control	13.8a	1.3	0.8	0.5	0.3	0	0
Signif.	*	ns	ns	ns	ns	ns	ns

* and ns = P<0.05 and P>0.10

Means with the same letter within a column are not significantly different according to Duncan's Mulitple Range Test.

Table 6. Water Drop Penetration Time (WDPT) in seconds for Aquatrols injection study soil cores taken on August 2, 2000.

	Depth (cm)						
Source	0	1	2	3	4	5	6
Break-thru	11.8	5.8	2.8	1.3	0.5	0.3	0.3
Infiltrx	10.8	4.8	3.3	0.5	0.3	0	0
1761 1/8"	11.3	4.3	1.8	0.8	0.3	0	0
1761 1/16	9.3	5.0	2.8	1.0	0.8	0	0
Control	6.8	3.8	2.8	0.5	0	0	0
Signif.	ns	ns	ns	ns	ns	ns	ns

ns = P>0.10

Means with the same letter within a column are not significantly different according to Duncan's Mulitple Range Test.

Table 7. Water Drop Penetration Time (WDPT) in seconds for Aquatrols injection study soil cores taken on August 16, 2000.

	Depth (cm)						
Source	0	1	2	3	4	5	6
Break-thru	7.8	1.5	0.8	0.5	0	0	0
Infiltrx	8.5	3.0	1.8	0.5	0	0	0
1761 1/8"	9.3	2.3	0.8	0.3	0	0	0
1761 1/16	5.0	1.5	0.5	0.3	0.3	0	0
Control	10.5	2.0	0.8	0.3	0	0	0
Signif.	ns	ns	ns	ns	ns	ns	ns

ns = P>0.10

Means with the same letter within a column are not significantly different according to Duncan's Mulitple Range Test.

Table 8. Water Drop Penetration Time (WDPT) in seconds for Aquatrols injection study soil cores taken on November 1, 2000.

	Depth (cm)						
Source	0	1	2	3	4	5	6
Break-thru	5.0b	2	0.3	0	0	0	0
Infiltrx	3.3b	0.8	0	0	0	0	0
1761 1/8"	5.5b	1.5	0.5	0	0	0	0
1761 1/16	7.8ab	1.8	0.8	0.3	0	0	0
Control	12.0a	1.3	0.3	0	0	0	0
Signif.	*	ns	ns	ns	ns	ns	ns

ns = P>0.10

Means with the same letter within a column are not significantly different according to Duncan's Mulitple Range Test.

Addition of Surfactants to Turf Systems: Effect on Infiltration Rates and Root Zone Water Storage.

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Abstract: The projected increase of 15 million in California's population by the year 2020 will result in further competition among various sectors for the State's limited water supply. In an effort to deal with this competition, the turfgrass industry has been adopting management practices that will increase water use efficiency and ensure the industry's sustainability. The overall goal of this research was to evaluate the addition of surfactant to irrigation water as a management strategy for commercial turf systems such as golf courses. The impacts of three surfactant formulations, applied at two rates, on overall turf quality, steady rate infiltration and water storage in the root zone were investigated. Based on visual evaluation, there was generally a positive effect of the surfactants on the overall improvement in turf quality. Surfactant addition significantly affected infiltration rates at both the high and low application rates. However, the surfactant that resulted in the highest infiltration at the low application rates was different from the one that significantly increased infiltration at the high rates. For the low application rates, the surfactant that resulted in the greatest increased infiltration also indicated the potential for maximum water use efficiency. However, for the high application rates, water loss from the root zone for the surfactant treated plots were either greater than or equal to that from the control plots.

Introduction: In the San Joaquin Valley- and in general, California- economic and population growth has resulted in competition for water supply between the agriculture sector and the increasing urban population. Environmental restoration is also placing increased demands for water supplies. For example, the growers of the California's Central Valley West Side recently lost 800,000 acre-feet of water that was redirected for environmental purposes (City of Fresno Dept. of Public Utilities, 1999). The projected increase of 15 million in California's population by the year 2020 will only result in further competition among the various sectors for the State's limited water supply (California Farm Water Coalition, 1999).

Besides the increased competition for a limited water supply, the agriculture sector must also adhere to strict environmental protection regulations. As a result, this sector has been adopting Best Management Practices (BMPs) in order to ensure its sustainability. As defined, a BMP is a practical, affordable approach that will eliminate or minimize air, water and soil degradation without sacrificing productivity of the operation. The approach comprises of a number of strategies, which when implemented either simultaneously or sequentially would maintain the productivity and sustainability of the system. In keeping with this philosophy, members of Turfgrass Producers International (TPI) have acknowledged that (a) water is the single most important resource for every aspect of this green industry, (b) management is the critical factor in water use efficiency, and (c) BMPs should be implemented to enhance water use efficiency (Slack, 1999). Some examples of the strategies currently used in establishing BMPs for the turf grass industry include: laser leveling of fields; lining of ditches; use of soil moisture monitoring devices; use of overhead or drip irrigation systems; use of wind and rain sensors; reuse of water on site; on-site water management analysis; early mornings and late night waterings; higher mowing during the hotter months; and, use of effluent water for irrigation (Slack, 1999).

Another approach being adopted by the turfgrass industry is the application of non-ionic surfactants. The premise behind the use of the surfactant is that it reduces the surface tension of the water, and thus enhances the penetration of the water into the soil profile. For example, Miller (1999) demonstrated in a column study that for six cm of two hydrophobic soils, the infiltration times of an 8000 ppm solution of a non-ionic surfactant blend was 98% lower than the times for distilled water alone. In a subsequent study, involving a San Joaquin sandy loam collected near Bakersfield, CA, it was found that addition of surfactants and gypsum greatly improved infiltration into this soil (Mauser, 1999). At the field scale, Kostka (2000) demonstrated that systematic treatment with a commercially available surfactant reduced soil water repellency, enhanced turf performance, improved uniformity of turf, and increased available water in soils.

Despite the laboratory tests that show a major improvement in infiltration rates of water through a soil column, and the study by Kostka (2000), there is a need to evaluate the use of different surfactants at the field scale, for systems such as commercial turf sites. Such an evaluation will scientifically examine the use of a surfactant on infiltration rate, irrigation efficiency and overall sustainability of the system. These evaluations should also document the impacts (both positive and negative) of the surfactant treatment on the water, soil and vegetation. Hence, the objective of the current study was to evaluate the systematic application of surfactants as a management strategy for commercial turf systems such as golf courses. The impacts of three surfactant formulations, applied at two rates, on overall turf quality, steady rate infiltration and water storage in the root zone were investigated.

Procedure: Trials were conducted at the Riverside Golf course in Fresno California, located in the center of the agriculturally rich San Joaquin Valley. Riverside Golf Course sits along the San Joaquin River in the North West corner of the city. The course is very old and has developed dry spots along the edge of fairways that watering has little or no effect on. The fairways are planted in a Bermuda grass and top seeded in the winter with rye. The soil type ranges from a loam to a sandy loam, with soil pH ranging between 6.5 and 7.9. A water resistant hardpan layer that may occur as shallow as 20 cm from the soil surface also characterizes the area.

The trials comprised of two experiments: (1) A High Rate experiment; and, (2) A Low Rate experiment. A total of 32 experimental plots (2 meters x 2 meters) were used, with 16 plots for the High experiment and 16 plots for the Low experiment. The areas chosen for the experiments were based on the recommendations of the golf course superintendent. The High Rate experiment was conducted in an area characterized by lower water infiltration and by relatively poorer turf quality than the area used for the Low Rate experiment. Both experiments followed a completely randomized design with four treatments replicated four times.

Treatments for Low Rate Experiment:**

(1) L0- no surfactant, Control;
(2) L1- a commercially available non-ionic surfactant blend, applied once a month at 17.5 mls/100m^2;
(3) L2- a commercially available non-ionic surfactant blend, applied once a month at 10mls/100m^2; and,
(4) L3- an experimental surfactant formulation, applied once a month at 250mls/100m^2.

Treatments for High Rate Experiment:**

(1) H0- no surfactant, Control;
(2) H1- a commercially available non-ionic surfactant blend, applied once a month at 25 mls/100m^2;
(3) H2- a commercially available non-ionic surfactant blend, applied once a month at 17.5 mls/100m^2; and,
(4) H3- an experimental surfactant formulation, applied **twice** a month at 250mls/100m^2.

** In keeping with the 2002 Irrigation Association Technical Conference guidelines that presentations be "**non-commercial**" in content, the brand names of the treatments are not reported.

Treatments were applied in 2 liters of water using a portable carbon dioxide pressurized sprayer. Applications were done from July though November 2001, and again in January 2002. All 32 plots were visually evaluated on July, August, October, and November of 2001 and finally in May 2002, approximately four months after the last surfactant application. The resident golf course superintendent conducted visual ratings of the plots for color, density, uniformity, general growth vigor, and overall turf quality. The evaluation method used was a scale of 1 to 9, with 1 to 3 indicating unacceptable quality turfgrass, 4 to 6 indicating acceptable quality turfgrass, and 7 to 9 indicating superior quality turfgrass (Zoldoske, 1994).

Infiltration studies were conducted in June (T0), August (T1) and October (T2) in 2001, and finally in January 2002 (T3). The objective was to determine the effect of the different surfactant on steady rate infiltration, also referred to as *steady-state infiltrability* or as the *final infiltration capacity* (Hilllel, 1998), after one (T1), three (T2) and five (T3) rounds of surfactant treatments. Double ring infiltrometers were used, for a total of 384 infiltration experiments (32 plots x 3 infiltration expts. per plot x 4 rounds of expts.), in order to calculate the average steady rate infiltration (cm h^{-1}) for each treatment.

Four rounds of cumulative volumetric soil moisture content for the 0-20cm depth were taken with a Diviner 2000 portable soil moisture monitoring system (Sentek Environmental Technologies, 1999). The objective was to see how the surfactant treatments could be affecting the water movement or water holding capacity within the root zone, as plots were exposed to similar water application and evapotranspiration rates. These moisture readings were taken two hours apart, and the relative change in moisture content for the various treatments were assessed. Percent changes in moisture assessments were determined at times T1, T2 and T3 corresponding with the infiltration studies, and then at the end of May 2002 (T4) to coincide with the final visual assessment of the plots.

Results and Discussion: As expected, at the start of the trials the plots used for the Low Rate experiment had a relatively higher overall turf quality rating (Figure 1a) than those used for the High Rate experiment (Figure 2a). At the final visual evaluation (May 2002), there was a general improvement in turf quality of all plots (Figures 1b and 2b). More importantly, a positive effect of the surfactant was noticeable in the High Rate experiment. The H3 treatment resulted in the best turf quality rating followed the plots treated with H2, H1, and no surfactant, respectively (Figure 2b). The improved turf quality ratings were due primarily to visual improvements in color (Figures 3 and 4), and growth vigor (Figures 5 and 6). Throughout the experiments, no substantive improvements were observed for mean growth density and growth uniformity.

In this study, the steady rate infiltrations were examined rather than the initial or "early time" infiltration. In general, soil infiltrability is relatively high in early stages of infiltration, particularly where the soil is dry, but tends to decrease monotonically and eventually approach an asymptotic constant infiltration rate (Hillel, 1998). Hence, by comparing the "late time" steady rate infiltrations, care was taken to ensure that the values being compared were not influenced by the initial moisture content of the plots or by the differences in ponding head in the ring infiltrometers (Stephens, 1996). The infiltration experiments were conducted for 120 minutes, and generally, the steady state infiltrability (or " late time" steady rate infiltration) was attained after 90 minutes.

There were no significant differences in the steady rate infiltrations for the plots prior to the addition of any surfactant (T0). In general, the addition of surfactant resulted in an increase in the steady rate infiltrations (Figures 7 and 8). ANOVA tests indicated that with the exception of the treatment 1 (L1 and H1), the surfactants resulted in a significant difference in infiltration rates. For both the Low and High rate experiments, the effects of the surfactant were observed after the first application of the surfactants (T1, August 2001). In addition to the ANOVA, a Tukey's HSD revealed that there were significant differences among the surfactant treatments. For example, within the relatively better quality plots (i.e. at the lower application rates) the treatment H3 had the greatest significant ($p = 0.05$) positive effect (Figure 7), whereas in the High rate experiment H2 was most effective after the first surfactant application (Figure 8, see Aug.01). Then, by the third (Oct. 01) and fifth (Jan. 02) rounds of surfactant application, the treatment H3 (experimental formulation) was having the most significant impact on infiltration for the relatively poorer quality plots. It is also noteworthy that in the Low rate experiment, after the 5th rounds of surfactant application both H3 and H2 resulted in significant differences ($p = 0.05$) in infiltration rates.

It is not clear why the treatment 1 (H1 and L1) had no significant effect on the steady rate infiltration. The nonionic surfactant was expected to reduce the surface tension of the water, and thus enhances the penetration of the water into the soil profile. Laboratory tests involving treatment 1 by Miller (1999) and Mauser (1999) indicated that the addition of this surfactant and gypsum greatly improved infiltration into the soil. A probable explanation for the lack of effect observed in the current study could be that a relatively lower application rate was used in the current study.

The objective of measuring soil moisture was to observe which treatment resulted in the greatest percentage change in moisture within the top 20cm of soil (root zone). By considering the mechanisms by which water can enter, exit, or be stored in the root zone, the net change in water storage, ΔS, over the two hour time interval that the moisture readings were taken can be represented by (Stephens, 1996),

$$\Delta S = I - E - R \qquad \text{Eq.1.}$$

where, I is infiltration or precipitation, E is evapotranspiration and R is runoff or deep percolation. Relative change in root zone water storage was calculated using $\Delta S \div S$. It was assumed the all plots were subjected to similar amount of irrigation or precipitation and evapotranspiration. Since there was no runoff occurring then it can be deduced that any change in moisture was a result of water percolating beyond the root zone.

<u>For the Low rate experiment (Figure 9):</u> There appears to be significantly more "deep" percolation from the plots subjected to treatment L2. Interestingly, the moisture changes observed for the L3 was less than that observed for L2 and similar to the plots receiving no surfactants (L0). Recall that from the steady rate infiltration studies (see above) that L3 resulted in the greatest improvement in infiltration for the Low rate experiment. The enhanced infiltration as a result of L3 application combined the lower deep percolation would mean that the water entering the soil would have been available for uptake by the turfgrass, thereby increasing water use efficiency. It should also be noted that: (1) the L1 treatment had the least amount of water loss, but recall that there was also no significant increase in infiltration for the plots treated with this surfactant; and, (2) the relative change in moisture recorded in May 2002 (four months after the plots received any surfactant) from the plots receiving the L3 treatment was similar to the water loss observed for the treatment L2 and no surfactant. Taking into consideration that both the turf quality and infiltration rate due to L3 were considerably better than that observed for the other treatments at May 2002, then the similarity in water loss would imply that after 4 months from the last surfactant application, there is the potential for increased water use efficiency in the plots receiving surfactant L3.

<u>For the High rate experiment (Figure 10):</u> After the first round of surfactant application, the greatest water loss appeared to have occurred within the plots treated with H1 (see Aug 01, Figure 10). At this time, there was minimum water loss from the H3 treated plots and water loss from the H2 treated plots was intermediate between the control (H0) and the H3 treatments. By the time the trial progressed to the fifth rounds of surfactant application, the water losses from the surfactant treated plots were greater than from the control plots. Also, four months after the last surfactant application (May 02, Figure 10), there were similar water losses from within the root zone by all plots (treated and non-treated).

Conclusions and Recommendations:

- There was generally a positive effect of the surfactants on the overall improvement in turf quality.
- Surfactant addition significantly affected infiltration rates at both the Low and High application rates.
- The L3 surfactant resulted in the highest infiltration at low application rates.
- Both H2 and H3 surfactants significantly increased infiltration at the high rates.
- For the low application rates, the surfactant that resulted in the greatest increased infiltration also indicated the potential for maximum water use efficiency.
- For the high application rates, water loss from the root zone for the surfactant treated plots were either greater than or equal to that from the control plots.
- It is suggested that surfactant treatment L3 can be used on plots that are of relatively high quality to ensure maximum water use efficiency.
- It is recommended that for plots of relatively poor turf quality and reduced infiltration rates, at least one application of H2 or H3, and possibly up to a maximum of three consecutive monthly applications, at the rates used in the current study can be used to increase infiltration rates. More than three rounds of applications in consecutive months may result in water percolating pass the turfgrass root zone.

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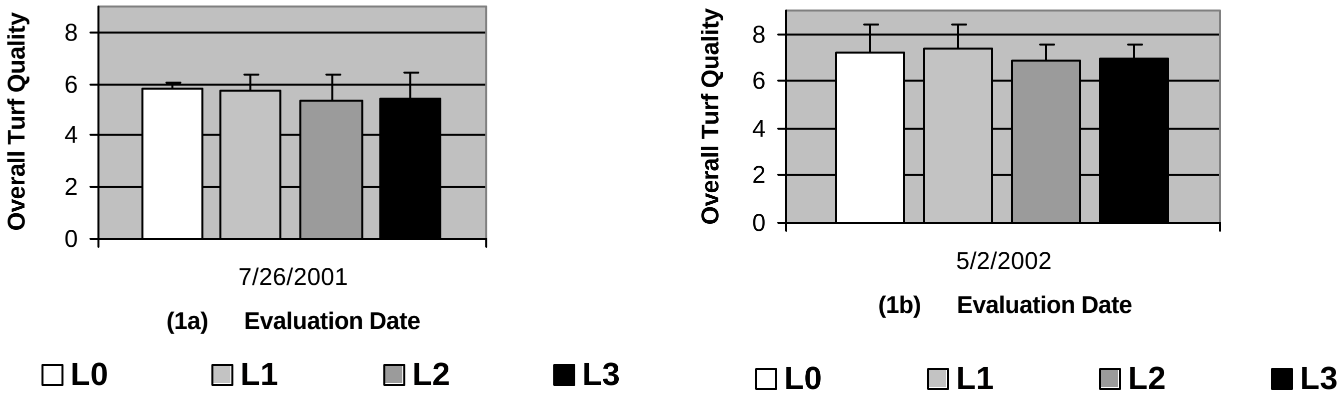


Figure 1: Overall turf quality for Low rate experiment at (a) July 2001 and (b) May 2002.

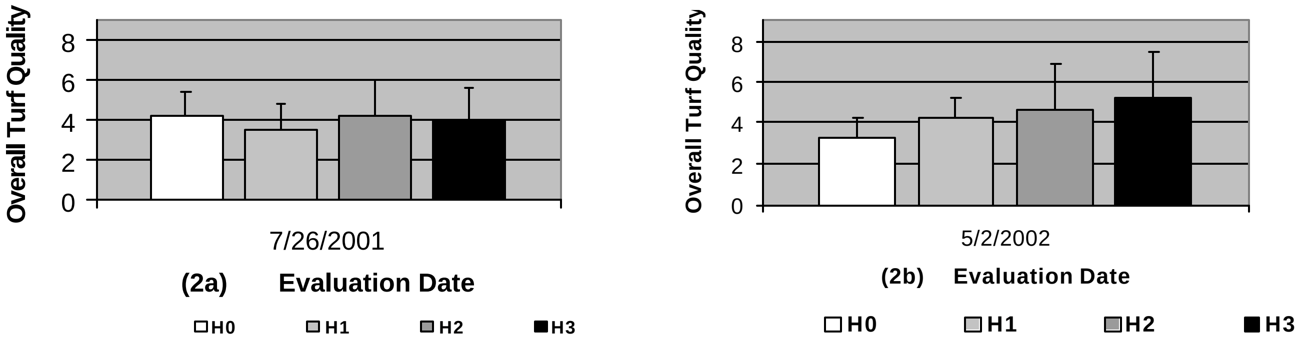


Figure 2: Overall turf quality for High rate experiment at (a) July 2001 and (b) May 2002.

Figure 3: Mean color rating for Low rate experiment at (a) July 2001 and (b) May 2002

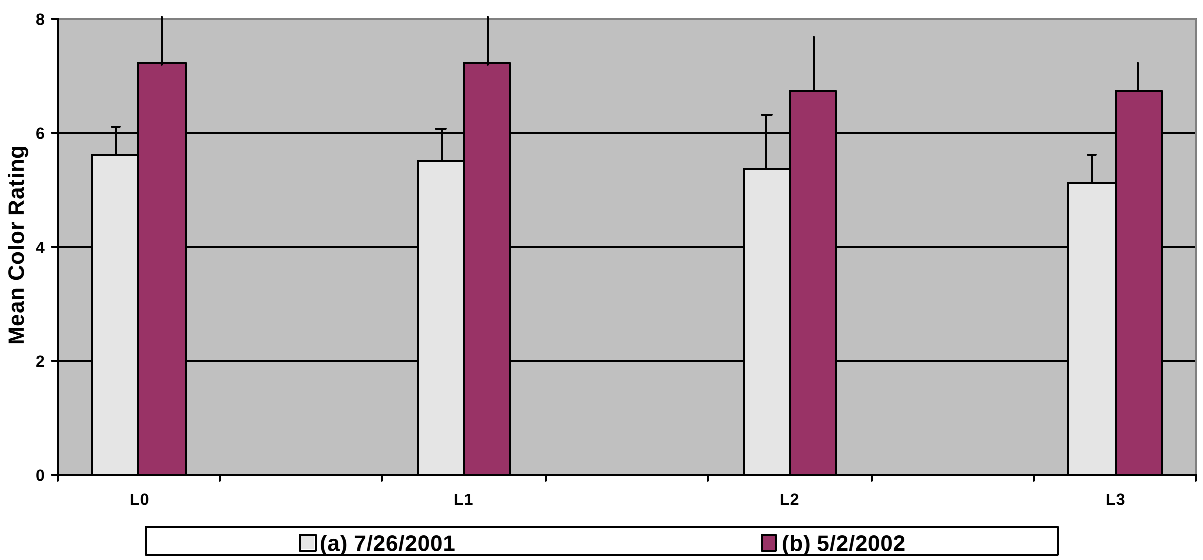


Figure 4: Mean color rating for High rate experiment at (a) July 2001 and (b) May 2002

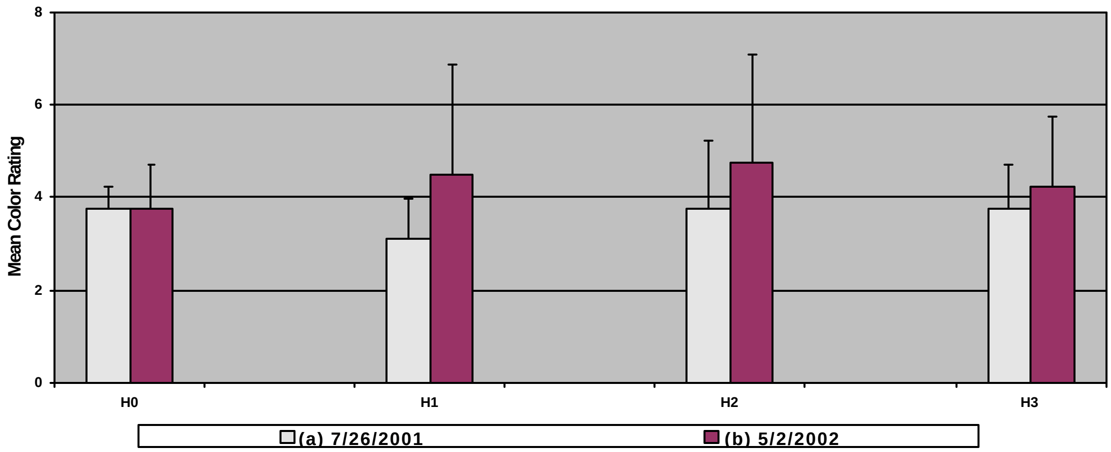


Figure 5: Mean growth vigor for Low rate experiment at (a) July 2001 and (b) May 2002

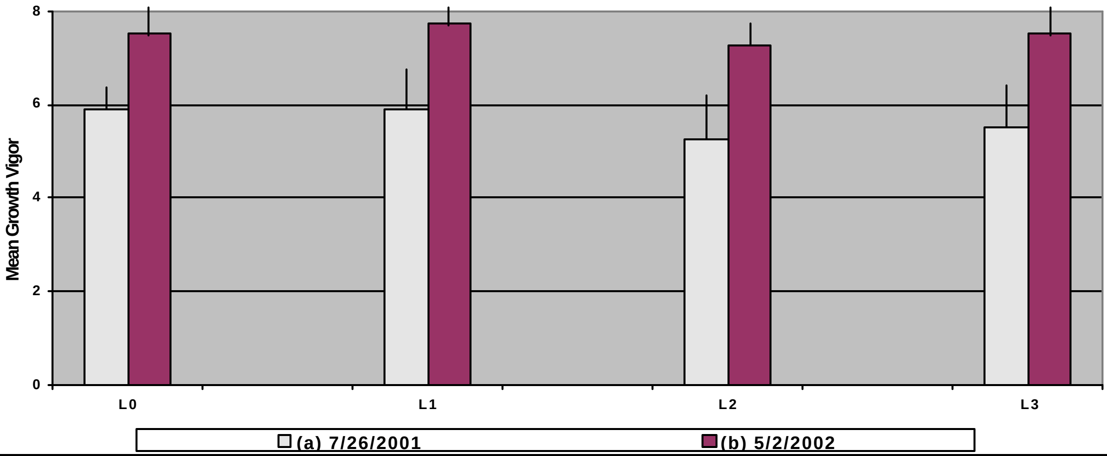
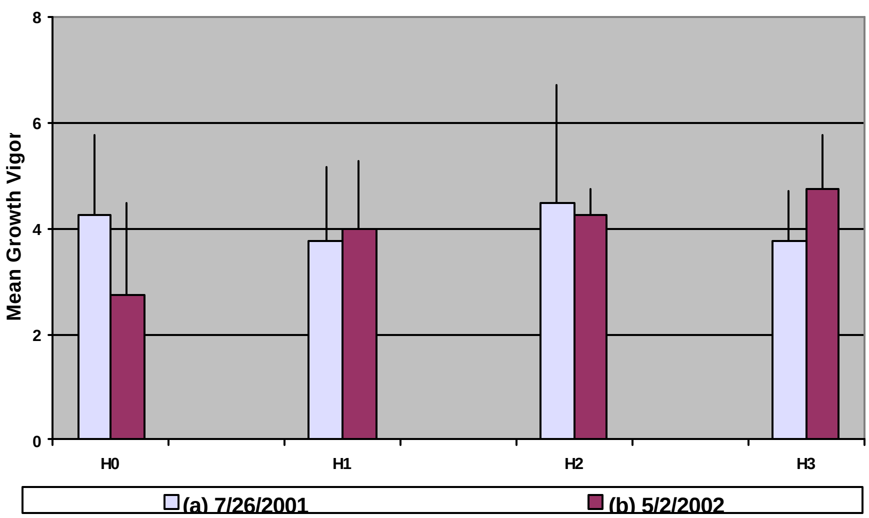


Figure 6: Mean growth vigor for High rate experiment at (a) July 2001 and (b) May 2002



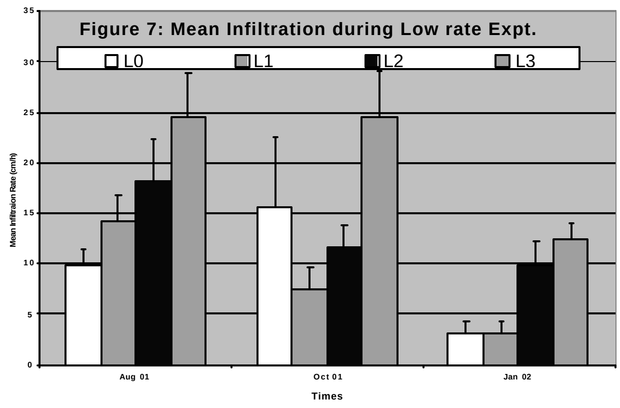
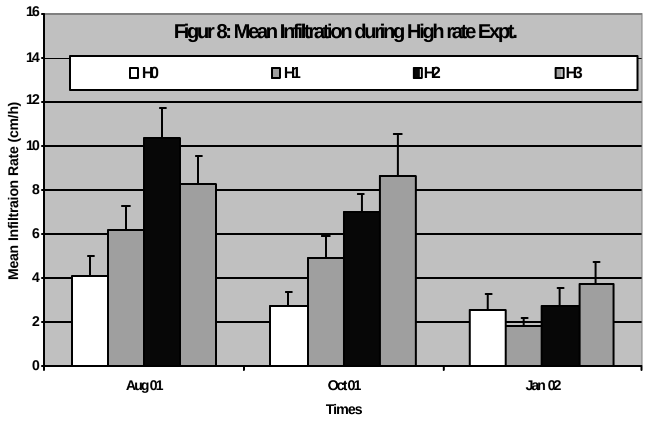


Figure 7: Mean Infiltration during Low rate Expt.
L0
L1
L2
L3
Mean Infiltraion Rate (cm/h)
Aug 01
Oct 01
Jan 02
Times


Figur 8: Mean Infiltration during High rate Expt.
H0
H1
H2
H3
Mean Infiltraion Rate (cm/h)
Aug 01
Oct 01
Jan 02
Times

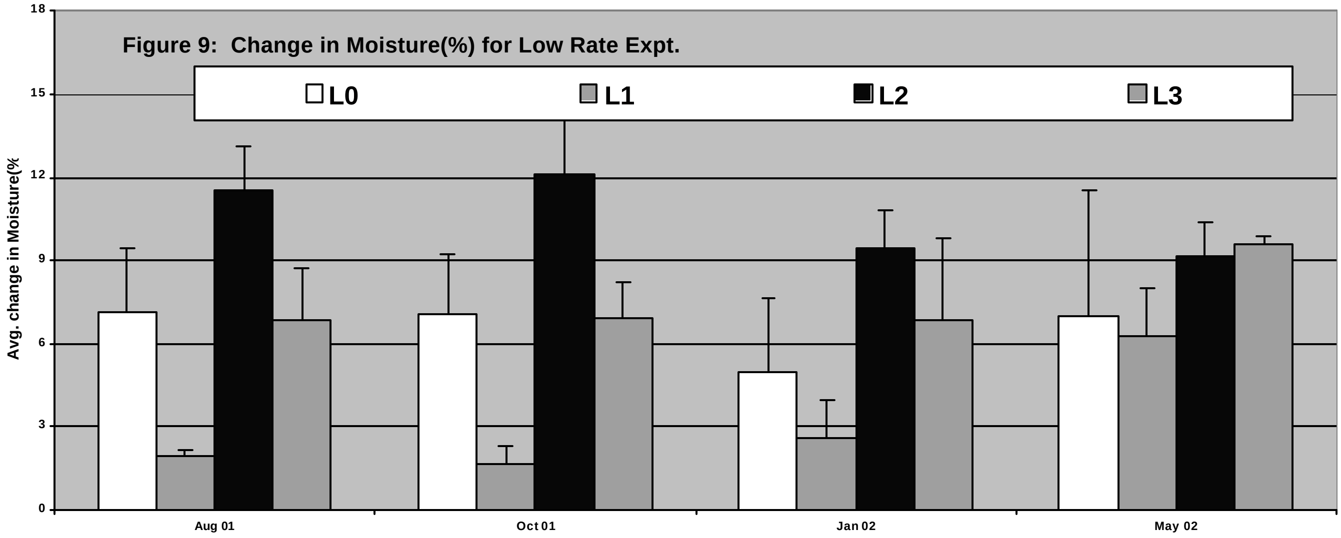


Figure 9: Change in Moisture(%) for Low Rate Expt.
L0
L1
L2
L3
Avg. change in Moisture(%
Aug 01
Oct 01
Jan 02
May 02

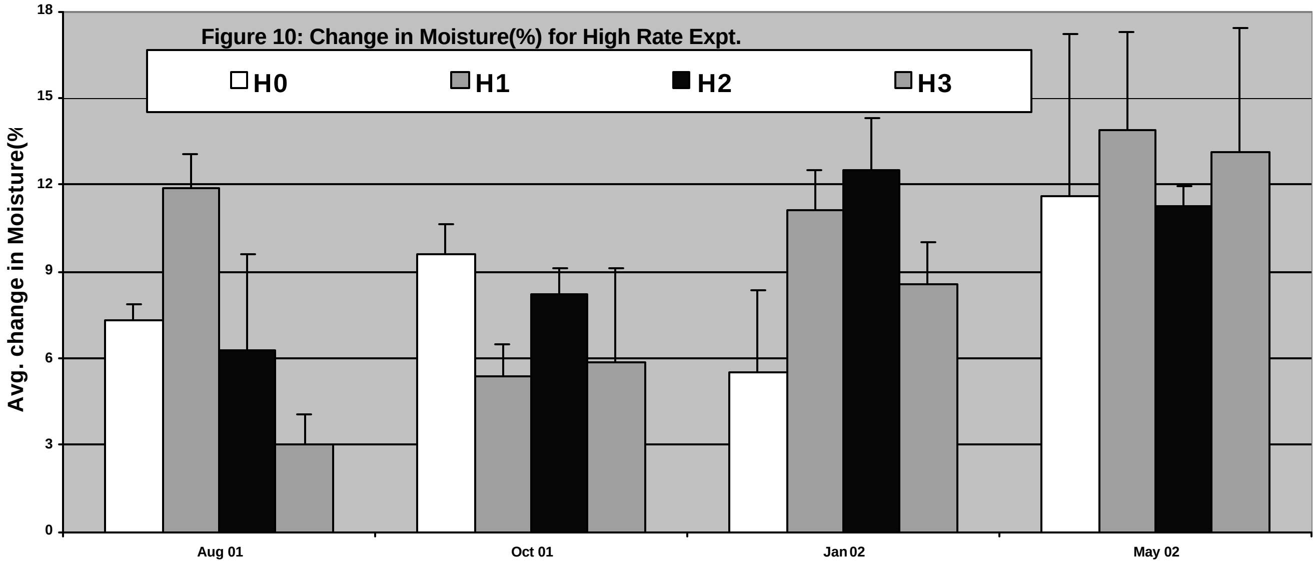


Figure 10: Change in Moisture(%) for High Rate Expt.
H0
H1
H2
H3
Avg. change in Moisture(%
Aug 01
Oct 01
Jan 02
May 02

Advances in understanding and managing water repellent soils.

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Abstract
Water repellency occurs in most irrigated soils, but is most pronounced in coarse sands and sandy soils due to accumulation of hydrophobic compounds on soil particles or to physiochemical changes in soil organic matter. As soils dry, hydrophobic compounds polymerize and water repellency increases. Once a critical moisture content is reached soils shift from wettable to non-wettable, impacting infiltration and unsaturated flow in affected soils, and consequently water use efficiency and turf quality. Surfactant formulations were evaluated on water repellent or susceptible soils at diverse test locations in the United States, the Netherlands and Australia. Treatments reduced water repellency (measured as water drop penetration time), shifted critical moisture content, improved temporal infiltration rate of applied irrigation water, and increased rootzone volumetric water content.

Introduction
Water repellent soil is found worldwide in diverse soils, crops, and cropping systems (Wallis and Horne, 1992) and is common in sandy soils supporting turf or pasture grasses. The phenomenon is most pronounced in coarse sands and sandy soils and is attributed to the accumulation of hydrophobic organic compounds as coatings on soil particles and aggregates, as well as, physiochemical changes that occur in decomposing soil organic matter of plant or microbial origin (Miller and Williamson, 1977; Hallett, 2001). The environmental consequence is decreased infiltration of irrigation water and precipitation, non-uniform wetting of soil profiles, increased run-off and evaporation, and increased leaching due to preferential flow (Dekker et al., 2001a).

Surfactants are well documented for the management of water repellency (hydrophobicity) in thatch and soils, and for the enhancement of soil hydration in managed turfgrass (Miller and Kostka, 1998; Cisar et al., 2000; Kostka, 2000; Karnok and Tucker, 2001). Leinauer et al. (2001) reported that different soil surfactants could influence the depth of water distribution in a sand rootzone mix, but not loamy soils under greenhouse conditions. The use of soil surfactants has been suggested as a tool to improve irrigation efficiency and water conservation, yet systematic studies to substantiate this hypothesis have not been published.

Maintenance of turf quality and simultaneous optimization of irrigation and conservation of water are goals of turfgrass managers, especially under drought conditions. Water may be conserved by maximizing input effectiveness (irrigation, precipitation) or minimizing output losses (transpiration, evaporation, runoff, and leaching or drainage below the rootzone) (Anon., 2002). The key to water conservation is maximizing the amount of water entering the turfgrass rootzone and it's storage and availability once in the rootzone. Management tactics include: reducing transpiration, reducing evaporation, increasing infiltration, reducing ponding, optimizing retention in the rootzone, and controlling water movement below the rootzone (leaching).

Materials and Methods

Two commercial surfactants, Primer®604 or Aqueduct® (Aquatrols Corporation of America, Cherry Hill, NJ), were evaluated at selected locations. Treatments were applied according to label recommendations to soils in replicated plots which exhibited symptoms of, or had a history of, soil water repellency. Plot size varied by test location ranging from 0.9 m^2 to 6 m^2, with the exception of the Netherlands where plots were 25m x 5 m. Aqueduct treatments were applied weekly (250 ml/100m^2) in a curative management strategy at sites in New Jersey and Arkansas. Primer was applied monthly in a program or preventative strategy at sites in Australia and the Netherlands. In Australia, the surfactant was evaluated at two rates (125 ml/100m^2 and 190 ml/100m^2), while in the Netherlands, the surfactant was tested at 190 ml/100m^2. Soils in New Jersey, Victoria (Australia), and Arkansas were putting greens built to USGA specifications (USGA, 1993). The Dutch test location was a fine sand with less than 3% clay.

Soil water repellency was assessed in soil cores extracted prior to application of treatments. A minimum of five cores were extracted from each plot on each sampling date, then transported to the laboratory and allowed to air dry prior to assessments. Water repellency was measured using water droplet penetration time (WDPT) (Letey, 1969). WDPT was measured in soil cores beginning at the thatch-air interface then proceeding at 1 cm intervals to a depth of 4-6 cm. WDPT was measured to the nearest second. Trials were conducted as randomized complete block designs with four replications. Temporal infiltration rate in the Arkansas trial was measured by placing 5 ml of distilled water on the surface of untreated or surfactant treated plots and measuring the time for the applied water to infiltrate (Thomas and Karcher, 2000).

For tests conducted in the Netherlands, spatial and temporal variability in soil moisture content was evaluated eight times in vertical transects by intensive sampling of the treated and untreated plots. Soil samples were collected in stainless steel cylinders (5 cm dia) at six depths in 2.5 cm intervals beginning at the soil surface and to a depth 19 cm. A total of 35 samples were collected at each depth along a 1.8 m transect and 75 samples in a 15 x 5 grid in a horizontal fashion at each depth in adjacent soil blocks. Cylinders were placed in sealed plastic bags and transported to the laboratory. WDPT was measured in field moist and laboratory dried soil. Mean soil water content was measured gravimetrically and resistance to wetting was determined by subjecting soil samples to a constant pressure head of –2.5 cm of water applied to the sample surface according to methods described by Dekker (1998) and Dekker et al. (2001b).

Results and Discussion

In most cases, water repellent soils were confined to the upper 1-3 cm of the profile (data not presented). Notable exceptions occur, such as the Netherlands site where water repellency was detected to a depth of 50 cm under extremely dry conditions (data not presented). Both surfactants tested (Aqueduct and Primer) reduced soil water repellency in the upper regions of the soil profile over the duration of the study periods (Figure 1, Figure 2, Table 1). At one week post-application, Aqueduct significantly reduced water repellency in the thatch-soil interface (Figure 1). At the next depth interval, (cm 1), statistically significant differences became apparent by week three (Figure 2). These were the sole depths where WDPT indicated the presence of soil water repellency. While water repellency increased in the untreated soils, Aqueduct treatment either reduced water repellency or prevented it from increasing over the course of the three-week study period.

Monthly applications of the soil surfactant Primer significantly reduced soil water repellency (Table 1). Prior to treatment applications, water repellency (WDPT) was similar in all plots. Reductions in soil water repellency were observed after a single surfactant application with residual effectiveness lasting for at least one month. Subsequent monthly surfactant treatments maintained soil water repellency below that of the untreated control for the duration of the study. At the Victoria (Australia) test location, water repellency was confined to uppermost region of the soil profile, just below the soil surface, the region containing the highest organic matter content. Reductions in WDPT (as a measure of soil water repellency) were observed in trials conducted in the Netherlands (data not presented). Changes in WDPT were observed in the surface layer and to a depth of 5 cm after two treatment applications. Changes in water repellency were most pronounced in the upper regions of the soil profile, which contained the highest organic matter levels. These studies confirm that while soils and decomposing organic matter may differ, surfactants will consistently ameliorate water repellency in treated soils.

Dekker et al. (2001b) recently introduced the concept of critical soil water content; the nominal volumetric water content below which a soil becomes non-wettable in the field. Surfactant treatment shifted the mean critical soil water content in the top 15 cm of the rootzone (Figure 3). In the top 2.5 cm of the rootzone, untreated soils were wettable until volumetric water content dropped to 18 vol%, while surfactant treated soils were wettable to 11 vol%. At 5 cm, the surfactant-treated soil remained wettable until soil water content reached 6.4 vol%, while the untreated soil became non-wettable at 11 vol%. Between 7.5 cm and 15 cm, differences were still encountered between the treated and untreated soils, though not to the degree observed in the upper regions of the soil profile. The consequence of this shift in critical soil water content is that soils remain wettable and irrigation water or precipitation may more effectively infiltrate a surfactant treated soil under more edaphically stressed conditions (drought) than in untreated soil. Mean soil volumetric water content in field moist cores was greatest in the upper 10 cm of the profile (Figure 4). At all depths, Primer-treated soils tended to have volumetric soil water contents greater than the untreated controls. This trend was evident for the duration of the study and suggests that under field conditions, surfactant treatment may increase mean soil water content in the region of the rootzone with the greatest root density and highest organic matter content.

Turfgrass irrigation strategies deliver water uniformly to the soil surface in finite irrigation cycles (10-60 minutes). Irrigation efficiency may be influenced not only by the degree of water repellency (or wettability) of the top 1-2 cm of the soil profile, but also, the depth of water repellency in the soil profile and hence how effectively water can infiltrate into the soil under unsaturated flow conditions. A single surfactant treatment applied to a water repellent, localized dry spot on an Arkansas bentgrass green increased the initial infiltration rate from 40 ml/min (untreated) to 150 ml/min (surfactant-treated) (Figure 5). Infiltration was increased 3-fold to 7.5-fold in the surfactant treated plots. In a second study in which two surfactant applications were made, infiltration was increased 1.5-fold to 30-fold over the control (data not presented). These results were corroborated in a Dutch trial on a water repellent fine sand soil that received a monthly surfactant treatment and a simulated 60-minute irrigation cycle (Figure 6). After one surfactant treatment, no differences in infiltration were observed at the 0-2.5 cm depth. By June (two surfactant applications), soil volumetric water content after a 60-minute simulated irrigation was only marginally higher in surfactant treated soils than in untreated soils (47 vol% versus 40 vol%). In surfactant treated soils, infiltration rate and increase in volumetric water content approached plateau levels within the first 10-20 minutes of simulated irrigation. On subsequent sampling dates, volumetric water content in surfactant treated soils was 2-fold to 5-fold greater than in the controls. Infiltration rate and the rate of change in soil volumetric water content increased asymptotically in treated soils, while it was generally linear in the untreated controls. On two dates (27 July and 2 September), both the surfactant treated soils and the untreated soils had volumetric water contents below 10 vol%. After 60 minutes of simulated irrigation, volumetric soil water content did not increase in the controls, indicating that these soils were below the critical soil water content and would be susceptible to severe runoff and ponding. Conversely, the surfactant treated soils, though at the same initial soil water content, remained wettable. After the 60 minute simulated irrigation cycle, approximately 10 mm of water infiltrated the surfactant treated soil and volumetric water contents approached 40 vol%.

This study confirms that surfactants reduce soil water repellency in sandy soils regardless of the origin of the soil, the nature of the organic matter, or the local environment. While this conclusion was anticipated, these trials also provide substantiation that surfactants influence irrigation efficiency and enhance water conservation in turfgrass systems on water repellent soils. We have demonstrated that surfactants as a consequence of managing soil water repellency will:

- modify critical soil water content so that soils remain wettable even under periods of limited irrigation and high evaporative demand.
- increase the infiltration rate of applied water, so that less water is lost to evaporation and runoff.
- rapidly increase soil volumetric water content upon irrigation, improving water reserves in the rootzone.
- limit deep percolation of water and hence losses to leaching.

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Table 1. Effect of surfactant treatment on soil water repellency as measured by water drop penetration time (in sec) in the water repellent 0-1 cm zone of a soil core (Melbourne, Victoria, Australia).

Treatment	**0 MAT**	**1 MAT**	**2 MAT**	**3 MAT**
Primer (125 ml $100m^{-2}$)	312	53	173	92
Primer (190 ml $100m^{-2}$)	311	58	120	82
Control	229	150	426	203
LSD (p<0.05)	ns[z]	29	92	79

[z] ns = not significantly different

Figure 1. Effect of surfactant treatment on soil water repellency in the 0 cm zone (* = p<0.05) (New Brunswick, NJ)

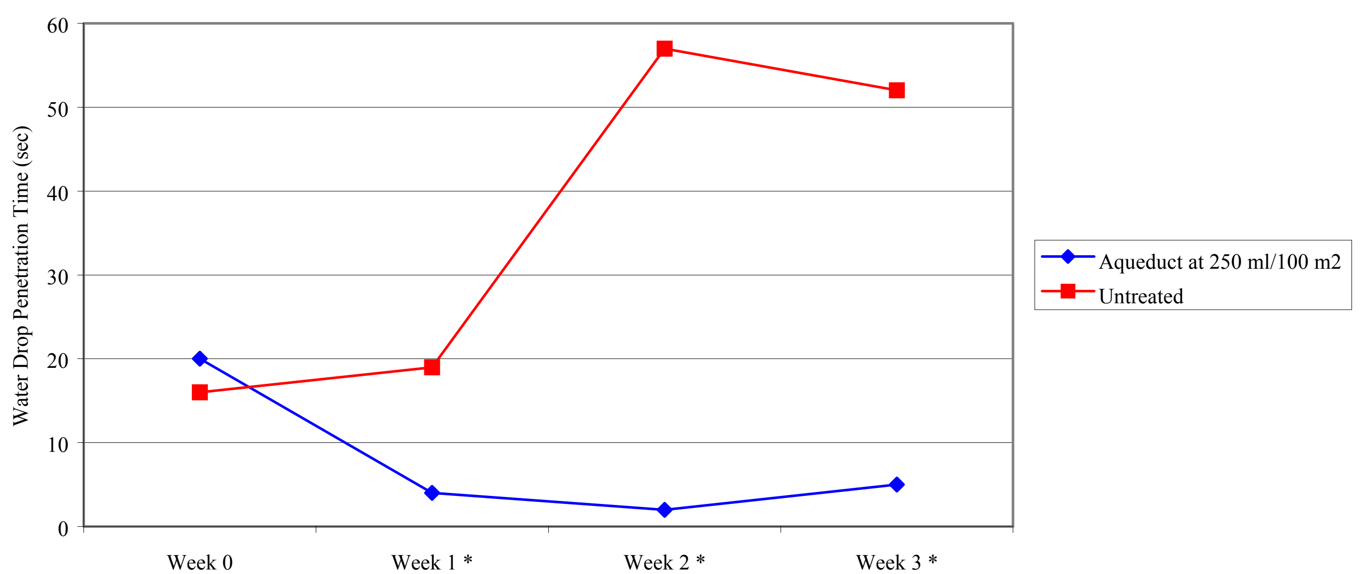


Figure 2. Effect of surfactant treatment on soil water repellency in the 1 cm zone (* = p<0.05)(New Brunswick, NJ)

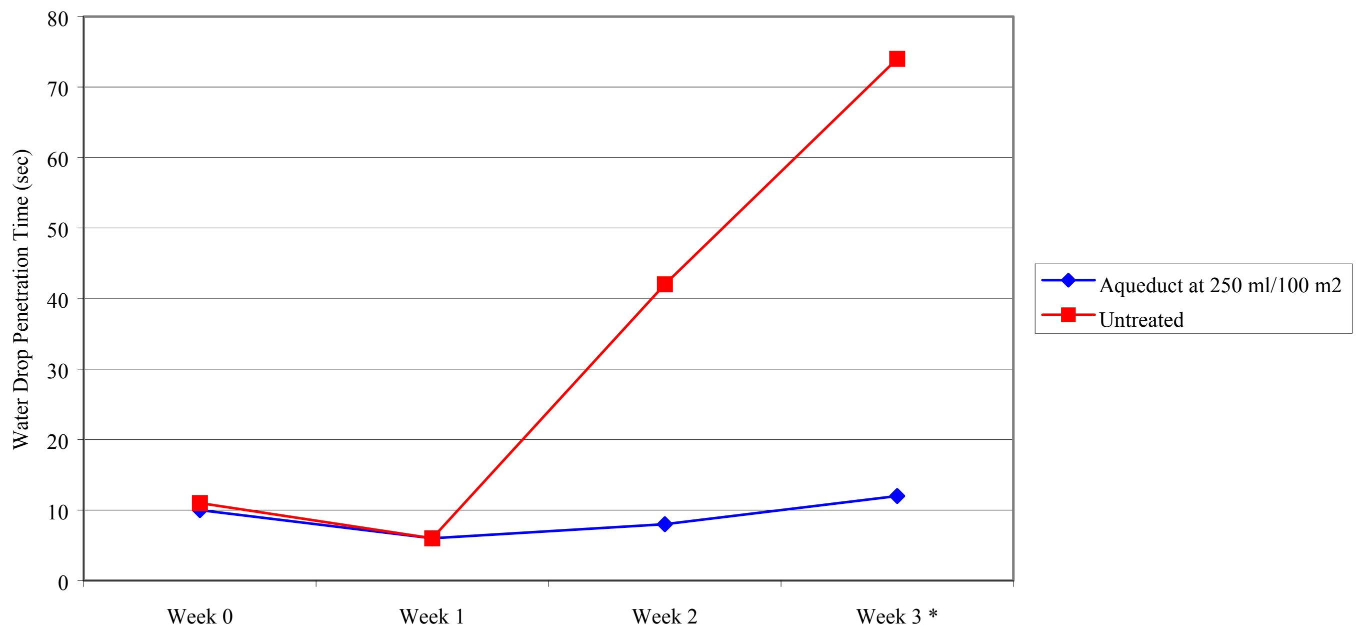


Figure 3. Critical soil water content curves - surfactant treated (Primer 604) and untreated control (Alterra, The Netherlands)

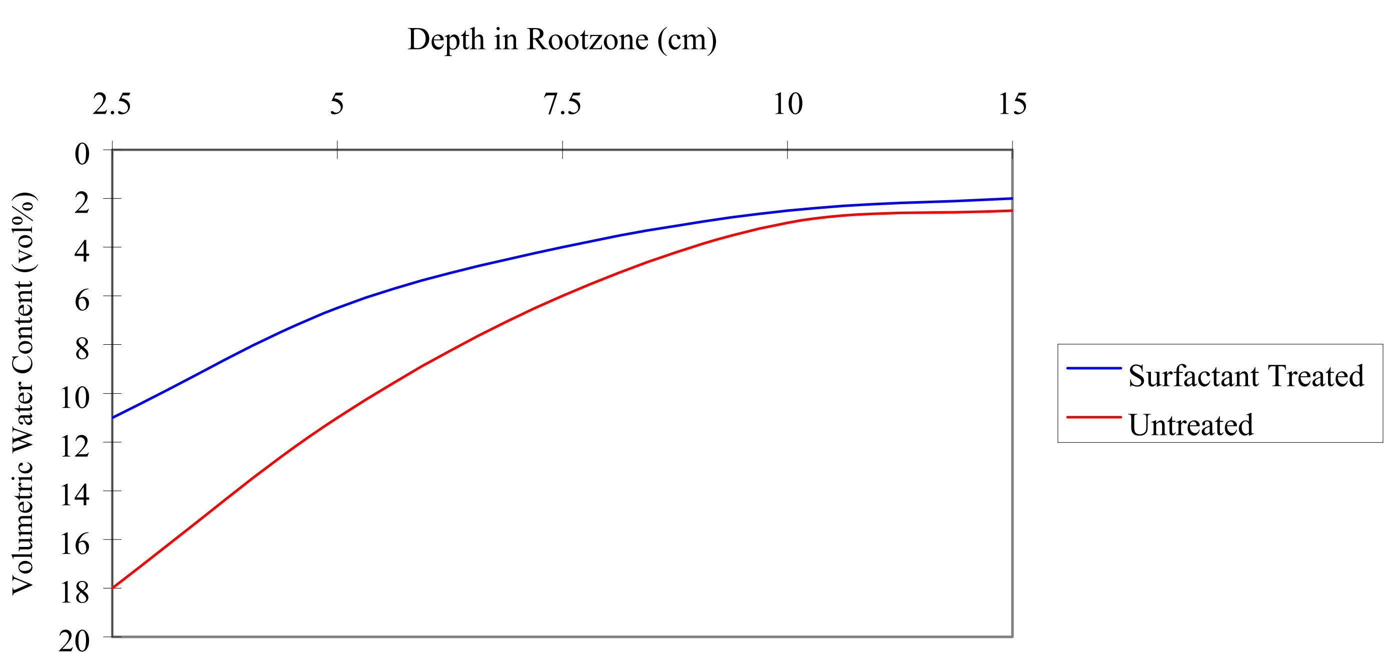


Figure 4. Comparison of volumetric water content (vol%) at different depths in the soil profile (Alterra, The Netherlands)

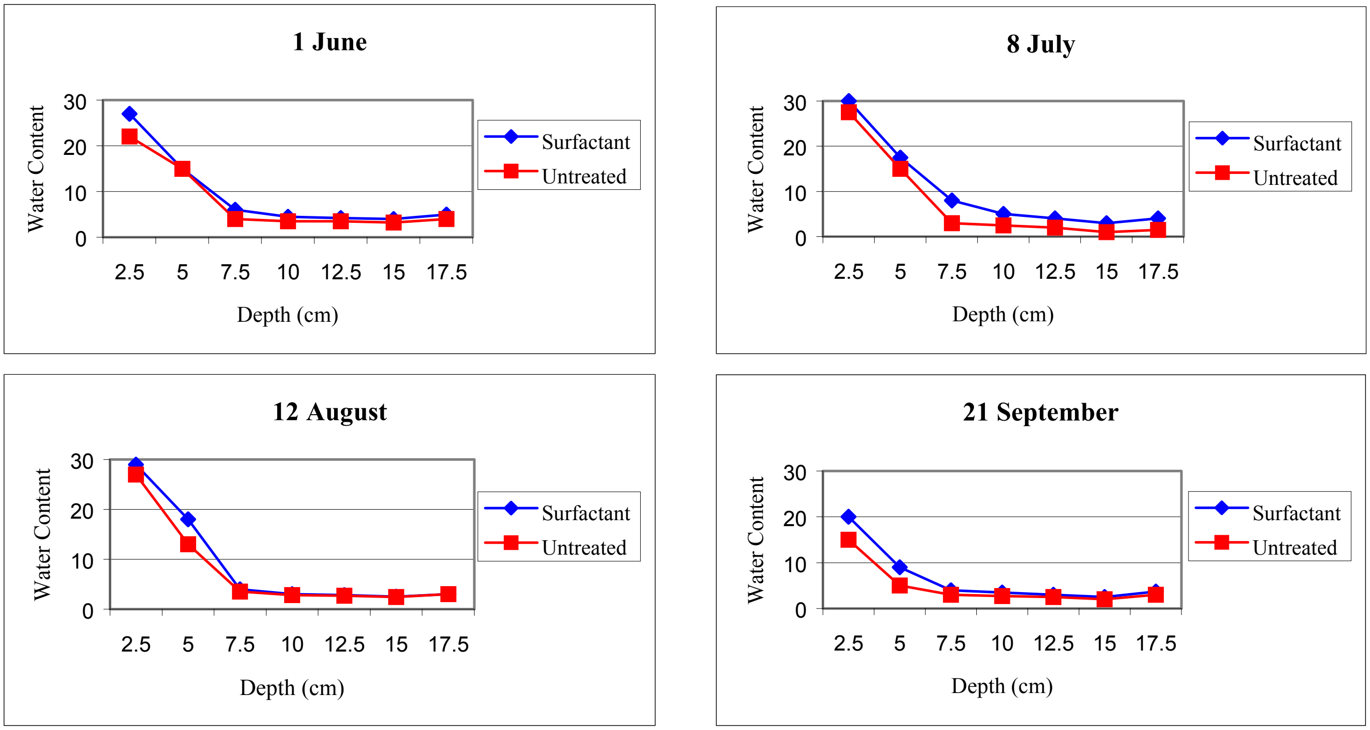


Figure 5. Effect of Aqueduct treatment on temporal infiltration rate (Fayetteville, AR)

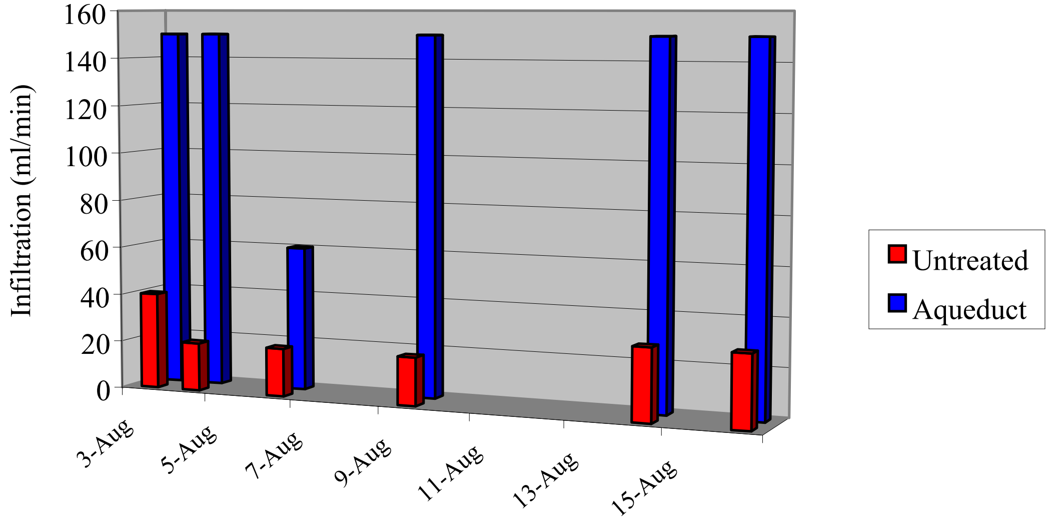
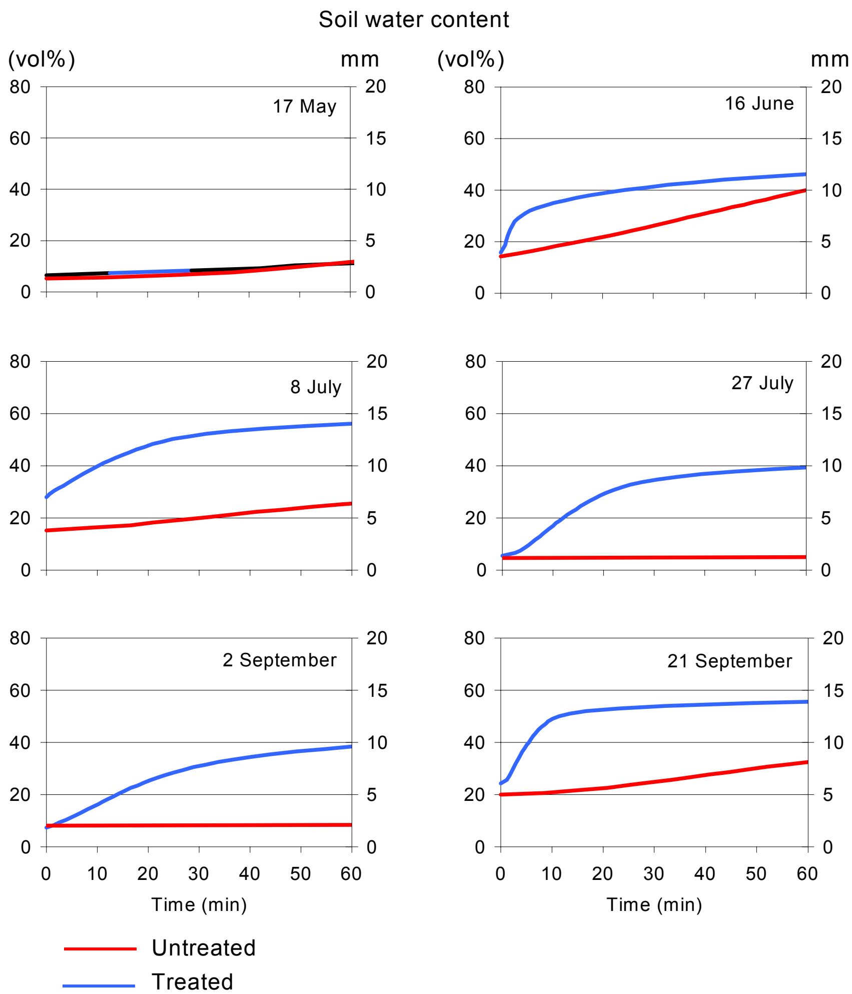


Figure 6. Effect of surfactant treatment on wetting of field moist samples of surfactant treated and untreated soil cores (0-2.5 cm) (Alterra, The Netherlands)



SEWAGE EFFLUENT – LIABILITY OR ASSET?

by

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Summary:
Subsurface drip dispersal (SSDD) and reuse of domestic effluent under conditions where conventional drainfields do not work is both economic and environmentally friendly. The technology was introduced about ten years ago. Because of the formidable regulatory barriers to entry, it has been difficult to penetrate the market.

Keywords:
Irrigation, drip, subsurface, reuse, effluent, disposal, drainfield.

INTRODUCTION
During the last five years, 40% to 50% of all new residences were built with on-site septic systems. As housing density increases, and land with soils that are not suitable for a conventional drainfield are developed, disposal of the effluent is an increasing problem. The growing metropolitan population is putting pressure on water supplies. Subsurface drip dispersal combined with reuse is advantageous, as is the low risk of human contact with the effluent.

Barriers to entry are both technical and bureaucratic:
- Federal, state, and county health and environmental regulations are inconsistent, and discourage new technology
- The “no-growth” lobby uses the regulatory process to advance it’s agenda
- Civil engineers are conservative and risk averse
- The poor reputation of this technology is caused by inept application by innovators who had to go through their learning curve
- Year-round operation is required, regardless of climatic conditions
- Designers, operators, installers and regulators are inadequately trained
- Biological slime can build up in the drip system and plug the emitters
- A biological mat can plug the soil, resulting in surfacing of the effluent
- Root intrusion into the drippers

THE TECHNOLOGY

The following illustration demonstrates the movement of water applied in small pulses. The subsurface application results in a 40% increase of wetted volume over the surface application. We can, therefore, imply that there is more air in the subsurface wetted area. Most of the sewage effluent pathogens are anaerobic bacteria and virus. These are absorbed under aerobic conditions. Thus, SSDD can be an efficient technology for the treatment of the sewage effluent.

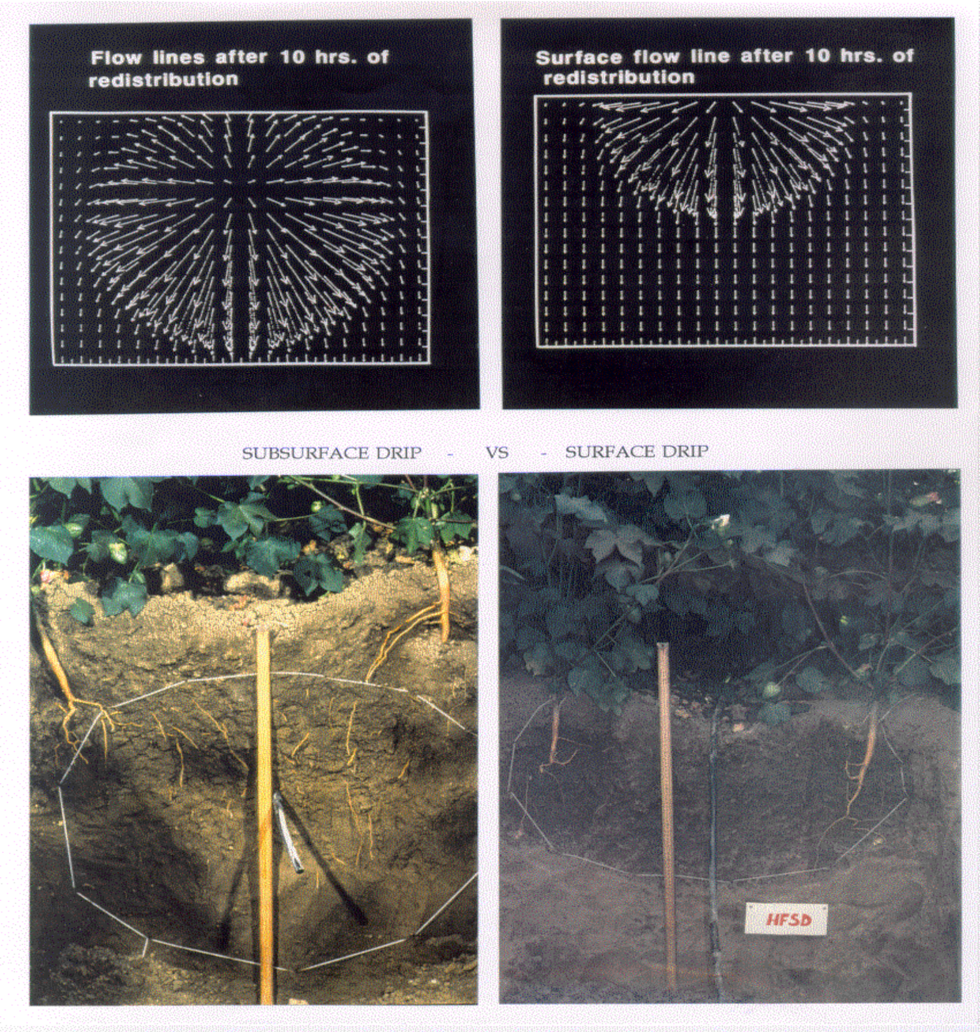

Fig. 1: Movement of water with pulsed subsurface application **Photo: Dr. C. Phene of the USDA**

Hydraulic engineering skills are required in order to design a conventional subsurface drip irrigation system. In the case of SSDD, one is effectively operating an independent sewage treatment plant at each and every emitter. In the event that the bacteria are not absorbed, a biological mat can form in the soil. This mat will plug the soil and prevent the movement of the effluent away from the dripper (1), thereby causing the effluent to surface and the system to irrevocably fail. The designer must know the capacity of the soil, both to absorb the pathogens, and to dispose of the volume of water being applied. Soils science is an essential part of the technology.

MATERIALS

BIOLOGICAL SLIME: The risks of slime build-up in the dripperline and root intrusion can both be solved.

Biological slime easily builds up inside the dripperline. This slime will slough off the tube wall and plug the emitters. The risk of slime build-up is a function of the effluent quality, the temperature of the effluent, and the length of time the effluent stays in the system. One solution is to use a tube with a bactericide lining. This will prevent slime formation on the walls of the tube, even with extremely poor quality effluent. Another solution is to frequently flush the system at very high velocity. However, as Dr. Sievers of the University of Missouri has reported (2), despite frequent high velocity flushing, aerobic slime built up in the drip system. In order to clear this slime, it was necessary to apply repeated treatments of industrial strength Drano.

ROOT INTRUSION: Nitrogen, which is a component of almost all sewage effluent, will attract dense growth of roots around the emitters. While this root growth is beneficial in improving the soil permeability, it also increases the risk of root intrusion. Root intrusion is a severe risk, particularly if the system is used under grass or other vegetation. There are three techniques registered with the US EPA, which are used to prevent root intrusion. They all depend upon the application of the herbicide trifluralin. One technique incorporates Treflan®[1] into the polymer of the dripper. This technique is known as ROOTGUARD®[2] (3). A second technique adds Gowan Trifluralin 5 directly into the irrigation water. The third technique adds Triflurex®[3] into the irrigation water by means of a dosing system incorporated as a feature of a disk filter.

YEAR-ROUND OPERATION: Systems can freeze under extreme winter conditions. Freezing can be controlled by draining the system at every cycle, and insulating the other operating parts of the system (4). Systems must continue to operate by means of percolation, even during heavy rain events when the soil is at field capacity. Good soils science, combined with correct design, can achieve this balance.

DISCUSSION

In the Introduction I stated: Barriers to entry are both technical and bureaucratic:

- Federal, state, and county health and environmental regulations are inconsistent, and discourage new technology
- The “no-growth” lobby uses the regulatory process to advance it’s agenda
- Civil engineers are conservative and risk averse
- The poor reputation of this technology is caused by inept application by innovators who had to go through their learning curve
- Year-round operation is required, regardless of climatic conditions
- Designers, operators, installers and regulators are inadequately trained
- Biological slime can build up in the drip system and plug the emitters
- A biological mat can plug the soil, resulting in surfacing of the effluent
- Root intrusion into the drippers

The last four items of the above list have been shown to be manageable by product selection and competent hydraulic engineering and soils science. Consequently, we must address the first three bureaucratic barriers, and the perceived barrier that “SSDD does not work”.
These barriers have been formidable. For example, California has fifty-one counties with independent health departments. There are nine Regional Water Quality Control Boards with twelve offices. There are also state health and environmental regulatory bodies. There are no state regulations covering on-site sewage. The county regulations are based upon the use of septic tanks and drainfields, and the Uniform Plumbing Code. Consequently, 19th century seepage pits are permitted, while 21st century SSDD is not! The regulators are generally open-minded and approachable; however, they are restricted by the rules and precedents that do not include new technologies, especially the introduction of a technology as innovative as SSDD. This chaotic situation discourages civil engineers from specifying SSDD, because they do not know whether or not the health and environmental authorities will approve their designs. The market has finally begun to open for new innovations when nothing else will work. If our industry maintains high standards, it will slowly gain credibility and acceptance.

CONCLUSIONS

As is almost inevitable with new ideas, the pioneers in the field had failures, due to both inappropriate equipment and lack of soils science knowledge. Despite several well-recorded local successes, on a national level the regulatory barriers change at glacial speed and remain formidable.

NOTES

(1) Treflan is a registered trademark of Dow Agrosciences
(2) ROOTGUARD is a registered trademark licensed to Geoflow, Inc.
(3) Triflurex is a registered trademark of Makhteshim-Agan

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PLANNING FOR REUSE IN NORTH CAROLINA

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ABSTRACT

In 1996, North Carolina adopted rules governing the use of reclaimed water, allowing for the beneficial reuse of reclaimed water. Since that time, communities have begun looking at reuse to reduce discharges to the state's waterways and to offset growing potable water demands. Many communities have initiated reuse distribution systems, particularly in areas that have irrigation demands near the wastewater treatment facilities. This paper will present the regulatory framework for reuse distribution in North Carolina, including a summary of the rules and incentives for reuse. The City of Raleigh is one of those communities that recognized the value of reuse water and began a reuse program in 1996. This paper will provide a history of Raleigh's reuse program and its plans for the future.

The rules allow reuse water to be used for most non-potable applications, including irrigation, industrial uses, toilet flushing, and fire protection. The rules also specify requirements for reuse water quality, buffers, labeling, and cross-connection control. Communities are allowed to approve irrigation systems, provided they demonstrate the resources and standards to oversee the expansion of their reuse distribution system.

The rules also state that "It is the intent of the Commission to encourage the beneficial use of the state's water resources concurrent with the protection of public health and the environment." In light of this, many state programs are offering incentives for reuse or dictating that reuse be evaluated. Funding agencies are giving priority to projects involving reuse. The North Carolina Department of Environment and Natural Resources is requiring evaluation of reuse before issuing any new or expanded NPDES permits.

The City of Raleigh began developing a reuse program in 1996 to serve a recently constructed golf course near the Neuse River Wastewater Treatment Plant. The facilities also serves a portion of the City-owned agricultural fields. Currently, the City is developing a Reuse Water System Master Plan for expansion of the system, with intentions to expand the reuse customer base to include additional irrigation users, and industrial and commercial users. The first phase of the program is to educate the public and survey potential customers to determine reuse demand across the region. The demand data is mapped to determine areas of high reuse demand, and hydraulic modeling is used to determine the distribution system requirements.

A reuse water ordinance and design standards are also being developed. The ordinance includes a rate structure for the City to recover some of the capital and operating costs. Cross-connection control and labeling requirements are also specifically addressed.

The master plan is also used to obtain the necessary permits to construct the facility. The plan includes an environmental assessment. The plan will also demonstrate the ability of the City to permit individual irrigation systems to expand the distribution system. This paper will conclude with a discussion of the benefits to the City of Raleigh and surrounding region.

KEY WORDS

reuse, water reuse, reclaimed water, master plan, public education, North Carolina

REGULATORY FRAMEWORK

In 1996, North Carolina amended its statutes that govern the disposal of wastes that are not discharged to streams or other waterways. These non-discharge rules were modified to define and control highly treated wastewater effluent for reuse application. The previous rule governed the disposal of secondary wastewater effluent, biosolids, and some industrial wastes. Reuse is defined in the rules as a tertiary quality effluent with water quality parameters shown in Table 1.

Table 1. **Reuse Water Quality Requirements**

Parameter	Monthly Average	Daily Maximum
Total Suspended Solids	5 mg/l	10 mg/l
Fecal Coliform	14/100 ml	25/100 ml
BOD_5	10 mg/l	15 mg/l
NH_3	4 mg/l	6 mg/l
Turbidity	10 NTU (continuous monitoring)	

The rules are similar to many other states and allow for typical reuse applications such as irrigation including public areas, cooling water, toilet flushing, fire suppression, decorative ponds and fountains, and industrial uses. The rules specifically prohibit reuse in swimming pools, hot tubs, and spas. Reuse cannot be used to irrigate edible crops. In addition, the rules prohibit the use of reclaimed water from being used as a raw water supply for potable water systems.

Cross-connection control is another critical component of the rules. All reuse facilities must be colored purple and identified as reuse piping, either by painting, marking tape, and other identification. Hose bibbs or other connections must be in a lockable vault and marked as reuse.

In addition to protecting public health, the rules and intended to protect the State’s waterways. Spray irrigation systems are required to maintain buffers from streams and wells. For most streams, the spray influence must not be within 25 feet of any surface water or wetland. For higher quality SA streams, the required buffer is 100 feet. Potable wells are provided with a 100-foot buffer while non-potable wells have a 10-foot buffer. Run-off is not allowed from any reuse application.

STATUS OF REUSE IN NORTH CAROLINA

Many communities in North Carolina have begun a reuse program. Charlotte-Mecklenburg Utilities (CMU) was the first permitted facility in the State. Their Mallard Creek Water Reclamation Facility serves a nearby park and golf course. CMU is currently adding reuse to its other waste treatment facilities. The Town of Cary has recently completed the first phase of its reuse distribution system that supplies an up-scale residential development, as well as cooling water for office buildings. Brunswick County is pursuing reuse as a means for a zero-discharge waste treatment facility. The County is a coastal resort area that includes 18 golf courses as potential reuse sites. Others including Johnston County, Clayton, Orange Water and Sewer Authority, Sanford, and Goldsboro are at various stages in the development of reuse programs.

The City of Raleigh has also initiated an aggressive reuse program. Shortly after the rules were promulgated, the City entered into an agreement with a golf course to provide reuse water from the Neuse River Wastewater Treatment Plant (NRWWTP). Design and construction were subsequently undertaken and the facilities were completed in 1999. The City also supplies reuse water for non-potable water at the NRWWTP and uses reuse for agricultural irrigation on City-owned farms.

The success of reuse systems in the State is a function of many items. The climate is conducive to a relatively long growing season, providing for ample irrigation opportunities. Many of the reuse systems include one or more golf courses as the primary users. Although North Carolina is not considered an arid State and typically has adequate water resources, recent droughts have shown many communities that their water resources are limited and continued growth requires protection of those resources. One of the driving factors for the Town of Cary’s reuse system is the lack of adequate water resources within its watershed. The Town pumps raw water from an adjacent watershed that requires an Interbasin Transfer Certificate, which requires extensive permitting.

The receiving waters of the State are becoming impaired in some areas. The Neuse River has been classified as nutrient-sensitive water. As such, the State has required all dischargers in the Neuse River to reduce nitrogen discharges by 30 percent. One of the drivers for the City of Raleigh is to minimize the discharge of nitrogen into the Neuse River.

The North Carolina Department of Environment and Natural Resources (DENR) is another proponent of reuse. The rules adopted by North Carolina state that “It is the intent of the Commission to encourage the beneficial use of the state’s water resources concurrent with the protection of public health and the environment.” As such, the State has done several things to promote reuse. The Clean Water Management Trust Fund provides grants to communities for capital projects that will benefit the quality of the State’s waters. They have identified reuse as a critical component in the evaluating projects to receive funding. Similarly, the State uses reuse as a criteria for prioritizing projects applying for State Revolving Loans. The State has also mandated that any proposed wastewater expansion must evaluate reuse opportunities before the expansion will be permitted.

CASE STUDY

The City of Raleigh currently operates a water reuse system at the NRWWTP. The vision for the City is to provide a regional reuse water system that satisfies non-potable water demands with high quality reclaimed water. To that end, the City has undertaken a master planning effort to distribute reuse water to users throughout the City of Raleigh as well as many of the surrounding municipalities and Wake County. By expanding the reuse system throughout the region, the City will gain the following benefits:

- Reduce demand on the potable water system
- Make better use of the available raw water supply
- Reduce nutrient loadings on the Neuse River
- Provide a new water resource to the citizens of Raleigh and surrounding areas

Existing Reuse System

The existing reuse system utilizes the effluent from the NRWWTP, which includes filtration and UV disinfection. A sodium hypochlorite feed system provides a chlorine residual to the reuse water. Four vertical turbine pumps deliver reuse water to the distribution system which serves the adjacent agricultural fields, the plant non-potable water system, and the nearby River Ridge Golf Course. The existing pumping facility can deliver as much as 5 mgd for irrigation. Current demand is approximately 0.9 mgd.

MASTER PLAN APPROACH

The master plan is a comprehensive study that will provide all necessary components to implement a large reuse distribution system. Key components of the master plan include public education, identifying customers and associated demand, hydraulic modeling of the distribution system, identifying costs and rate structures to recover the costs, updating the City's design and construction standards to include reuse facilities, developing a reuse ordinance to set the City's policies governing the development of the reuse system, and permitting of the reuse facilities.

Public Education

The public education is a critical component for the success of the program. Irrigation of parks and school grounds are among the many reuse opportunities available in Raleigh. Without public acceptance of reuse water, these potential reuse sites would not be available. The City's education program includes a reuse brochure and information on the City's web site. The brochure was distributed with all of the demand surveys that were mailed and will also be located at each of the major reuse facilities. In addition, the brochure and other materials will be used for site-specific educational opportunities. Reuse was added to the City's WaterFest 2001 celebration and will continue to be a significant component of that annual event.

Demand Projections

Several methods were used to identify and survey potential reuse customers. The City's water meter sales records were evaluated for potential reuse customers. Data from all large water meters (1 ½-inch and larger) were compiled for the year 1999. The data was segregated by potable water meters and irrigation meters. The records included almost 3,500 large water meters with an average daily demand of 24 mgd. Approximately 300 irrigation meters registered an average daily demand of 1 mgd.

The largest total water users and irrigation meter sales were identified and surveyed. In addition, zip codes were used to identify the general location of the users. The zip code including the NRWWTP was of significant importance because it helped identify customers for the first phase of development. From this listing, 68 specific customers were identified. Questionnaires were mailed to each potential customer along with the educational brochure. Only a small fraction of the questionnaires were returned. Therefore, additional efforts for determining reuse demand were required.

Golf course irrigation was identified early in the project as a large customer base. In addition, other types of uses were identified including industries, parks, schools, institutional users, nurseries, construction, and commercial irrigation. A listing of potential customers for each type of use was developed, and telephone interviews were conducted to assess potential reuse demand. A variety of methods were used to develop the lists, including the industrial pretreatment program, meetings with key officials in the parks and school systems, and the yellow pages.

The large number of golf courses provides a significant reuse opportunity. In addition, there are a number of smaller golf facilities including executive courses and driving ranges. Moreover, 9 of the golf courses are located within six miles of the NRWWTP. To gauge the interest and estimate the irrigation demand, each golf course was interviewed. Overall, the golf courses were very interested in reuse, even though most have a low cost supply of irrigation water. Over 75 percent of the courses expressed some level of interest in using reuse for irrigation. Several courses could not meet their irrigation demand with their existing facilities and were primarily interested in augmenting their existing irrigation ponds. Two courses currently use potable water for irrigation and would recognize a significant cost savings by converting to reuse.

There are primarily two users of agricultural irrigation: the City of Raleigh and North Carolina State University (NCSU). Each owns and operates over 1,000 acres of agricultural land. The City of Raleigh has an estimated demand of 3.5 mgd. The demand at the NCSU facilities varies significantly and is largely dependent on on-going research. The NCSU sites near the NRWWTP do not currently have any reuse demand.

The City surveyed the significant industrial users participating in the pretreatment program. Most industries were receptive to the idea of reuse, particularly for cooling water and irrigation. Nineteen responses were received for a total reuse demand of 350,000 gpd.

Commercial landscape irrigation was estimated with the metered water sales data. From the list of top water users, seventeen commercial irrigation meters were identified that used 200,000 gpd of irrigation water. These users represent approximately 20 percent of the total commercial irrigation demand.

Plant nurseries also offer a potential reuse demand. The reuse service area includes 20 nurseries. Telephone interviews were conducted with a sampling of nurseries to determine an average irrigation usage of 25,000 gpd. This represents a potential reuse demands of 500,000 gpd for all the nurseries. One advantage of nurseries is the demand will be throughout the year because of greenhouse irrigation demands.

Institutional users include the local universities and hospitals. The six universities offer many reuse opportunities including irrigation, cooling water, and possible research opportunities. The four hospitals include irrigation and cooling water as significant reuse demands. The North Carolina State Fairgrounds could use reuse water for irrigation, dust control, and street cleaning.

The reuse service area is home to 12 high schools and 16 middle schools that all have ball fields that can be irrigated. Typically each school has a baseball, football, and soccer field, at a minimum.

The City of Raleigh Parks & Recreation Department operates over 100 park facilities. Those facilities include a total of 60 ball fields that are irrigated. In addition, the Cities of Garner, Knightdale, Wendell, and the Capital Area Soccer League operate many other park facilities.

The residential irrigation is a practical alternative for two major developments in southeast Raleigh. One development is associated with the River Ridge Golf Course and includes approximately 200 homesites. The estimated irrigation for this development is 125,000 gpd assuming a 50 percent participation in the program by the homeowners. The second development is a proposed golf course community located 3 miles from the NRWWTP. The development is expected to include 1,600 estate homes. The estimated residential irrigation component is 500,000 gpd assuming 75 percent participation.

Hydraulic Modeling

The reuse distribution system will be designed much the same as the City's potable distribution system. A combination of elevated storage, ground storage, and booster pumping stations will be used to maintain the system pressure. However, there are several unique challenges in modeling the reuse distribution system, including very high peaking factors, wide ranging pressure requirements, and development of a large regional model from a small local system.

The nature of reuse demands, particularly irrigation demands, require the system be very flexible in meeting high peak demands. Seasonal impacts on irrigation demands can create daily peaking factors as much as 3 times the average daily demand. In addition, most golf course irrigation takes place during early morning hours, before the golfers begin play. If all courses irrigate during a four-hour period in the mornings, the hourly peaking factor could be as high as 20 times the average daily demand. By comparison, hourly peaking factors for potable water distribution systems typically range from 2.0 to 2.5 times the average daily demand. To mitigate the impacts of peak hour demands, the users were categorized by the type of use, and the times that peak hours would occur. The night time peak hour demand for the system was estimated as 35 mgd, while the day time peak hour demand was estimated as 10 mgd. The night peak hour demand is 6.2 times the average daily demand of 5.7 mgd.

The wide range of flows for the reuse system is accompanied by a wide range of pressure requirements. Many golf courses use irrigation ponds to store water. These systems will discharge to atmosphere. However, other systems prefer to connect directly to the distribution piping and let the system pressure deliver flow to the irrigation systems. In these cases, minimum pressures as high as 50 psi could be required. The specific requirements of each individual user must be clearly understood to ensure a system that meets the customer's needs. The model was designed to provide a minimum of 25 psi residual pressure during peak hour demands. Users that would take fill ground level ponds from the system will be provided with pressure sustaining valves to prevent them from depressurizing the surrounding distribution system.

Modeling a third utility in a large area that is well-developed offers unique challenges. The extent of the system requires phased construction over many years. The initial phases must economically distribute reuse water to the customers in the first phase and allow for economical expansion for future phases. The distance to some of the reuse sites is extensive and may preclude construction of that portion of the system for many years. However, a comprehensive plan must allow for connection to these sites at some point in the future. Therefore, initial transmission network must consider future demands, while incorporating the time factor of money in determining the most effective phasing of the system.

The total proposed system includes over 750,000 feet of piping ranging from 4 inches to 24 inches in diameter, three elevated storage tanks totaling 2 million gallons, two ground storage and pumping stations, and three inline booster pumping stations. The system was divided into 5 phases for implementation. The primary goal of modeling the entire service area is to determine the size of the main transmission lines. Although the entire system will take decades to construct, the initial construction should allow for future demands.

The first phase encompasses the southeast section of town, which includes six golf courses, several industries and institutional users, and two potential residential developments. The initial phase includes a 24-inch transmission main that connects to an existing 16-inch line and an elevated storage tank to sustain pressure at the outer portions of the system. This configuration also works well in the complete system. With the addition of a booster pumping station and a ground storage tank, the first phase piping network will be able to transmit reuse water to Northeast Raleigh. The second transmission line is required to provide reuse water to the Garner and West Raleigh areas.

IMPLEMENTATION

The master planning effort also includes a number of items that are essential to implementing a successful reuse program. Permitting, rates, design standards, and a reuse ordinance are included in the master plan to allow for uniform and timely growth of the system.

Permitting

The completed master plan will be the basis for the permitting of the proposed facilities. The document will include an Environmental Assessment meeting the State Environmental Protection Act (SEPA) requirements. After receiving the Finding of No Significant Impact (FONSI) is received, the City will use the master plan as the basis for applying for delegated authority to permit expansions to the reuse distribution system.

Rate Structure

After the modeling is complete, the capital and operating costs for each phase of the reuse distribution system will be determined. A rate structure will be developed to recover as much of the costs for the system as practical. The City's goal is to get complete cost recovery with usage rates less than the potable water rate. However, the City recognizes the potential difficulty in recovering all of the costs initially and is willing to contribute some capital that may take longer than 20 years to recover.

Design Standards

The City currently maintains a Utility Handbook that includes design and construction standards for the water distribution and sewer collection systems. This master plan project includes a new handbook section dedicated to the reuse system. This section will include cross-connection control measures, labeling requirements, and minimum separation requirements from potable water and sewer lines.

The design standards are a critical component of the development of the reuse system, particularly for residential developments. The standards will be implemented by developers installing dual systems.

Ordinance

A reuse ordinance will be developed to set the City's policies governing the reuse system. The ordinance will set policies related to providing reclaimed water inside the City limits as well as areas outside the City limits. Specific requirements for the reuse system, such as cross-connection measures, will also be incorporated into the ordinance.

CONCLUSIONS

Many communities in North Carolina have recognized the value of reuse and are developing programs to distribute reuse water. The City of Raleigh is one example of a community that has significant reuse opportunities and is looking to capitalize on the benefits of reuse. With the need to protect the need to reduce discharges in the Neuse River and protect the finite water resources, the City intends to systematically develop their reuse system. Reuse has become an important water resource to many communities.

REFERENCES

Hazen & Sawyer Environmental Engineers & Scientists, "Neuse River WWTP Wastewater Reuse Study." June, 1996.

Dual Water Systems in Northern Colorado

By

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In northern Colorado, the cost of water rights acquisition has risen dramatically over the past five years. Because of this dynamic, it has become economically feasible to retain the existing agricultural water rights with urban developments. Surface and ground water rights are often used to meet the landscape and outdoor water requirements of urbanization on land that was previously used for agricultural crop production.

A separate utility for outdoor water use, typically referred to as a dual water system, is developed to distribute the untreated water supply, or raw water, to individual residential lots, commercial lots and common open space. In many cases, the savings realized by a developer in reduced potable water right costs is less than the cost for developing the dual water system infrastructure.

This paper describes design considerations and solutions for dual water systems based upon completed projects in northern Colorado. Design issues to be discussed are water rights analysis, annual water requirements, water well water and surface water delivery constraints, storage requirements, determination of peak system flow, pump station and control requirements, distribution system hydraulic analysis, distribution system layout, coordination with other utilities, service connections for residential/commercial customers, system operation and maintenance. In addition, design considerations for drought management will be discussed.

Economic Feasibility

Many northern Colorado cities estimate that the typical single-family residential customer will use approximately ½ acre-ft of water per year for inside and outside use, with 45 to 55 percent of the annual water use going for outdoor use. This assumption is backed up by a three year, unpublished study by a small northern Colorado city where monthy water use was monitored for 100 residences with an average lot size of 7,000 square feet. Most northern Colorado water districts require the developer of residential and commercial properties to turn over appropriate raw water rights to them prior to gaining approval to build a development to ensure an adequate supply of potable water. For example, a northern Colorado city requires that 0.52 acre-ft of raw water rights be turned over per 8,000 square foot residential lot. At a cost to the developer of $11,500 per acre-foot for acceptable raw water rights, the cost for a single 8,000 square foot lot would be over $6,000.

Many cities have allowed developers to reduce the water rights dedication for residential lots, if a dual water system is installed for landscape irrigation use. The cost to install a dual water systems range from $1,500 to $3,500 per lot, depending on the lot size, density, and system design guidelines. A typical dual water system for a residential development with 8,000 square foot lots would cost between $2,000-$2,500 per lot.

Many cities have allowed the developer to reduce their potable water rights fees if a dual water system for landscape irrigation is installed. Since approximately half of the annual water use is for landscape irrigation use, some cities have allowed up to a 50 percent reduction in potable water rights acquisition fees. Using the previously cited example, with water rights costing $6,024 per lot, a reduction of $3,000 in water rights fees can be realized. Given typical dual water system infrastructure costs of $1,500 to $3,500 per lot, immediate savings can be realized.

Many times, the property being developed has existing agricultural water rights that have been historically excellent water rights, but cannot be transferred to a city to meet potable water dedication. Some water rights may be undesirable to a city simply due to the fact that the water cannot be delivered to a municipal potable water treatment plant. By using the existing agricultural water for outdoor water use in new residential developments, and assuming the city will reduce the potable water right dedication if a dual water system is installed, the existing rights maintain their value to the developer and the project.

In addition to initial cost savings, the long term operational cost to deliver raw irrigation water is lower than the cost of potable water and in some cases potable water treatment plant improvements can be delayed or even avoided.

Water Requirements

Annual irrigation water requirements for dual water systems are estimated based upon the same basic criteria as any irrigation system would be, namely plant material crop coefficient, reference evapotranspiration, effective rainfall, irrigation efficiency, and irrigated area. The irrigated area for a residential lot can be estimated by subtracting the footprint of the house, driveway, patio, shed, etc. from the gross lot area. Irrigated common open space areas can be determined directly from final development plans. Many times, final landscape plans are not available for commercial properties, and some judgment may be required to estimate the irrigated area. Depending upon local ordinances, commercial properties generally require 15 to 35 percent of the gross area to be irrigated. In instances where these assumptions must be made, clear documentation of all assumptions must be understood by all involved to make sure adequate water rights are procured.

Water Source

In northern Colorado, water for agricultural irrigation has been historically provided by shallow alluvial water wells or roughly 100 independent irrigation mutual companies. The ground water wells in the northern Colorado front range area are typically 40 to 100 ft deep. The State of Colorado Division of Natural Resources regulates the pumping of water from wells. A valid well permit and ground water augmentation plan must be in place to meet current Colorado laws. The mutual ditch companies deliver direct flow river water or stored reservoir water through a network of canals, reservoirs, ditches and laterals.

One advantage of ground water pumped from wells for landscape irrigation use is that it is generally available during the entire irrigation season. One negative of ground water is water quality. The water available from the shallow alluvial wells are typically high in total dissolved solids (TDS) which can result in staining of buildings and vehicles along with the build up of salts within the plant root zone. Some ground water may be unsuitable for some plants or turf sensitive to salts. A qualified laboratory should test water samples during preliminary or conceptual system design to determine the risk. Based upon the results, additional water may be required for the leaching of salts from the plant root zones, and planting and irrigation system recommendations may developed and given to the developer to prevent claims by home owners regarding staining of houses, vehicles, or loss of plant material due to the high mineral content of the ground water. Also, many of these wells are old and poorly constructed. A video survey of the existing water well and an 8 hour stepped-draw-down pump test is highly recommended prior design and installation of any distribution system pumping equipment. A video survey of the well is useful in determining the structural integrity of the well, as well as some indication as to the level of corrosion, incrustation, or plugging of the well screen. It is recommended that the pumping test be conducted during the winter or early spring months, which historically is the time of year where static water levels are at the lowest elevation.

The historical yield and delivery constraints of individual water rights to a specific site through any mutual ditch company should be thoroughly researched prior to design. For example, ditch water delivery to a project in Golden, Colorado only allows water to be diverted into a storage pond for 4 days of a 9-day period. Another project in Longmont, Colorado allowed water to be diverted from the ditch to an onsite storage pond as required without a set schedule. A typical mutual ditch company will deliver water from May through early September, which is somewhat less than the typical landscape irrigation season running from mid April thru the end of October. To make up for this water deficit during the early and late season, commonly referred to as “shoulder months”, potable water or well water is used. In other cases, homeowners must adjust to this shortened season and accept turf greening up later in the spring and going dormant earlier in the fall. In some cases, on-site storage can help extend ditch water to the end of October, but it is not useful in the early spring since irrigation water cannot be stored from one year to the next in onsite ponds per Colorado water laws.

The quality of water delivered by mutual ditch companies is generally excellent for plant growth. Compared to ground water, ditch water is generally much lower in salts, however, it can be high in organics. The organic loading of ditch water varies by ditch, and can vary greatly throughout the irrigation season. The organic loading of ditch water quality is generally at its highest during late summer. Mechanical components such as screens, filters, and pond aeration systems are required to protect the pumps and irrigation system components and reduce odor problems associated with stagnant ponds.

Storage Requirements

The amount of onsite storage required for a dual water system is a function of water delivery constraints, peak day irrigation evapotranspiration requirement, number and reliability of water sources, and the availability of land to construct a storage pond. Typically a storage pond with enough capacity to hold a 3-to 4-day demand of peak season irrigation water is recommended. A storage pond of this size allows for some unplanned down time in the delivery of water to the site, and to allows for a reasonable cushion in the delivery of water to the pond. In any case, on-site storage must be large enough to hold the minimum order allowed by the individual mutual ditch company. For example, many ditch companies require a minimum order of ½ CFS over a 24-hour period, which is approximately 1 acre-ft. The pond, at minimum, must have the capacity to receive this volume of water without overflowing. Having to a small pond may result in the pond going dry, or overflowing when filling due to the delivery constraints imposed by individual ditch companies. On the other hand, having a large pond may result in excessive installation costs due to the value of the land lost for development, the cost of excavation and possible liner installation.

In some instances where the water supply is highly reliable and available on demand, or where multiple sources of water are available, a pond with as little as one day of storage may be adequate. In planning a dual water system for a small town in northern Colorado, a pond with one day of peak season irrigation demand was recommended due to limited availability of land to build a pond, and the fact that 8 to 10 wells are used as sources of irrigation water. The likelihood of multiple wells failing at the same time is very small. The downside of a system with limited storage and multiple water sources is the need for more sophisticated management and controls, such as telemetry or SCADA systems, to efficiently manage the operation of the dual water system.

A pond may not be required at all for some systems utilizing only well water. In many cases the irrigated area for a typical development is much less than when the site was used for the production of agricultural crops. If the irrigated area is reduced, and the well was capable of meeting the irrigation requirements of most agricultural crops, the well may have the capacity to meet the instantaneous peak demand of the dual water system.

System Sizing

As with any irrigation system, the system capacity is based upon the irrigated area, irrigation system efficiency, peak season evapotranspiration, days of operation per week, and allowable daily irrigation window. The major difference between a dual water system to individual home sites and a large irrigation system for a golf course, is the number of irrigation system managers. In the case of a golf course irrigation system, for example, one irrigation manager is typically in charge of scheduling and operating the system. This scenario allows the pump station and mainline pipe be sized to operate at capacity for a given window of time, say 8 hours per day. A typical system demand over the course of a day is very predictable and represented by a relatively flat curve. The flow ramps up to full capacity over several minutes at the start of the irrigation window and runs at capacity until the demand drops off at the end of the irrigation window.

A dual water system for a typical 80-acre development in northern Colorado may have 200 to 400 individual lots, in addition to common open space areas. As a result, these systems must be designed to accommodate 200 to 400 individual water managers, most of whom are homeowners with little or no experience in operating or managing irrigation systems. One way to design and manage a dual water system is to impose tight irrigation watering windows for each lot. For example, group 1 lots would be only be allowed to operate their irrigation systems between the hours of 10 pm and 1 am, Monday, Wednesday, and Friday, group 2 lots would be allowed to operate their systems between 1 am and 4 am Monday, Wednesday, and Friday, and so on. While this approach to system design can reduce the installation cost of the dual water system and maximize pump station operating efficiency, it is generally more troublesome and difficult to manage. Many times the restrictions are not clearly presented by real estate agents, builders, or homeowners when they sell their houses. Over time, the rules and order can breakdown leading to an overall dissatisfaction with the dual water system by homeowners. The design of systems that require users to follow very narrow operating parameters are generally only successful in systems with a small number of lots or customers, such as a development with estate lots, and with a very strong and active homeowner’s association in place.

Another approach is to design the system around current lawn watering restrictions imposed by water districts or municipalities where potable water is used for irrigation. It is common for most northern Colorado cities and water districts to encourage homeowners to irrigate every other day, or every third day. Using this as a basis for design, the dual water system would be designed to allow between one-half and one-third of the individual lot irrigation systems to operate on any given day. It is common to limit the flow from an individual tap to 10 GPM, the typical flow allowed by systems using potable water and a typical 5/8" or ¾" water meter. Sizing a dual water system to allow the simultaneous operation of ½ of all irrigation services in a typical development consisting of 7,000 square foot lots is very conservative, and probably will result in excessive pump station capacity and distribution pipe sizing.

Whichever method is used for estimating peak flow, the pump station and distribution system must be sized to accommodate the estimated peak flow. Hydraulic modeling software is very useful in analyzing pipe sizing within networks. Typically the distribution pipe is sized to keep velocities below 5 feet per second. In many instances dual water systems are installed in phases and some upsizing of pipe may be required to accommodate project phasing. The irrigation pump stations must be designed to provide consistent pressure over a wide variation in flow. Pump stations with variable frequency drives are typically specified.

A typical system pumping water from a storage pond will include an pond intake screen, intake pipe, wet well, multi-pump prefabricated pump station, automatic self cleaning filter. Generally, a two or three pump system is adequate. Three or four main pumps are provided on large systems, or where redundant pumps are required to meet specific owner demands.

Where possible, the existing diversion structure and headgate that has historically been in place to control the delivery of water for agricultural use can be maintained and kept in place for the dual water system. Many times however, the existing diversion does not work with the site layout, grading, etc. In these instances, a new diversion structure, headgate, water-measuring device, and diversion ditch or pipe may need to be designed and installed. In all cases, the design and construction of any new diversion structure, the mutual ditch company must approve water measuring devices or headgates. In some cases, pumps are required to lift water from the diversion structure to a storage pond. In general, the lift pumps must be capable of diverting water to the storage pond within the constraints required by the controlling ditch company. For example, the lift pumps designed to divert water for a project in Longmont are designed to pump 1 or 2 cubic feet per second, the same flows that historically had been diverted through the gravity diversion system. In this example, the water lifted from the ditch is measured through a water meter, installed downstream of the lift pumps.

Distribution System Layout

The layout of a dual water system distribution pipe must be coordinated with all other utilities, and must be installed within defined utility easements. Generally, the distribution pipe is either installed beneath the street, along with potable water and sanitary sewer, or installed in utility easements at the back or front of each lot. Irrigation service stub-outs should be located at the same relative location for ease of installation and coordination with the installation of other utilities. Figure 1 illustrates a typical irrigation service stub-out provided to individual lots.

Regardless of where the pipe is routed, the system must be installed to safeguard the public from the possibility of cross connections with the potable water system. Where dual water system distribution pipe is installed parallel to potable water pipes under streets, a minimum separation of 10 feet is often imposed between the two pipes. Where the non-potable system must cross the potable system it is preferred to install the non-potable pipe

12-inches to 18-inches below the potable pipe. Where it is necessary to install a non-potable pipe over the top of a potable pipe many cities require the non-potable pipe be encased in concrete for a distance of 5 to 10 feet in each direction from the point of crossing.   At a minimum, the non-potable pipe shall be clearly marked with non-potable water warning tape. Some cities require that non-potable pipe be of a different color than the potable pipe. Purple pipe, which is primarily required for systems using reclaimed water (treated sewage effluent), is required by some water districts for dual water systems using raw irrigation water.

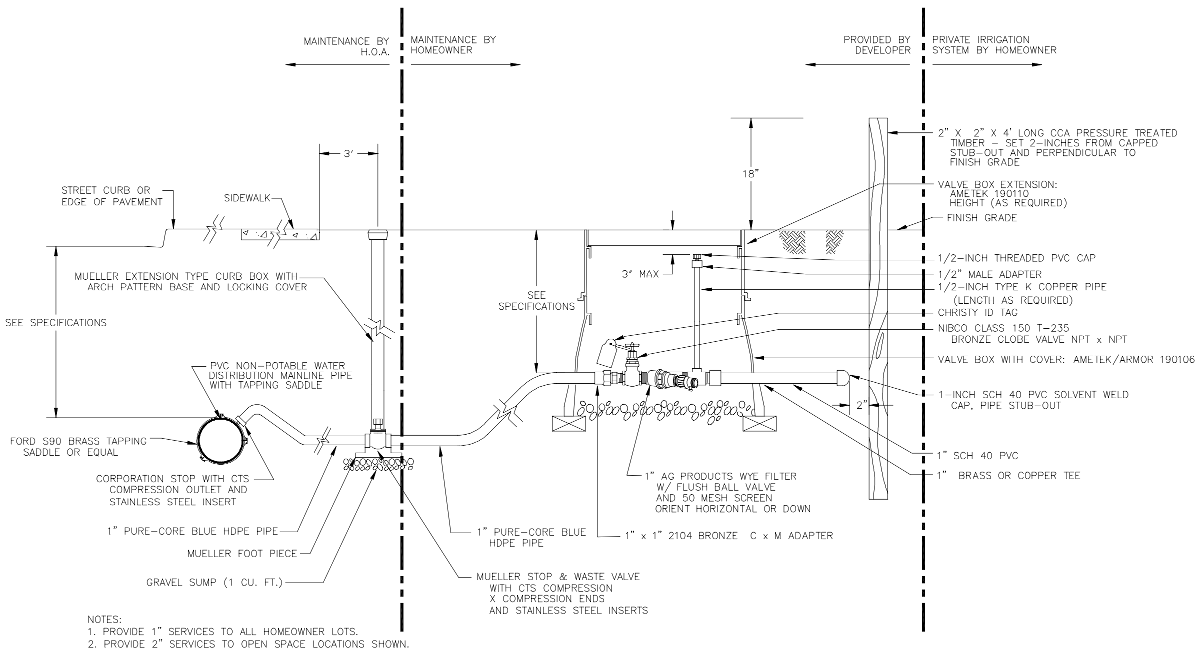

Figure 1
Typical Dual Water System Service

The installation of distribution pipe within a utility easement in the back of lots is generally less expensive, and easier to construct when compared to installing the distribution pipe under streets. Installing the pipe in the back of lots also minimizes places where the non-potable and potable pipe crossings can occur. Developments with extensive trail and open space areas, especially if the lots back up to the open space, are ideally suited for the installation of the distribution pipe in the back of lots. Access to service shut off valves and pipeline maintenance can generally occur within the open space, with little or no inconvenience to individual homeowners. For traditional developments, maintenance and service activities can be complicated since the pipe and irrigation service connections are located in backyards. Since most backyards are fenced and landscaped, annual maintenance and repair activities can become difficult.

The installation of dual water system distribution pipe under streets is generally more accessible for maintenance and service activities; however, the installation costs are generally higher than back of lot systems. Distribution pipe installed under streets are usually installed at a greater depth than backyard systems to avoid issues associated with the non-potable system crossing over the top of the potable pipes. Also, many cities require dual water systems to be constructed and installed to the same standards as potable water pipelines. Where dual water system distribution pipe is installed parallel to potable water pipes under streets, a minimum separation of 10 feet is often required between the two systems. Because of this, it is common to install the dual water system distribution piping above the sanitary sewer pipe, offset 1 to 2 feet. This allows for some economy in the installation of the dual water system since a common trench can be excavated for the sanitary sewer and dual water system pipes and services.

A majority of the systems installed in northern Colorado do not have meters at individual service connections. The advantages and disadvantages of meters is discussed for all projects, and most developers decide that the additional cost for individual meters and the ongoing maintenance cost for reading the meters and the associated costs for billing are not justified. Some HOA's charge homeowners a flat rate for irrigation water and include the cost for operation of the system with homeowner's monthly or annual dues. The provision of meters allows HOA's to charge homeowner's who waste water more. During drought conditions, the installation of meters also allows the HOA's to impose a stepped rate structure to financially penalize homeowners who use more water than allotted. The provision of meters can also reduce the potential for conflicts between homeowners over water use, particularly between the xeriscapers and the mushroom growers (those who water three times per day whether the turf needs it or not).

Other pipeline components, such as isolation valves, air relief valves, and blow off valves should be located in easily accessible locations and preferably not in back yards or locations with difficult or limited access. If possible, isolation valves should be located to allow the isolation of a small section of the distribution pipeline. An ideal system would allow the isolation of one block of distribution pipe without shutting down service to the rest of the system.

Adequate space must be provided for maintenance access to pump stations, well pumps, and other equipment. For systems using well water, adequate utility easements should be provided to allow for a replacement well to be constructed some time in the future.

System Management

On going management of each dual water system requires a competent maintenance contractor, and a cooperative homeowner's association. In many cases, the developer of the project maintains ownership and operation of dual water systems. The system is operated as a utility and offers an opportunity for ongoing revenue and profit, while at the same time reducing irrigation water costs for individual homeowners.

A clear line of responsibility and maintenance must be established between the HOA and the individual homeowners. As noted in Figure 1, the HOA is in control of the distribution pipe up to and including the main shut-off valve, typically a brass stop and waste valve. The homeowner is responsible for the system downstream of main service shut off valve. A separate hand-operated shut off valve, wye strainer, and winterization riser is provided in a separate box for the homeowner's use.

At the start of each season the HOA will typically start up the pump station, fill the distribution pipeline, and inspect the integrity of the system. Then each service will be turned on. Where problems are noted with individual systems, the hand-operated valve downstream of each main service shut-off valve should be closed and a note given to the homeowner about the nature of the problem. At the end of each season, each service should be shut off and the distribution and pumping system winterized as required. The HOA must clearly communicate with the homeowners prior to each of these activities.

One of the most important tasks of any maintenance contractor is the monitoring and management of the main water supply for the dual water system. If a well water source is used, the annual water use from each well must be documented. To make sure water use does not exceed the annual limit, monthly water use should be recorded and monitored. If excessive water is being used, the manager of the system must notify the HOA so conservation or water restrictions can be imposed to decrease water use.

If raw surface water is the dual water system source, the maintenance contractor must monitor the water levels in the storage ponds and order water through the ditch rider to be diverted into the storage pond. As noted above with ground water, the operator of the dual water system must know how much water has been used and how much water is available for use at any point during the irrigation season. This information is especially critical during drought years, just as we are currently experiencing in Northern Colorado. Some irrigation mutual companies are seeing record low yields this year, resulting in early shut down of ditch and canal systems. It should be noted that during this past year most northern Colorado cities and towns have imposed strict water conservation policies for irrigation systems using potable water, making dual water systems no more or less desirable than systems supplied with potable water during drought conditions.

The owners and/or managers of dual water systems must also determine how much to charge customers for raw water delivered to their homes or properties. The water rate must include the cost for electricity, pump station and distribution system maintenance and repairs, system management, and profit. In addition, a sinking fund should be set up to collect and save money for the eventual replacement or renovation of the entire dual water system.

Summary

Given the high value of water in northern Colorado, dual water systems are economically viable. By installing dual water utility in new developments, developers and cities can take advantage of the existing infrastructure of raw water canals, reservoirs, mutual irrigation companies, and ground water wells that previously supplied irrigation water for agricultural crop production. By using these resources, developers can benefit by reducing their costs for the procurement of potable water rights, and cities and/or potable water suppliers benefit by delaying or even avoiding expansion to their potable treatment facilities.

A well planned, designed, constructed, and managed dual water utility will ensure that cities, developers, homeowners, and HOA's will all see long lasting benefits of using existing irrigation water resources with minimal inconvenience.

Alternatives to Potable Water for Landscape Irrigation

by

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Introduction

There are a number of alternatives to using potable water for landscape irrigation. Generally speaking, these include treated sewage effluent, harvested rainwater, and raw or agricultural water. Raw or agricultural water, both "untreated" or "non-potable water supplies", include groundwater and surface water. Most potable water, considering the enormous import of this commodity for modern life, is readily available at reasonable cost, at least in the United States. Over time, many landscape irrigation project owners or subdivision developers deferred to, or at least easily opted toward, a potable water source. The reasons were most often related to economics and basic common sense reality.

Potable water is acceptable, water quality wise, for even drip irrigation. Other key advantages are that potable water is available on demand and available year round. Most importantly, the plant investment fees and the unit water rate have most often been low enough that it was not patently obvious that alternatives should be considered. And, thinking more of the plant investment fees, there is often no additional plant investment fee if the water tap, as required for domestic needs, is used for irrigation during night time hours and not in conflict with domestic culinary needs. So, the cost of potable water for irrigation becomes a cost of paying the going unit rate that is often quite reasonable considering these inherent benefits. On the other side of the economic picture, alternative water supplies require additional infrastructure and present water quality or availability aggravations as well. So, it was, and is, easy to opt for the potable solution with landscapes.

In some areas, this situation has changed or is changing, and northern Colorado is an example. This paper is directed toward the specifics of northern Colorado but the points may be very applicable to other areas, especially states governed by prior appropriation doctrine and having irrigation mutual companies involved in raw water[2] delivery. The cost of the northern Colorado raw water, necessary for municipalities to meet their treatment needs[3], has increased dramatically. Municipalities require raw water or "cash in lieu of" from developers which services are expanded for development. Another factor is that Colorado water rights must be put to beneficial use or risk a challenge to the right under the prior appropriation system. Yet another factor is

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2 The terms "raw water", "agricultural water", and "non-potable" water are used interchangeably in this paper.

3 Referred to as the "raw water turnover requirement."

drought. Colorado is currently experiencing a drought of something of a greater magnitude than a 100-year event and the use of potable water for landscapes is currently under varying levels of restriction.

Brief History of Water and Water Rights in Colorado

Colorado was the first state to develop a system of water rights and laws that are based on the prior appropriation system[4]. The core of the system is "first in time, first in right." So, if you were the first to divert the water from a stream, then you are the first priority on the river, and so forth. Calls on the river are satisfied according to the priority or priorities enjoyed by the water right holder. This approach, begun in the mid-1800s, has worked quite well for Colorado and other western states.

Today, 19 western states employ the prior appropriation system or a hybridization of it. This legal basis of water administration resulted in the formation of irrigation mutual companies that have successfully functioned for more than 100 years in Colorado. The actual decree and diversion right is most often vested with the irrigation mutual company and, at least within the company and the historic service area, water rights can be bought and sold freely. Shareholders who annually pay prorated expenses and enjoy the benefits of proportional ownership of the company and the water right own irrigation mutual companies. The irrigation mutual company's share price is market driven.

In the 1960's, the fact that groundwater is tributary to surface water became legally recognized by state statute so both groundwater and surface water are administered under the Colorado prior appropriation system. Therefore, Colorado's raw water can come from either surface supplies or groundwater but are essentially governed in the same way.

In the 1930s in northeastern Colorado, what ultimately became known as the Northern Colorado Water Conservancy District was founded to construct a project to divert and store Western Slope water and deliver it to the Eastern Slope to supplement the native water supplies. The project itself is known as the Colorado-Big Thompson project or C-BT project. The premise of the C-BT project was to provide insurance against drier years and drought and meet the late season water requirements of the "allotees", 90% of whom were farmers at the time the project was commissioned.

The historic annual yield, and therefore the relative "wet water" value of shares in the mutual companies, varies between companies. Municipalities have come to demand water rights from developers that are the most predictable and solid from their standpoint. C-BT water is viewed by the municipalities and the rural domestic water purveyors to be the most desirable for their potable water needs. Subsequently, the unit price for C-BT water has quadrupled in recent years and this dynamic becomes an important motivating factor in the increasing

4 The prior appropriation system is also referred to as the "Colorado doctrine."

interest to utilize a raw water alternative for landscapes. See Figure 1. The 2002 market price for C-BT continues to hold at around $10,000 per unit. One C-BT unit represents one acre-foot of water but each year a Board determination is made concerning the allotment. Dry years have a high allotment (70 to 100%) and wet years experience a low allotment (50 to 70%)5.

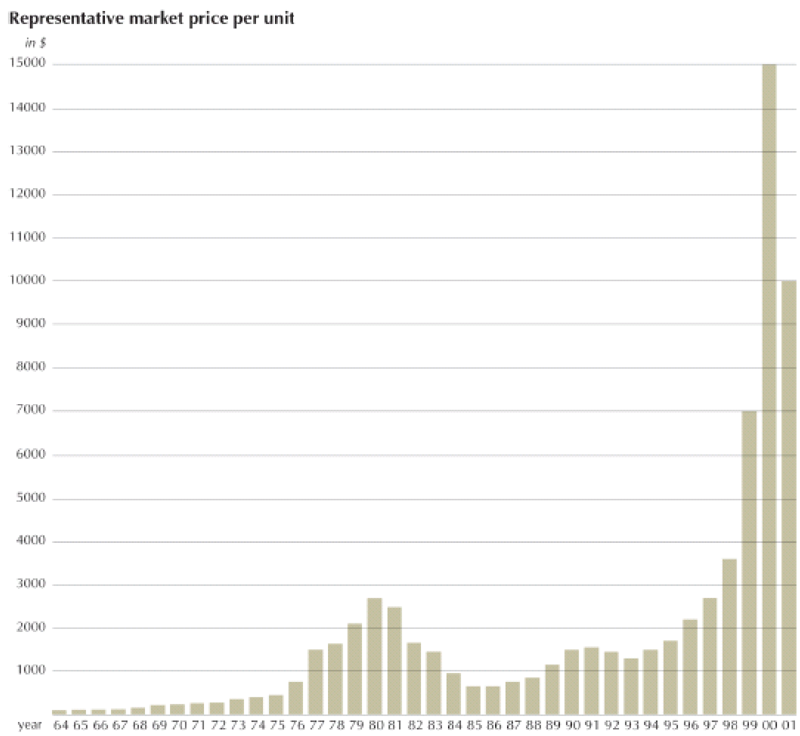

Figure 1. The market-driven purchase price of C-BT water has risen dramatically over the past 40 years because of municipality preference for this predictable water resource.

Urbanization Dynamics

Northern Colorado has experienced several significant growth spurts in the past two decades. Population increases have an important and stressing effect on water supplies and this is especially true with the current drought. Most now agree that the current drought in northern Colorado started, with hindsight view, in July of 2000 and currently exceeds a 100-year event. Low river flows in 2002 are unprecedented in the written historical river flow records. A recent tree ring study even suggests that the magnitude of the current drought can be related to drought dating back to 1703.

Approximately 40% of the present northern Colorado population has migrated into the state since 1990 and the 1990's was a period of relatively wet conditions. A significant portion of the population does not appreciate the desert environment of northern Colorado. Significant market demand exists for lush irrigated landscapes, for both private and public landscapes, and a shift in the public's desire in this regard is not likely any time soon.

There is much to be said about opportunity to change public opinion through policy or economics, but right now, most homeowners prefer bluegrass as a primary ground cover and landscape aesthetic. Bluegrass is a significant water consumer in the landscape, but ironically, is also quite drought tolerant. But the demand is for

5 This is a reversal from what you would normally think but the allotment if governed in consideration of storing and delivering water to meet the dry year, late season needs.

lush and manicured bluegrass, not stressed blue-gray or dried out bluegrass. Until the demand for the green lushness of bluegrass is quelled by either water cost or water availability (restrictions on landscape irrigation), bluegrass will continue to be the landscape turf and landscape plant of choice.

As area cities expand, it is common for farms to be acquired by developers, along with the water rights, and then developed into residential properties, streetscapes, parks, golf courses, and open space. The native water rights become an interesting factor in the equation. The rights may be entirely suitable for agriculture but questionable from the municipal water purveyor's viewpoint if they are not predictable enough to satisfy the city.

As mentioned earlier, urbanization has created a significant, market-driven cost increase for the water demanded by local municipalities for development. The requirements vary significantly between different purveyors but some amount of raw water must be turned over to the city or rural domestic for the provision of potable water into perpetuity. More or less 40% of the developed property will be landscaped and irrigated. Water for irrigation must come from the potable system, or alternatively, from a raw water system if such is available.

So, the opportunity to utilize raw water for landscape irrigation is enhanced by the market-driven price of the preferred water rights. Briefly stated, the developer can consider turning over C-BT water to meet the raw water turnover requirement of the water purveyor and keep other water rights with the project for landscape irrigation. There is a non-trivial cost for the raw water infrastructure, but all of this works economically if the potable water purveyor recognizes the value of the raw water system and therefore adjusts the raw water turnover requirement downward. Some purveyors will reduce the water turnover requirement by 50% recognizing that half the annual potable water requirement, namely that going to irrigation, has been eliminated.

The Role of Irrigation Mutual Companies in Landscape Irrigation

The implementation of raw water systems, also called secondary supply or "dual" systems, can occur in several ways and the ultimate ownership, management, and replacement are very important factors in project success. The developer can implement the secondary supply system and turn the system over to the homeowner's association (HOA). However, HOA's are typically geared to routine maintenance operations and not to infrastructure management, upkeep, and replacement. Some developers have created metropolitan improvement districts to own the systems and others have retained ownership with the idea of generating cash flow and a payback of the investment.[6]

In Utah and Idaho, the irrigation mutual companies or districts have gotten involved in the provision of raw water. Interestingly, this began more than a decade ago and mutual companies are now actively involved in secondary supply. One irrigation mutual company in Utah has 40,000 urban accounts in their service area. If you

6 This can create a circumstance where the developer is looking for a faster payback than a non-profit entity would be. Ironically, the unit cost of raw water for irrigation can be higher to the homeowner than the unit cost of the potable water.

think about it, mutual company involvement makes a lot of sense. The company represents an established organization dedicated to the business of managing a water right or rights, delivering water to users, and maintaining a ditch. The future can be bright and exciting with a simple repackaging of the mutual company's historic role.

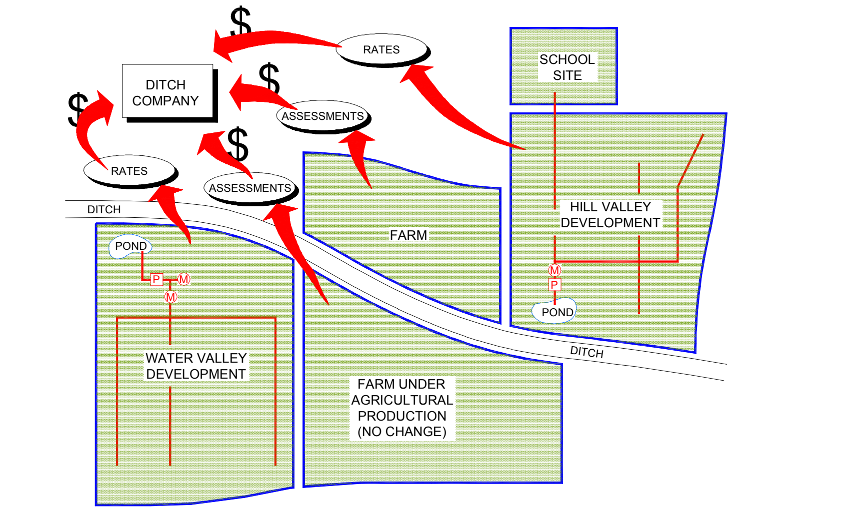

Figure 2. The historic role of the irrigation mutual company can be expanded to deliver pressurized water to urban projects as well as agriculture.

Approach

From the technical perspective, there are several nuances of how to approach landscape irrigation with raw water. Most of these issues will be addressed in a complementary paper. The primary questions to answer relative to water rights are:

- Are the water rights suitable to the mature landscape needs in quantity, quality, and seasonal availability?
- Is water storage necessary?
- Are there local standards or imposed practices to the approach or the equipment?
- Who will construct, manage, maintain, and ultimately replace the raw water system?
- Will potable water hose bibs be allowed on the structures?

The primary questions related to delivery infrastructure are:

- Will the water be metered?
- Will the piping be located at the front of lot or back of lot? If front of lot, will it be in the street?
- Are offsets from other utilities required?
- Is the pipe network to be below frost line?

Legal Issues

There are some perceived and real water right issues connected with using water that was historically used for agricultural irrigation and moving the application toward landscape irrigation. Most often the decree is worded such that the water right is associated with “irrigation” and irrigation is irrigation whether used for agricultural crops or landscapes. Some urban projects are built on land that may not have been irrigated previously or that was only partially irrigated previously. Bringing new ground under irrigation is most likely an issue and, in all likelihood a Colorado Water Court issue, that can be lengthy and costly in process.

Benefits and Economics

The gratifying aspect of this topic, raw water for landscape irrigation, is that everyone comes out ahead and benefits from this approach. The housing developer saves money that can be potentially realized in lower cost housing. The potable water purveyor can delay, even indefinitely delay, expansion of water treatment facilities[7]. The homeowner pays a lower unit rate for raw water for irrigation than they would if they used potable water. The State of Colorado benefits through the strengthening of the water right and the beneficial use criteria associated with the accumulated State of Colorado water rights. When irrigation mutual companies are involved, the provision of raw water to landscapes can offset annual costs of operation and allow assessments on the agricultural water to be stabilized or even reduced.

Summary

In northern Colorado, urbanization has created a rather dramatic market-driven increase in the price of the Colorado-Big Thompson (C-BT) project water that is desired by the municipalities. Developers are required to turn over C-BT water to the municipality to meet the treated potable water needs. Landscape irrigation is a significant (more or less half) component of the annual potable water demand unless a secondary supply of raw water is provided for landscapes. Municipalities, developers, homeowners, and the State of Colorado can all benefit if landscape irrigation is accomplished using the native water supplies that were associated with the land when it was farmed. The irrigation mutual companies that have played a role in Colorado water delivery for more than 100 years may have a potential expanded roll as urbanization occurs in the future. The pros and cons, the organizations, concepts, management, and the technical aspects of implementing raw water for landscape irrigation are an interesting current dynamic in Colorado water.

7 A common rule of thumb suggests that it costs $1 million to expand an existing water treatment facility by one million gallons per day of treatment.

**Changes to the Irrigation Paradigm:
The City of Calgary Parks as a Case Study**

Denis Gourdeau, Doug Marter – The City of Calgary

Abstract

A decade ago the City of Calgary Parks business unit began investigating central control systems. That process lead to an evolution in the perception and thinking around irrigation and water. The ensuing paradigm shit, from being irrigation system focused to water management focused, has been validated by recent drought and concerns about future weather trends and water availability.

This paper highlights the changes and processes that The City of Calgary underwent, and analyses how these influenced further changes and resulted in cyclical feedback loop. It also demonstrates through examples how other municipalities could undergo a similar process resulting in more effective and efficient use of our finite water resources.

Past and current practices will be discussed in relation to how these have positively or negatively affected Calgary Parks move toward efficient and effective water management and the shaping of the new paradigm.

Background

The City of Calgary is located in the southern part of the Province of Alberta in Canada. It is situated 100 km (60 miles) east of the Rocky Mountains and 300 km (180 miles) north of the border between United States and Canada. Calgary has a population of approximately 1,000,000 and covers an area of 721.73 square kilometers (278.54 square miles). The city is home to Canada's oil and gas industry together with telecommunications and computer related businesses.

Calgary has approximately 3,000 parks covering 7,822 ha (19,328.51 acres). Of those, 2,000 parks have irrigation services and some form of irrigation system. The total park area with irrigation equals 2,290 ha (5,700 acres). Systems range from hose connections, galvanized turf valve and quick coupler, manual hydrant and canon, manual pop-up to automatic pop-up with wireless central control. Calgary Parks water bill in 2001 was over $1.6 million for 3.9 million cubic meters (1,377,368 CCF) of irrigation water.

Beginnings

In 1993 Parks staff began to wonder about the long-term availability of cheap water. This was liked to the question of when the cities growth would be slowed or limited by the availability of water for human consumption and hence applying pressure on large users of irrigation water. It was determined at that time to begin looking at ways to reduce water use. Central control was seen as one way to possibly reduce the water consumption of irrigation systems.

Parks had just moved from building manual pop-up irrigation system to electric automatic in 1991. Building parks that would be watered during daylight hours when wind and evaporation were at it's highest was becoming unacceptable to conservation watch-dogs. To a small group it was looking like parks should be proactive and plan for the management pressures that the future would bring now and save tomorrows high retrofitting costs. Staff began investigating central control systems reading promotional literature and periodical articles. After approximately six (6) months a decision was made to evaluate some competitive products and conduct field-testing.

Request For Proposal

In mid 1993 a Request For Proposal (RFP) was issued by the City of Calgary to prospective manufacturers and distributors. The RFP highlighted what criteria would be used in the evaluation, and the general features and expectations that Calgary was interested in. Parks worked together with the Information Technology Services department in drafting the RFP. As part of the RFP, contenders would have to agree to install evaluation equipment in city parks for a minimum of one year and have that equipment actively operate the irrigation systems in those parks. For systems that utilized remote field managers and satellites in concert with the central computer, the manufacturer would have to provide ample equipment to demonstrate how all components contributed to the overall operation of the system. Venders would have to provide assistance setting up office and field hardware and the initial programming of irrigation programs.

Four (4) manufacturers answered the RFP. The evaluation proceeded in two phases. First the written proposals and supporting documentation was evaluated. Documentation was extensive and was reviewed exhaustively. References and contacts were checked and interviewed in detail. Once the first phase was completed the evaluation moved to the second phase of field-testing the equipment. Sites that represented the diversity of types and sizes of Calgary parks were selected. Each manufacturer had sites representative of the complete mosaic. Equipment was installed on site with representatives of both Calgary Parks and the manufacturer and their distributor. Once equipment was ready in the field, computers at the main office were configured and irrigation programs written and dispatched to the field.

System Evaluations

Testing the various central control systems became more than just a product evaluation exercise. Each system was tested against what the RFP and promotional literature said that it would do. The different products were also put through different operational procedures and their performance compared against what Parks believed it needed these systems to be able to accomplish. As time passed it became evident that some systems could not meet the expectations set by the literature. Some features were found to still under development and not field operational. Still others were found to be proposed but with no quantifiable work done on them.

At the same time, Parks was finding that its vision about what it wanted in these systems was being clarified and shaped by the results of the evaluation. Certain features were becoming very important and others demonstrating potential for future integration into different lines of business in the corporation. For example, the communication medium becomes very important if the system will be implemented in a city where is extensive holdings of land that will have to be retrofitted with the

Figure 1: Central control system at Kingsland Dry Pond.

system. Bringing telephone service to existing parks in cities with underground wiring often requires excavation sometimes across streets, which can be very expensive. Bringing electric power to a site can also be cost prohibitive. In Calgary we have seen these costs easily run from $5,000 to $15,000.

Other features were tested and found to significantly impact the usability of the system. Some of these included real-time weather station interfacing for ET calculations, low flow monitoring, conditional programs, sensors, inputs and computer networking.

At the end of the trials a successful system was selected and the unsuccessful candidates removed their equipment. With some manufactures the decision was swift. With others, the results were reviewed more closely before a decision was made. In 1994 the final decision was announced and The City of Calgary selected their future central control system manufactured by Motorola Inc. and marketed at the time as the Toro MIR5000.

Thinking Changes

As Calgary Parks installed central control in their first few parks a change began to occur. Some individuals were realizing that though central control systems were a major part of reducing water use in park irrigation systems in a predictable and consistent manor there was something more. If an organization is installing central control in order to conserve water and make irrigation more efficient then they will have to start looking beyond the central control hardware and software for some of the help.

For the City of Calgary this meant rethinking the business that the irrigation staff were in. For decades staff believed that if a park was built then it must have an irrigation system built in it. We call this being in “the business of irrigation”. If however, your mandate becomes conserving water, has your business not changed? Our answer to this question is “yes” and we therefore say that the business now becomes “water management”. So here starts the paradigm shift and the cyclical process that implementing central control can take you on, if you are serious about water conservation.

For Example: In the old paradigm, all parks in a neighborhood would be built with irrigation systems. In the new paradigm parks would be evaluated on the bases of the adjacent land base and the amenity they need to provide to the community. From that evaluation the need for irrigation, or not, would be determined.

Case #1: A park is to be built in a neighborhood. The park is located at the head of a residential collector road leading into the community. It is flanked by residential homes or community service business (i.e. convenience store). In this setting an ornamental park would be well suited. An irrigation system would be an integral part of this parks development. Water conserving technologies would for the basis of equipment selection and design decisions.

Case #2: In the same neighborhood another park is to be built. This park is located along a residential road with houses on each side and across the street. The back of the park is boarder by a natural area that ends with an escarpment over looking a small creek. Historically, in Calgary, this park would have been constructed as an ornamental park with a full irrigation system. Because of the water management focus development inspectors now ask the question: What is the best focus of this park? Does an ornamental park make sense in this location? Should this park be naturalized and serve as an extension and leader to the natural area? By building the park as an extension of the natural area two positive results are achieved. First the natural environment is integrated into the community. This inclusion in the community causes less separation between human kind and our natural environment. Second and most importantly to our new paradigm we conserve water through the most effective means, not irrigating if we don't have to.

Other changes occurred in Calgary Parks because of the water management focus. Traditionally water for irrigation was flat rated. If a park had an irrigation service the area of the was multiplied by one inch of water per week times 16 weeks of irrigation. With flat rates increasing Parks wanted to be sure that it was only paying for the water it was really using. Calgary Parks recognized that it had some parks with only a single quick coupler on a 0.3 ha (0.74 acre) site. It was obvious that with this configuration the whole park was not being irrigated to the amount being billed. Staff also recognized that staffing and budget reductions had lead to some parks with manual systems not being watered and therefore water being billed for but not actually used.

In 1997 Calgary Parks and Waterworks partnered to meter the 2000 existing irrigation services and meter all new park developments as they are constructed. Meters were evaluated for their accuracy and suitability for use by Waterworks for billing and their low flow accuracy (40 GPM on 6" meters) for leak detection in future central control systems. In the end and after problems with a previous manufacturer the City of Calgary settled on Hydrometers (meter/master valve combination) by ARAD. To date Parks has installed approximately 1200 hydrometers and will install the remaining 800 by the end of 2003 if capital budgets and cost sharing programs allow.

The Growing Toolbox

As conserving water became more important, the challenge of saving more water has grown. If we were saving water by watering at night because of lower wind speeds and reduced evaporation they were there other ways we could reduce our water consumption. Signals from Hydrometers installed on central control sites enable flow monitoring. Flow monitoring can detect leaks from broken pipes, damage irrigation heads, non-closing valves and systems that been tampered with.

In order for central controlled sites to only apply the actual amount of water necessary to meet plant demands Parks is building a weather station network. Weather stations are constructed in various parts of the city where weather is known to vary. Controllers in the local area are fed weather information from the closest weather station and the daily evapotranspiration (ET) rate is calculated

prior to the programmed irrigation cycle. To further conserve water remote field managers (Remote Terminal Units) are fitted with rain switches. These switches, through a change of state, tell the control system that there is a local rain event occurring and the controller suspends irrigating, further saving water and improving public profile. This suspension affects all satellites under the management of the RTU. Freeze sensors are also fitted on the system. This helps prevent frost damage to plant material and also prevents the icing of sidewalks and pathways and potential legal battles.
Parks is developing partnerships with Waterworks Recreation and the Fire Department for the sharing of its weather data and the further development of the weather network. The Fire department wants the data to do real-time fire hazard prediction and fire behavior modeling. Plans are underway to install weather stations at Fire Stations where Park Depots do not exist. For Waterworks, Parks will be building a web site where weather and ET data together with irrigation recommendations will be posted. This information will allow residential and commercial users to adjust their watering practices and controller settings in order to reduce their operating costs and help conserve water.

Calgary Parks move to a water management focus has led to its new role as an internal corporate consultant for irrigation water users such as Calgary Recreation, Calgary Roads and Calgary Transit. Parks was a key partner in the writing of Calgary's new bylaws for water rationing and the recognition of water managed properties as a ally in the battle to reduce water waist.

Paybacks and Results

A water management focus brings many paybacks to the business unit. These include not only reductions in water use and water costs but reductions in operating costs, improvement in turf and plant health, and reductions in herbicide and pesticide use. A random check of water use at 13 sites of various sizes, uses and designs demonstrated a water use reduction of 44.3% as compared to our water allotment. Table one shows the results of six of the sites. The results were substantially greater than what we used to promote the switch to central control but consistent with what we had been told by the manufacturer.

Table 1: Water use comparison.

Park Name	Water Used	Area	Flat Rate	Saving
355 Sandarac Dr. NW	13,081.2 cu. M	6.142 Ha	24,568 cu. M	**46.7 %**
4 Schooner Landing NW	631.9 cu. M	0.225 Ha	900 cu. M	**29.8 %**
20 Sunpark Drive SE	11,422.5 cu. M	7.260 Ha	29,040 cu. M	**60.6 %**
150 Millrise Dr. SW	10,786.9 cu. M	3.580 Ha	14,320 cu. M	**24.7 %**
1120 Prominence Hill SW	10,504.2 cu. M	4.526 Ha	18,104 cu. M	**41.9 %**
727 Coach Bluff Cres. SW	527.2 cu. M	0.217 Ha	868 cu. M	**39.3 %**

We also found that sites exhibited improved turf quality and an overall improvement in plant health under central control. Figure2 shows the turf quality at an existing park with a hydraulic valve in head system that has been problematic to maintain and operate. Figure 3 shows the improved turf at a similar site, 150 Millrise Drive SW, which was retrofitted with central control. This site also achieved a 24.7% reduction in water use as shown in Table 1.

Figure 2: Turf on site without central control

Figure 3: Turf on site retrofitted with central control.

The comparison is not to suggest that central control is a miracle worker that will fix all ills with park irrigation systems, but rather to show that the water that is being used may not be effectively applied. The results can be harmful to the business unit's image with the public and council. With central control instructions are carried out as designed and in the most effective way possible.

Central control has saved the City of Calgary labour costs. A park with a manual pop-up irrigation systems costs Calgary Parks $1,877.00 / ha / year ($759.92 / acre / year) to water the site. This cost includes travel time between neighboring parks and the task of turning on gate valves to activate sprinklers. A quick coupler / water cannon system costs parks $2,675.00 / ha / year ($1,083.00 / acre / year) to water the site. The cost of watering a park with central control for the City of Calgary is $334.30 / ha / year ($135.34 / acre / year) including staff to program and monitor the central computers and field technicians to troubleshoot and service the field equipment. These watering costs do not include the cost of water, which was separated out and discussed earlier.

Future Directions

The shift to a water management paradigm is leading Calgary Parks in some new directions. In coming years we are looking at developing a reserve fund where the savings from reduced water use will be reinvested in further water management projects such as retrofitting quick coupler systems into automatic pop-up systems using central control. Parks also wants to start an irrigation audit program, following Irrigation Association guidelines, to determine the amount of water inefficiency and invest savings into the retrofitting of existing systems. Calgary Parks also wants to establish a regular program to audit sites so that systems remain operating at their peak efficiency so that water and budgets are not wasted.

Adopting a new paradigm has led parks towards the development of a Water Management Strategic Plan. The plan will include best management practices and guidelines for the development of performance based construction specifications. This plan will also influence park planning through the development of policies related to the appropriate use of irrigation in parks. It is expected that in the not too distant future irrigation systems will have to meet specific targets for distribution uniformity and inspectors will not approve parks that fail a water audit.

Conclusion

Central control has changed the way Calgary Parks looks at irrigation and sent the business unit headlong into the world of water management. This change is showing in our staff. Long time employees find it hard to adapt to and understand the changes that are taking place. Many cannot grasp the technology that is now being used and a new type of worker is emerging. The municipal employee of the future in Park Water Management work units may include technologists trained in electrical, electronics, instrumentation or computers with Irrigation Association training and certification.

LANDSCAPE IRRIGATION AUDITING:

A MOBILE LABORATORY APPROACH FOR SMALL COMMUNITIES[1]

D. L. Thomas, K. A. Harrison, R. Reed[2]

INTRODUCTION

Landscape irrigation is one of the first water resource uses to be affected by designated drought or water restriction conditions. Odd/even watering (based on the last digit of an address), time periods of allowable water use (such as no outside watering between 10 a.m. and 6:00 p.m.), and complete outside water use restrictions are logical approaches that communities have used to help manage limited water resources. In large cities, personnel and funds may be allocated to help encourage improved approaches to outside water use. However, many small communities lack the funds to hire personnel to help with their outside water management and must revert to "system-wide bans". Obviously, outside watering bans have a direct and long-term potential impact on some of our most dynamic and thriving industries: landscape plant nurseries and turf/sod farms.

The opportunity to tap the extensive information and technology alternatives for urban landscapes and landscape irrigation, package this information in a comprehensive program that is oriented toward small communities, and then determine the best approaches to present this information, provide a foundation for a good rural extension program.

Landscape irrigation is notoriously inefficient because irrigation systems can rarely be designed, installed, and maintained at the highest level attainable (unless available funds are not limited and the owner is very conscientious and knowledgeable).

The information provided in this paper is not new. In fact, any community that is interested in improving their landscape irrigation can find good resources to help manage their landscape water use, if they are willing to take the time and investigate alternatives. Unfortunately, many small and large communities may not be using the resources that are available. A large percentage of homeowners and business owners are unfamiliar with current landscape irrigation technologies. The need to provide a mechanism for direct investigation and education about good landscape irrigation practices is real. This paper presents an approach that could be implemented by

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[1]The use of tradenames, etc. in this publication does not imply endorsement by the University of Georgia of the product named, nor criticism of similar products not mentioned. The team wishes to acknowledge the support and contribution of the water utility organization, especially Mr. Jerry Lott, City of Douglas, GA who were essential partners in the project.

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extension service personnel or other groups for improving landscape irrigation efficiency, with direct alternatives that can potentially save water. Most of the ideas presented are being tested in South Georgia. Since Georgia is in the humid region, precipitation is an essential component of the water used by landscapes. In most years, precipitation is sufficient to supplement the irrigation required for landscape areas. Landscape irrigation is extensively used to keep turf green and provide supplemental water to landscape plants. For most areas, little effort has been spent to ensure "sustainable landscapes" or to maintain an efficient irrigation system. Within the past four years, drought conditions have caused severe water shortages across the state. In 2001, outside watering restrictions were implemented state-wide for the very first time. These restrictions remain in effect for the majority of the state. For many communities with limited water supplies, their only alternative to meeting their water needs was to restrict outside watering (some were restricted 24 hours a day, seven days a week).

PROCEDURES

The steps indicated in this paper are those that are expected to be viable for Georgia communities. For areas where conditions are not similar, particular steps can be removed or changed to meet specific needs.

Overall Goal

The mobile laboratory approach was designed as a resource to small communities that could be moved into a community for a short period of time, do evaluations, make reports, and then move on to another community. The ability to have personnel "in a community" indicates the commitment of the sponsoring and funding organizations toward the needs of that community. The mobile laboratory approach (personnel and equipment) should logically be funded through some type of state appropriation. Specific recommendations that are tailored to a community can improve overall water use and provide incentive programs for the future.

Developing the Initial Team

For this particular effort (with a lack of substantial outside funding), it was essential to involve the County Extension Specialist from the community that is interested in water conservation. The knowledge of a local county extension specialist can include essential contacts and the potential for acceptance of the ideas (local politics). If a local extension specialist is unavailable, the Soil and Water Conservation Commission, Natural Resources Conservation Service, or a Rural Development Cooperative may be good alternatives. Having the mobile audit team in good communication with a local person is essential to "buy-in" and the potential for success of the effort. In addition, the participation of a local agency can create a local contact person who will be knowledgeable about landscape irrigation practices.

Approaching the Water System Purveyor

The organization that is involved in distributing the water to customers is an essential component to the success of a landscape auditing program. Since their direct revenues are usually associated with the amount of water being distributed, the idea of "reducing" that water is not always met with a positive reaction. It is important to assure the local water system purveyor that recommendations will include approaches to maintaining their economic viability while reducing overall water use.

Approaching the Water Users

If a community has separate water meters for outside landscape irrigation, it may be very easy to approach those who can benefit from irrigation conservation alternatives. In the pilot study in Coffee County, Georgia, that was the case. A letter was sent to each individual with an outside water meter indicating the opportunity to receive an audit of their landscape irrigation system. This letter contained information about the program, who was doing the activity, what would be expected of the participants, and what they would receive in return.

For each potential water user, their personal audit information was to be maintained as confidential. However, a community report would be created that consolidated information from all the individual reports. None of the information in that report was to be identified with any individual audit.

If a community does not have separate water meters for outside irrigation, the initial contact with potential participants is very critical and essential. A community- or county-based meeting is a recommended approach to initiate the audit program. This meeting would provide essential information about the audit process, why it will be important to consider water saving alternatives, and who would be involved in the audit program. Typical and innovative contact approaches (mass media) are essential to good participation in such meetings. "Incentives" could be provided by the water system purveyor to help encourage community attendance at the meeting. In this paper, "incentives" can be both positive and negative. We have encouraged positive approaches to participation, but the typical response of a community may require negative incentives. Examples of positive incentives for attending the first meeting include a small water rebate for a coming month, a coupon to be used with excessive future water bills, raingages to help determine water use. The raingages could be provided by a local irrigation dealer who is also interested in water conservation in landscape systems. Brochures about landscape water use, landscape planting (Xeriscaping, etc.) could also be available at this initial meeting. Potential negative incentives could be an added charge to a water bill if participants with outside irrigation do "not" attend the meeting.

UGA

WATER RESOURCES TEAM

Figure 1. Logo used on shirts for the water auditing program.

<u>The Audit</u>

After a time was scheduled for the team to meet the water user, the audit team visited the irrigation system directly. For our and the customer benefit, we developed a particular shirt to help identify our team members with the University of Georgia (UGA) and the water auditing effort (Figure 1). It was our perception that elderly and young women may be reluctant to visit with the audit team until they are confident of the groups identity. The logo was generic enough to allow other water-related programs at UGA to use the same shirts.

During the audit, the system was operated through each of the different zones. One member of the team recorded the zone information (sprinkler types, number of sprinklers, nozzles, areas covered, i.e., full circle and part circle) while another team member observed individual sprinklers on zones for off-site applications, other maintenance problems, and pressure conditions at near and far sprinklers. A third team member usually asked questions to the water user while recording information on the time clock. In most cases, digital pictures were obtained to help illustrate problems or good characteristics of the irrigation system.

Figure 2. Water team member visiting with a homeowner.

These images would be essential to helping explain particular characteristics to the water user in their report.

The water user was requested to be present during the audit (turn system on and answer questions, Figure 2). Many of the observed problems with the system could be discussed directly with the water user. In most cases, the water user was armed with sufficient information to make some initial changes for direct water saving and to improve water use efficiency, prior to submitting a formal report.

Figure 3. Installing catch-cups for a uniformity analysis at one of the audit sites.

Uniformity Analysis

A uniformity analysis was performed on a selected number of irrigation audit sites (Figure 3). The uniformity was of main concern for irrigation applications from rotating sprinklers in turf areas. If the water user indicated the presence of "wet" or "dry" spots during irrigation, a uniformity analysis was useful for visual and quantitative analysis of the problems. In most cases, a uniformity analysis was not required. The uniformity analysis included installing catch cups at ground level on a reasonable grid interval. More than one zone area may be required to water the uniformity area, but the purpose was to demonstrate to the water user whether water was being used wisely.

The computer program used for the uniformity analysis is available from the University of Georgia (Harrison, 2002). This uniformity analysis program provides the three basic uniformity calculations that are used most in analyzing irrigation systems: the Christiansen uniformity coefficient, low quarter, and Heerman-Hein equation (Keller and Bleisner, 1990; ASAE Standard, 1994), and is applicable to solid set and center pivot irrigation systems (landscape and agricultural applications). The Heerman-Hein equation is used only for center pivot irrigation system analysis. The three different uniformity calculations are provided because different groups like particular numbers.

Reports

An individual report was prepared for each audit site. This report contained general information that relates to most irrigation systems, as well as, specific information on the system being audited. For example, some water saving technologies were illustrated (rainfall cut-off switches). Particular off-site application or maintenance problems were also identified. Specific recommendations for the irrigation system (nozzle changes, time of application within a zone, etc.) were described for calculating direct water savings. These potential water savings were reported to the water user as a way to encourage changes in the system.

A community report was also prepared to illustrate the overall water savings that could be expected by instituting water saving alternatives. Most results were reported in percentages with direct reference to potential gallons saved during a period of time. The opportunity to save water was indicated in combination with alternatives to maintain income for the water purveyor. Incentive programs are essential to the potential buy-in by the water purveyor and the customers. Recommendations for nozzles to be available for retrofitting rotating sprinklers, raingages to help keep track of current conditions, and other water saving practices were provided in the community report.

RESULTS

The pilot study in the Douglas community in Coffee County Georgia was the initial location for implementing this mobile landscape auditing program. Douglas is located at about 31º 31' N and 82º 50' W in South Georgia. Ground water is the primary source for the drinking and landscape water supply. Water is supplied from Upper Floridan aquifer wells with pumps located about 35 m from the ground surface. Douglas has about 186 meters on outside watering systems. Total city water use to household water uses (excluding industry) is about 2 million gallons per day (mgd). The city of Douglas uses a block rate structure for their water users (Table 1). The current block rate structure does not specifically encourage water savings since the cost per 1,000 gal. decreases with increased gallons used. Most water users with operating irrigation systems would be in blocks 3 or 4, depending on the lot size (area being irrigated). For example, a 1/3 acre (14,500 ft^2, or 1,350 m^2) irrigation area that is irrigated 1.5 inches (38 mm) per week would result in about 53,500 gallons used in a month. Water use would include block 5, and the water bill would be about $59.00 for that month. The potential to address income questions is a reality if water audit results are to have an effect on total water use.

Table 1. Block rate pricing structure for monthly water use in Douglas, GA

Block	**Rate, $/1,000 gal.***	**Description, gal.* used**	**Potential Monthly Bill, $**
1.	$6.68⁺	≤ 4,000	$6.68
2.	$1.26	4,000 to10,000	$14.24
3.	$1.08	10,000 to 20,000	$25.04
4.	$1.02	20,000 to 50,000	$55.64
5.	$0.89	50,000 to 100,000	$100.14
6.	$0.79	100,000 to 200,000	$179.14
7.	$0.71	> 200,000	>$179.14

*For SI conversion, use 3.8 liters/gallon

⁺This is a base charge regardless of amount used below 4,000 gal.

Audits were performed on 14 different systems in the community (>7% sample). The selection was based entirely based on those who requested an audit after receiving a notice in the mail. Half of the audits were on commercial or municipal sites, the rest were residential customers.

The Douglas community currently is under an odd/even watering restriction (based on address). That means that water users may irrigate every other day. There is also a 6+-hour time restriction during allowable irrigation days (4 p.m. to 10 p.m.) that has been initiated in many locations across the state. In practically all sites analyzed in this pilot study, the time-clocks were set to allow irrigation during early morning hours, thus reducing losses due to evaporation. Unfortunately, early morning hours (12 a.m. to 5 a.m.) creates the largest potential for other losses. Offsite applications, maintenance problems (broken sprinklers), and small leaks (if the evidence of the leak is not substantial) are not easily observed during those hours of operation.

Water Saving Opportunities

The largest problem observed within the audits was *selection of nozzles in rotating sprinklers*. Rotating sprinklers were defined as gear-driven or impact sprinklers that "rotated" across the area of irrigation need. Regardless of whether sprinklers were old or new, nozzles were not sized according to the area of coverage by the rotating sprinklers. For sprinklers that were operating over part circles, the same nozzles were typically used as compared to full circle sprinklers. This is not a problem if all full circle sprinklers are on the same zone, all part circle sprinklers are on a different zone, and the operating times are adjusted accordingly. Results from the Douglas community tests indicate that about 24% of the water used on rotating sprinklers could be saved by using the proper nozzles (based on those systems tested, with no other changes in operating schedules). This percentage translates into nearly 40,000 gallons of water per week that could be saved on the 14 systems tested, by using proper nozzles. For the individual systems tested, the water savings due to nozzle changes ranged from 0 to 45%.

Operating time was another concern illustrated from the irrigation audit results. In most cases, spray heads tend to put out three to five times the water application rate on a given area as compared to drip or rotating sprinklers. If the time is not adjusted accordingly for zones with spray heads, those areas will receive a much higher application of water. For those systems with spray head problems (60% of those systems with spray heads), about 19% of the water used through spray heads could be saved by adjusting the time to conform to a "recommended" amount that was consistent with the rotating sprinkler amounts. Turf needs about 1.25 in. (32 mm) per week during peak water demand periods (Tyson and Harrison, 1995; Wade et al., 2000). This water savings percentage translated into over 5,000 gallons of water saved per week for the systems tested.

On one single system, the operating time per irrigation was 180 minutes (with rotors). If this system is operated on an odd/even irrigation schedule, the application amount per week is nearly 2.0 inches (50 mm). By reducing the zone time to 120 minutes per irrigation, over 4,700 gallons per week could be saved on this system alone.

Off-site applications were a real problem in some areas. Spray heads and rotating sprinklers were observed putting water in roads, sidewalks, driveways, and parking lots; hitting nearby bushes and trees (significantly affecting the pattern); and even putting water into a swimming pool. Recommendations to save water were provided based on converting some full circle rotating sprinklers to part circle. Water savings based on off-site applications are "real" based on any application scenario because this water is not being used for any beneficial plant response. Off-site applications did represent a relatively small percentage of the overall water use. For one system tested, changing a full circle sprinkler to a 270 degree coverage would save about 210 gallons per week. For another system, changing a full circle sprinkler to a half circle sprinkler amounted to about 100 gallons per week in water savings. This was based on the current operating time that was set to provide 0.5 inches (12.7 mm) of water per week. All of the above savings were based on the current irrigation schedule (time of application in a zone) and the particular nozzles being used.

Changes were also recommended *based on the season*. In the majority of the audits no direct effort was identified by the water user to reduce water applications during the fall, winter or spring. In some cases the timing was modified if areas were observed to be too wet. Rarely were the seasonal adjust features (water budgeting) utilized on time clocks. The potential for educational efforts to help water users more effectively use their time clocks, was evident in almost all audit situations.

Efficiency improvements, but more water needed

In some cases, water application recommendations were provided to help meet potential plant water needs. Some irrigation systems were not providing sufficient water to meet plant water requirements at peak summer conditions. Recommendations that increase the amount of water to be applied to a particular area would result in increased efficiency, but also increased water use. Obviously, if the water user is satisfied with the condition of the turf and landscape plants, these recommendations should not be implemented (indicated in their report). Schools represent one type of irrigation system that may not need as much water during the summer. Most schools are not in session during the summer. Maintenance during the summer is desired to be low and visual appearance may not be as important (low application amounts may be acceptable). Unfortunately, the southern climate will encourage the encroachment of drought tolerant weeds if sufficient water is not available to the turf.

Application amounts for rotors seemed to be low for a large percentage of the systems evaluated (50%). These systems were putting out less than 0.6 in. (15 mm) in a week (based on an application “every other day”). These application amounts may need to be adjusted based on the stresses observed on turf and landscape plants. The amount applied can easily be corrected by adjusting operating time(s) per zone. However, this would result in increased water use (gallons) for those particular systems.

Alternative Water Rate Structures

The largest concern by the water purveyor, was the potential loss in revenue associated with water use reductions. The potential exists to modify the water rate structures to address those persons making the changes. It was estimated that most irrigators would be in blocks 4 and 5 based on their schedule and irrigated area.

What if the block water rate structure described in Table 1 were “readjusted” to penalize those who use more water? For example, the water rate for blocks 4 and 5 could be increased ($/1,000 gal.) to encourage outside water users to use less water. Income to the water purveyor would not be reduced, since those wishing to use more water would pay an increased rate.

Positive incentives, such as reduced water rate structures by the implementation of water saving alternatives, could also be used to encourage reduced water use.

Spreadsheet Analyses

The majority of the analysis of water savings and collection of results were developed on simple spreadsheets. The ability to quickly modify zone operating times and nozzle sizes to calculate water savings was a benefit. In addition, the data collected from each site could be entered to allow easy calculation of overall water savings potential.

CONCLUSIONS

A new mobile landscape irrigation auditing program was developed and tested in a pilot study in Douglas, Georgia. At least 14 individual systems were audited (>7% of outside water meters). Fifty percent of the audit sites were municipal or commercial sites, the rest were residential. For the audited systems, at least 250,000 gallons per week were estimated to be used if all systems were operating on an “every other day” irrigation schedule. If all recommendations for water savings were implemented on these systems, nearly 50,000 gallons per week (about 20%) would be saved. All potential water savings were based on adjusting irrigation schedules to apply less water if they were currently exceeding recommended amounts (per week).

Some audited sites were applying less water than is recommended for turf and landscape plants (during the hot part of the summer). Irrigation efficiencies, and possibly health of turf and landscape plants could improve by applying more water.

In practically all irrigation audit situations, no seasonal adjustments were being made to reduce water applications during the fall, winter, and spring. The need for improved education on irrigation and operating system alternatives was obvious.

The audit program represents a real and potentially viable method of improving water use for small communities. The potential to use water more efficiently and save water under drought conditions is necessary to the future viability of the landscape and turf industries, and the quality of life and beauty we expect from our landscapes.

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Practical Applications of Landscape Irrigation Water Management

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ABSTRACT

The goal of a landscape irrigation system is to maintain a functional and healthy landscape with the minimum required amount of supplemental water. Methods are provided that show how to achieve this goal through measurement of inefficiencies caused by distribution non-uniformity and excessive management-applied water. These measurements lead to understanding which further lead to system improvements resulting in higher distribution uniformity, higher water management efficiency, lower cost, and reduced water usage.

INTRODUCTION

How do you know if your landscape irrigation system is applying the right amount of water? How much of the water is attributable to plant need, to the equipment (as it relates to distribution uniformity), and to the extra amount applied by the water manager? How much money are you spending on each? These questions can be answered by applying some new and common sense landscape irrigation water management principles from the Irrigation Association's Turf and Landscape Irrigation Best Management Practices (reference 1). These BMPs can be downloaded from The IA's web site at www.irrigation.org.

This paper applies these principles to a real landscape. Several concepts are used; all of which are discussed in detail in the appendices of reference 1. These concepts include grass reference evapotranspiration, landscape coefficient, plant water requirement, effective rainfall, net plant water requirement, lower-quarter and lower-half distribution uniformity, run time multiplier, irrigation water requirement, overall irrigation system efficiency, and water management efficiency. See Appendix E of reference 1 on an irrigation system rating (ISR) method as it relates to water usage attributable to distribution uniformity.

BACKGROUND

The landscape test site is a commercial property located at 4646 West Sam Houston Parkway North in Houston, Texas. The landscape consists of about three irrigated acres of mostly warm-season plants including common bermudagrass, fountaingrass and Indian Hawthorns growing in full-sun conditions.

The irrigation system was installed in January 2002 and consists of 33 individual sprinkler zones controlled with an electronic controller. The irrigation system is not equipped with rain or moisture override sensors. Irrigation water is delivered by the City of Houston municipal water system and monitored through a separate two-inch meter. The cost of irrigation water for this site is $4.30 per 1000 gallons.

A weather station is located 1.2 miles south of the test site and reports daily grass reference evapotranspiration and rainfall data. This data was useful in the analysis, but was not used by the test site.

ANALYSIS AND RESULTS

Guideline for Managing Irrigation Water Use

The following steps are used to evaluate landscape irrigation water use:

1. Conduct a reasonability check to compare actual past water usage with that of a baseline "good" irrigation system. If the irrigation system uses too much or too little water as compared to the baseline system, then advance to step 2. Otherwise continue to monitor irrigation water usage and plant health on a frequent basis. Maintain desired plant health but without excess water usage.
2. Conduct an on-site audit to gather additional site data including station flow rates and distribution uniformity. This data will be used in step 3 to isolate irrigation system problems attributable to substantial over or under watering. Fix any known problems to improve distribution uniformity.
3. Re-evaluate pre-audit (i.e., past) water usage using audit results. Instead of comparing to a baseline system as in step 1, use actual distribution uniformity data to compare actual usage to expected usage. Use actual ET_o and rainfall data if possible.
4. Reschedule the irrigation controller and operate the irrigation system for a period of time. Continue to monitor irrigation water usage and plant health on a frequent basis.
5. At least monthly, re-evaluate water usage. Compare the actual water usage to the expected usage based on the previous audit results. Use actual ET_o and rainfall data if possible.

Conduct a Reasonability Check

Start by comparing actual irrigation water use with an estimate of what a "good" baseline irrigation system should use. If the month-to-month actual usage is consistently within 10 to 15 percent of the estimated requirement and the plants are healthy, the irrigation system is probably doing a good job. Otherwise additional tests and system adjustments may be warranted.

System Quality: What is a "good" irrigation system? From Appendix E of reference 1, the quality of an irrigation system can be related to its irrigation water use based on its distribution uniformity. A "good" system is one with an overall irrigation system rating (ISR) of 7 (on a scale of 1 to 10 with 10 being best). This baseline system will have an overall area-weighted average lower-quarter distribution uniformity in the range of 60 to 69 percent resulting in a run time multiplier (RTM) of 1.23 to 1.32. The overall distribution uniformity of the irrigation system may be unknown; however, by comparing actual water usage in this way, you can determine if you should spend the money to further investigate individual irrigation zones for problems.

Required Data: An initial reasonability check of irrigation water usage requires the following baseline information: 1) overall irrigated landscape area (A), 2) average landscape coefficient (K_L), 3) past monthly grass reference evapotranspiration (reference ET or ET_o), and 4) past monthly rainfall. Irrigation water usage can be derived from monthly readings of the water bill (preferred) or from knowledge of the actual schedule, runtime and flow rates of the individual stations. Use actual reference ET and rainfall data if available; otherwise use published long-term average historical data which are available for most regions. Make sure that reference ET data are referenced to grass.

Due to article space considerations, a reality check is conducted for the test irrigation system for only the most recent past month. The overall irrigated landscape area (A; sq. ft.) is 128,958 sq. ft. with an estimate of the overall average landscape coefficient (K_L) of 0.6. The actual irrigation water volume (V_{ACT}; same as V_{IWR} of the actual system; gallons) for the 28-day period May 25 through June 21, 2002, was 428,924 gallons, with historical ET_o of 7.48 inch and historical rainfall of 4.25 inch. The main question to be answered is: "Is this a reasonable amount of irrigation water usage for the period?"

Effective Rainfall: Effective rainfall (R_E; inch) is an estimate of the amount of rain (R; inch) that actually ends up in the root zone. A rainfall factor (RF) is used to convert rainfall to effective rainfall. The chosen rainfall factor depends on the intensity and frequency of rain events in a region, as well as the flatness and soil type of the landscape (among other considerations). If estimating effective rainfall from long-term historical rainfall, then dependability must also be considered. The test landscape is flat with mostly clay soil. Rain events in the Houston area in June and July can vary from slow, low volume events to heavy, short downbursts, to long intense heavy volume events. The test case uses long-term average historical rainfall; thus our best-guess estimate is that only 50% of the historical rainfall will actually be effective toward maintaining health of the plants. (If you use actual rainfall data, then your percentage could be higher for purposes of these calculations).

$$R_E = R \text{ x } (RF/100) = 4.25 \text{ x } (50/100) = 2.13 \text{ inch} \qquad (1)$$

Plant Water Requirement: The plant water requirement (PWR; inch) is that amount of water needed by the landscape plants to maintain health. This requirement depends on reference evapotranspiration (ET_o; inch) over a period of time (monthly for the test case) and the plant's landscape coefficient (K_L):

$$PWR = ET_o \text{ x } K_L = 7.48 \text{ x } 0.6 = 4.49 \text{ inch} \qquad (2)$$

Net Plant Water Requirement: The net plant water requirement (PWR_{NET}; inch) is the supplemental amount that must be made up by the irrigation system after subtracting out effective rainfall (R_E; inch):

$$PWR_{NET} = PWR - R_E = 4.49 - 2.13 = 2.36 \text{ inch} \qquad (3)$$

The equivalent volume (V_{PWR_NET}; gallons) is:

$$V_{PWR\_NET} = PWR_{NET} \text{ x } (A / 1.6043) = 2.36 \text{ x } (128{,}958 / 1.6043) = 189{,}703 \text{ gallons} \qquad (4)$$

Run Time Multiplier: The calculated values of R_E, PWR, PWR_{NET}, and V_{PWR_NET} apply to both the actual and baseline systems. The run time multiplier (RTM) is based on the lower-half distribution uniformity (DU_{LH}; %), where DU_{LH} is either calculated directly from catch-can data, or derived from lower-quarter DU_{LQ} data. The RTM from DU_{LH} data is:

$$RTM = 100 / DU_{LH} \qquad (5)$$

The RTM from DU_{LQ} data (see appendices C and E of reference 1) is:

$$RTM = 1 / [0.386 + (0.614 \text{ x } DU_{LQ} / 100)] \qquad (6)$$

The RTM cannot be initially calculated for the actual irrigation system because its distribution uniformity is unknown (an audit has not yet been conducted). However, from Table 1 of Appendix E of reference 1, the DU_{LQ} of a "good" baseline system with an ISR of 7 has a range of 60 to 69% for an RTM of 1.23 to 1.32, respectively, or an average RTM value of 1.27.

Irrigation Water Requirement for Distribution Non-uniformity: IWR_{DU} (inch) is that portion of the irrigation water requirement that accounts for distribution non-uniformity in delivering the water to the plant root zone:

$$IWR_{DU} = PWR_{NET} \text{ x } (RTM - 1) \qquad (7)$$

The portion of irrigation water due to non-uniformity cannot be calculated for the actual system because its RTM is unknown (without the benefit of audit data). However, for the baseline irrigation system with a midpoint RTM value of 1.27:

$$IWR_{DU} = 2.36 \text{ x } (1.27 - 1) = 0.64 \text{ inch}$$

Volume due to Distribution Non-uniformity: Similarly, the equivalent volume (V_{DU}; gallons) of the baseline system related to distribution non-uniformity is:

$$V_{DU} = IWR_{DU} \text{ x } (A / 1.6043) = 0.64 \text{ x } (128{,}958 / 1.6043) = 51{,}445 \text{ gallons} \quad (8)$$

For comparison purposes, the amount of water attributable to the water manager of the baseline system (IWR_{WM}) is zero inches (for a volume V_{WM} also of zero gallons) because all of the irrigation water has already been allocated to the net plant water requirement and the distribution non-uniformity. In a real but balanced system, the water management portion may be 10 to 15 percent of the overall irrigation water requirement of the baseline system (i.e., 10 to 15 percent of [$V_{PWR\_NET} + V_{DU}$] of the baseline system).

Overall Irrigation Water Volume: The overall irrigation water volume (V_{IWR}; gallons) can be expressed as the sum of the volume required by the plants after taking effective rainfall into consideration (V_{PWR_NET}), the volume due to distribution non-uniformity (V_{DU}) and the volume applied by the water manager (V_{WM}):

$$V_{IWR} = V_{PWR\_NET} + V_{DU} + V_{WM} \quad (9)$$

For the baseline system, the total volume $V_{BASE} = V_{IWR} = 189{,}703 + 51{,}444 + 0 = 241{,}147$ gallons.

The difference (V_{DIFF}; gallons) between the actual irrigation water volume (V_{ACT}; gallons) and that of the baseline system ($V_{BASE;}$ gallons), with both using the same weather data, is the amount attributable to over or under water use. If the percent difference ($V_{\%DIFF}$; %) is more than 10 to 15 percent, then the site is being over-watered due to 1) low distribution uniformity, and/or 2) too much "extra" water being applied by the water manager. A negative percent difference indicates that the site is 1) under-watered (too dry), 2) the overall actual distribution uniformity is better than that of the baseline system, and/or 3) there was actually less evapotranspiration or more rainfall (or a combination of the two) than the historical norm.

$$V_{DIFF} = V_{ACT} - V_{BASE} = 428{,}924 - 241{,}147 = 187{,}777 \text{ gallons} \quad (10)$$

$$V_{\%DIFF} = (V_{DIFF} / V_{BASE}) \text{ x } 100 = (187{,}777 / 241{,}147) \text{ x } 100 = 78\% \quad (11)$$

Cost of Excess Water: The cost of this difference (C_{DIFF}; \$) at the water rate (W_{RATE}; \$ per 1000 gallons) of \$4.30 per 1000 gallons for the site is:

$$C_{DIFF} = V_{DIFF} \text{ x } (W_{RATE} / 1000) = 187{,}777 \text{ x } (4.30 / 1000) = \$807 \quad (12)$$

Is the extra high water use and its related cost of the actual system due to distribution non-uniformity or the water manager? Perhaps it is because no rain or moisture sensors were installed. The amount and cost of excess water use caused by not having rain or soil moisture override can be estimated by converting the amount due to effective rainfall (R_E; inch) into a volume (V_{RE}; gallons). It is this volume that could be offset by overriding the irrigation system for rain, and thus saving irrigation water and its related cost.

$$V_{RE} = R_E \times (A / 1.6043) = 2.13 \times (128{,}958 / 1.6043) = 171{,}215 \text{ gallons} \quad (13)$$

Rainfall Analysis: For May 25 - June 21, 2002, at *this* test site, the associated monthly cost of not having a rain sensor (C_{RE}), and based on the current year being the same as the long term average norm, is calculated:

$$C_{RE} = V_{RE} \times (W_{RATE} / 1000) = 171{,}215 \times 4.30 / 1000 = \$736 \quad (14)$$

Is the impact decreased if actual daily ET_o and rainfall weather data are used in the comparison? From the nearby weather station, the actual ET_o and rainfall for the 28-day period was 7.71 and 3.78 inches respectively, resulting in a C_{DIFF} of \$642 and a C_{RE} of \$653. See Figure 1 and Table 1. These costs are based on a rainfall factor (RF) of 50 % due to the nature and frequency of actual rainfall events that occurred in May and June, 2002, at the test site. In this case, the impact decreased because less actual rainfall occurred than the norm and thus less rainfall needed to be compensated by the irrigation system. In general, the rainfall factor you select will depend on your particular site and regional weather characteristics. Your confidence may be higher in the amount of *actual* rainfall that will be both effective and dependable; thus using a higher RF value.

Conduct an On-site Irrigation Audit

In mid-June, 2002, an on-site irrigation audit was performed. Audit objectives were to: 1) document the existing landscape and irrigation system design and current irrigation schedule, 2) identify and record any hardware problems that were currently wasting water, and 3) measure and record the actual performance characteristics of each station of the irrigation system. The site's overall lower-half distribution uniformity (DU_{LH}) is 74.6 percent (as derived from catch-can data) resulting in an overall run time multiplier (RTM) of 1.34, and an irrigation system rating (ISR) of 5 (fair). The irrigated area is 128,958 sq. ft. About 99.5 % of the landscape is warm-season common bermdagrass, fountaingrass, and Indian Hawthorns with a small fraction being annual flowers. Thus, an overall landscape coefficient (K_L) of 0.6 is used for the test site.

Re-evaluate the Pre-Audit (Past-Water) Use Period

Re-evaluate past water usage, but this time use the overall RTM (RTM) of 1.34 as determined from the audit. (If you have DU_{LQ} data for your site, then use equation 6 to derive your overall RTM.)

From equations 7 and 8, the actual amount of the irrigation water requirement ($IWR_{DU;}$ inch) and volume (V_{DU}; gallons) attributable to the actual distribution non-uniformity can now be calculated:

$$IWR_{DU} = PWR_{NET} \times (RTM - 1) = 2.36 \times (1.34 - 1) = 0.80 \text{ inch}$$
$$V_{DU} = IWR_{DU} \times (A / 1.6043) = 0.80 \times (128{,}958 / 1.6043) = 64{,}306 \text{ gallons}$$

Equation 12 can be written in a general form where the cost of water (C; \$) is related to the volume of water (V; gallons) used and its water rate (W_{RATE}; \$ per 1000 gallons). With this general form, the cost of water due to non-uniformity (C_{DU}; \$) can be calculated:

$$C = V \times W_{RATE} \text{ or } C_{DU} = V_{DU} \times W_{RATE} = 64{,}306 \times (\$4.30 / 1000) = \$277 \quad (15)$$

The actual volume (V_{WM}; gallons) and cost (C_{WM}; \$) of water attributable to the manager can be calculated:

$$V_{WM} = V_{IWR} - V_{PWR\_NET} - V_{DU} = 428{,}924 - 189{,}703 - 64{,}306 = 174{,}915 \text{ gallons} \qquad (16)$$

$$C_{WM} = V_{WM} \times (W_{RATE} / 1000) = 174{,}915 \times (\$4.30 / 1000) = \$752 \qquad (17)$$

Finally, the overall cost (C_{IWR}; \$) of the irrigation water and individual costs are:

$$C_{IWR} = V_{PWR\_NET} + V_{IWR\_DU} + V_{IWR\_WM} = \$816 + \$277 + \$752 = \$1{,}845 \qquad (18)$$

See Table 1 and Figure 1 for a summary of actual irrigation water requirements, volumes and costs attributable to the net plant water requirement, irrigation system distribution non-uniformity and water management. Also see Table 1 for a description of scenarios A through E in Figure 1.

Operate the Irrigation System with an Updated Schedule

The controller schedule and station runtimes were modified and then set for the post-audit month based on long-term historical ET and rainfall data, and measured zone precipitation rates. The schedule was operated for a month (without change) while frequently observing the health of the landscape.

Evaluate Post-Audit Water Use

The final step is to evaluate monthly usage following the audit. For space limitations, this study evaluates one month of data; however, you should continue to evaluate your irrigation schedule and water usage each month. Following the methods above, the post-audit monthly *actual* water usage and cost are compared to the *predicted* amount using both predicted weather data (long-term average historical) and actual daily weather station data. For the period June 21 to July 18, 2002, if real weather conditions had actually been the same as long-term historical weather patterns, then the cost of irrigation water attributable to the net plant water requirement (C_{PWR_NET}) would have been \$812, to the distribution non-uniformity (C_{DU}) \$276, and to the water manager (C_{WM}) \$109, since the controller had been scheduled based on historic weather patterns. However, based on real weather conditions, the cost breakdown is: C_{PWR_NET} of \$52, C_{DU} of \$18, and C_{WM} of \$1127.

The plan for the site should be to reduce the C_{WM}-related cost to no more than 10 to 15 percent of the cost of the irrigation water requirement (C_{IWR}) of the baseline system. Additionally, the plan should be to reduce the C_{DU}-related cost by improving the distribution uniformity (DU) and thereby improving the overall quality of the irrigation system (as it relates to DU). For example, an increase in the actual "fair" ISR rating of 5 for the test site to a "good" ISR rating of 7, or a "very good" ISR rating of 8 will reduce the actual RTM of 1.34 (fair) to 1.27 (good) and 1.20 (very good) respectively, thereby saving water. Actual reduction of C_{DU} is achieved by close examination of individual irrigation zones in order to identify and improve those zones with low DU.

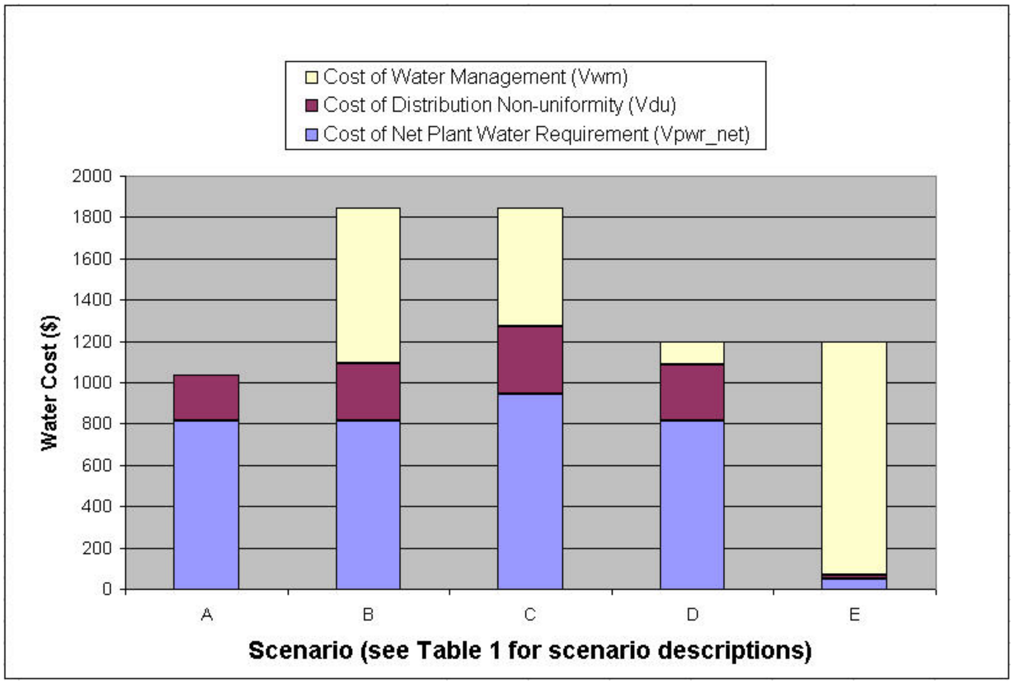
Additionally, the system can be evaluated in terms of its efficiency. Water management efficiency (E_{WM}; %) quantifies how well the irrigation manager minimizes the use of extra water needed by the landscape after accounting for irrigation non-uniformity and uncertainty in the weather. E_{WM} is the ratio of the amount of irrigation water not including management requirements to the total amount including management requirements. A good target is an E_{WM} of at least 85 to 90 percent. The E_{WM} of the *actual* irrigation system, and with *actual* weather data for the post-audit period is:

$$E_{WM} = 100 \times (RTM \times V_{PWR\_NET}) / [(RTM \times V_{PWR\_NET}) + V_{WM}] \quad (19)$$
$$= 100 \times (1.34 \times 12{,}057) / [(1.34 \times 12{,}057) + 262{,}291]$$
$$= 6\ \%$$

The overall irrigation system efficiency (E_S; %) is the percent of irrigation water that is beneficially used for plant growth. It is the ratio of the net plant water volume to the total irrigation water volume. A good target is an E_S of at least 65 percent. The E_S of the *actual* irrigation system, and with *actual* weather data is:

$$E_S = 100 \times (V_{PWR\_NET} / V_{IWR}) = 100 \times (12{,}057 / 278{,}448) = 4\ \% \quad (20)$$

FIGURE 1 - PRE AND POST AUDIT WATER COST SUMMARY



CONCLUSIONS

As competition for water resources continues to grow, the landscape irrigation industry must be equipped to meet the challenge with systematic methods and processes that quantify water usage. Actual design, performance and management of irrigation systems can be quantified in terms of needed water usage, water waste and water costs. It is important to manage irrigation systems based upon real-time weather data and utilizing water conserving devices to maximize water use efficiency.

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1. Turf and Landscape Irrigation Best Management Practices, The Irrigation Association, April 2002.

2. Irrigation Water Management of Commercial Landscapes, Texas Agricultural Extension Service, Texas A&M University System, July 1997.

3. Historical Data for Weather Source: Baseball USA Weather Station, May 1, 2002, to August 28, 2002.

TABLE 1 - SUMMARY OF IRRIGATION WATER USE

Scenario		A[1]	B[2]	C[3]	D[4]	E[5]
Description		Baseline	Test Site	Test Site	Test Site	Test Site
Evaluation Date[6]		Pre-audit, Historical Weather	Pre-audit, Historical Weather	Pre-audit, Actual Weather	Post-audit, Historical Weather	Post-audit, Actual Weather
ISR	--	7	5	5	5	5
A	sq. ft.	128,958	128,958	128,958	128,958	128,958
K_L	--	0.6	0.6	0.6	0.6	0.6
DU_{LQ}	%	65	64.6	64.6	64.6	64.6
DU_{LH}	%	78	74.6	74.6	74.6	74.6
RTM	--	1.27	1.34	1.34	1.34	1.34
ET_o	in.	7.48	7.48	7.71	8.08	5.20
R	in.	4.25	4.25	3.78	5.00	5.94
RF	--	50	50	50	50	50
R_E	in.	2.13	2.13	1.89	2.50	2.97
PWR	in.	4.49	4.49	4.63	4.85	3.12
PWR_{NET}	in.	2.36	2.36	2.74	2.35	0.15
$IWR_{DU,BASE}$	in.	0.64	0.64	0.74	0.64	0.04
$IWR_{WM,BASE}$	in.	0.00	0.00	0.00	0.00	0.00
IWR_{BASE}	in.	3.00	3.00	3.48	2.99	0.19
V_{RE}	gal	171,215	171,215	151,923	200,957	238,737
V_{PWR_NET}	gal	189,703	189,703	220,249	188,899	12,057
$V_{DU,BASE}$	gal	51,445	51,445	59,483	51,445	3,255
$V_{WM,BASE}$	gal	0	0	0	0	0
$V_{IWR,BASE}$	gal	241,147	241,147	279,732	240,344	15,312
$V_{DU,ACT}$	gal	51,444	64,306	74,885	64,226	4,100
$V_{WM,ACT}$	gal	0	174,915	133,790	25,323	262,291
$V_{IWR,ACT}$	gal	n/a	428,924	428,924	278,448	278,448
DIFF	gal	n/a	187,777	149,192	38,104	263,136
%DIFF	%	n/a	78	53	16	1,718
RATE	$/1000 gal	$4.30	$4.30	$4.30	$4.30	$4.30
C_{PWR_NET}	$	$ 816	$ 816	$ 947	$ 812	$ 52
C_{DU}	$	$ 220	$ 277	$ 322	$ 276	$ 18
C_{WM}	$	$ 0	$ 752	$ 575	$ 109	$1,127
C_{IWR}	$	$1,036	$1,845	$1,844	$1,197	$1,197
C_{DIFF}	$	n/a	$807	$ 642	$ 164	$1,132
C_{RE}	$	$736	$736	$ 653	$ 864	$1,027
E_{WM}	%	n/a	59	69	91	6
E_S	%	79	44	51	68	4

[1]A - Baseline "good" irrigation system, pre-audit month, historical weather patterns
[2]B - Actual irrigation system, pre-audit month, historical weather patterns, analysis used audit results
[3]C - Same as scenario B but with actual weather conditions
[4]D - Actual irrigation system, post-audit month, historical weather patterns
[5]E - Actual irrigation system, post-audit month, actual weather conditions
[6]Pre-audit date: May 18, 2002 to June 20, 2002. Post-audit date: June 20, 2002 to July 18, 2002.

Comparison of Catch Can Distribution Uniformity to Soil Moisture Distribution Uniformity in Turfgrass and the Impacts on Irrigation Scheduling

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Introduction

By using the standardized procedure for performing irrigation audits to measure distribution uniformity and the net precipitation rate, an irrigation schedule can be calculated based on system performance in the field. Current practice is to determine the plant water requirement and then divide it by the lower quarter distribution uniformity to calculate the irrigation water requirement. ($IWR = PWR / DU_{LQ}$) Once the irrigation water requirement has been determined, the actual precipitation rate is used to calculate the number of minutes the system should run to meet the need (IWR / PR = minutes of run time). Frequently the proposed schedule based upon the audit will have longer run times than what are currently programmed in the controller. This has caused auditors to question the validity of the work they are performing and has been frustrating to explain the proposed schedule to the owner when it would result in additional water being applied to the landscape unnecessarily.

In order to promote conservation of water resources, the proposed procedure that has been developed through the work of the IA's Water Management Committee helps account for the lateral movement of water within the root zone without changing the accepted methodology used to measure sprinkler system performance in the landscape. The proposed procedure focuses on how uniformity changes the minutes of run time that is programmed into the controller versus modifying the plant water requirement to calculate an irrigation water requirement. This alternate method will decrease the amount of water required compared to the current method without severely impacting most established landscapes.

Background

In a paper presented last year in San Antonio titled Distribution Uniformity Results Comparing Catch-Can Test and Soil Moisture Sensor Measurements in Turfgrass Irrigation by Brent Mecham showed that by using data from previous audits of well maintained, properly irrigated turfgrass that the soil moisture DU_{LQ} was 15-20 points higher than the catch-can DU_{LQ}. The paper proposed using the lower-half distribution uniformity (DU_{LH}) to create a run-time multiplier (RTM) from the same data collected to determine the DU_{LQ}. The DU_{LH} is used to divide into the average of all readings (CV_{avg}/ DU_{LH}) and the result is the Run Time Multiplier. The RTM is used to multiply the number of minutes for the perfect system that should be programmed into the controller. The result is fewer minutes of run time compared to using DU_{LQ} to determine IWR.

After the presentation in San Antonio, Rick Allen submitted to members of the Water Management committee a communication titled "Analysis of the Impact of Distribution Uniformity on Gross

Application Depth for Turf Systems” that showed the impact of using DU_{LQ} vs. DU_{LH} vs. $DU_{L3/4}$. Figures 1-3 show how much of each area will receive less than the desired amount (1inch) of water as well how much of the area is over-irrigated. It is assumed that the application depths within the zone were distributed according to a normal distribution which is a good assumption for catch can data. From his analysis the DU_{LH} or $DU_{L3/4}$ provides a profile of gross application depths that seem reasonable for most landscape applications. If a user has a low DU_{LQ}, then he should expect to have some portion of the landscape showing some stress. If the user is unhappy about seeing stress in the turfgrass, then he must make a management decision to over-irrigate most of the landscape to meet the needs of a small portion of the landscape. In other words he is fighting uniformity defects with water. With the many issues regarding the wise use of water resources throughout much of the country, reducing the recommend amount of water to be applied without causing injury would help conserve water resources. In many instances plant health would probably improve.

An aggressive approach to creating irrigation schedules would be to use the lower three-quarters distribution uniformity. For excellent sprinkler systems with high distribution uniformity this would work very combined with excellent water management. A more conservative approach to irrigation scheduling is to use the lower-half distribution uniformity to modify the runtime. In an effort to avoid introducing another DU term when the standard definition for DU is based upon the lowest quarter and to allow using DU_{LQ} to help create the RTM, the equation can be written as: **RTM = 1 / (.385 + (.00615 x DU_{LQ}))** where DU_{LQ} is expressed as a percentage.

As an example if the plant water requirement is 1” and the DU_{LQ} is 65% and the precipitation rate is .75 inches per hour the resulting schedule would be as follows:

Current method:

$IWR = PWR / DU_{LQ}$ = 1 in. / .65 = 1.54 inches

Run Time = IWR x 60 / PR = 1.54 inches x 60 / .75 = 123 minutes

Using the RTM concept the following schedule would be created:

RTM = 1 / (.385 + (.00615 x DU_{LQ})) = 1/ (.385 + .00615 x 65)) = 1.27

Run Time = PWR x 60 / PR = 1 inch x 60 / .75 = 80 minutes ideal run time

Adjusted run time is the ideal run time multiplied by the RTM

80 minutes x 1.27 = 102 minutes

Using the RTM method, nearly a 20% of the water would be conserved based upon the amount of time the system would run. A one-time event is not significant, but over the course of a season a substantial amount of water could be saved. In this example a savings of over a quarter inch of water for every inch needed to meet plant water requirement could be achieved.

Field Results

Because of the extreme drought in Colorado this year and the severe watering restrictions imposed by communities, it has been difficult to find many sites to audit that were not in stressed conditions. The few audits that were conducted used the traditional catch can from Cal-Poly. At each location that a catch can was placed, a soil moisture reading was taken using a portable TDR type soil moisture sensor prior to running the sprinkler system for the test. These audits were done after extended periods of very little rainfall (because we are in a drought) and the zones had been run according to the watering restrictions. Those sites that were irrigated close to ET have results similar to previous paper where the soil moisture DU_{LQ} is 10-15 points higher than the catch-can measured DU_{LQ}. The sites where deficit irrigation was occurring, (which is the majority of sites) the DU_{LQ} for the catch cans and the soil moisture was almost identical.

For the site that was being irrigated at ET the following table shows the results:

	Catch cans	Soil Moisture	RTM
DU_{LQ}	65%	80%	
DU_{LH}	77%	87%	
RTM (from DU_{LH})			1.29
RTM (from equation)			1.27
RTM (Soil Moisture DU_{LQ})			1.25

From this table we can see that the RTM whether it is based on actual field measurements, soil moisture readings or by using the RTM equation the results are very similar.

Another site was audited to measure sprinkler system performance as well as soil moisture uniformity. This site was scheduled to apply .60" of water on the days dictated by watering restrictions. The designated watering days are Mondays and Thursdays.
The audit results are compared to the irrigation schedule that was being used.

	Zone 1 & 2	Zone 3	Zone 4	Zone 5	Zone 6
DULQ(cc)	71	70	70	80	59
DULQ(sms)	74	71	71	80	83
DULH (cc)	85	81	81	84	87
RTM(DU_{LH})	1.18	1.23	1.23	1.19	1.15
RTM(equation)	1.21	1.22	1.22	1.14	1.34
RTM (SMS DU_{LQ})	1.35	1.41	1.41	1.25	1.20
Precip Rate (inches per hour)	1.62	.64	.32	1.06	1.21
Ideal Minutes	22	56	112	34	30
Minutes Using DU_{LQ}	31	80	160	42	50
Minutes Using RTM (eq.)	27	69	138	39	40
Minutes Current Schedule	30	50	99	36	30

Because of the limitations caused by watering restrictions as well as the controller being used for the irrigation system, the current schedule is even less than what would be recommended. This partly explains why there are a few stressed areas in the yard but overall is very acceptable. The current schedule almost meets the PWR for 3” bluegrass for the three weeks prior to the audit.

Table 1. shows DU_{LQ} values to create a “run time multiplier” by dividing the average by the lowest quarter average and comparing it to the results using the equation RTM = 1 / (.385 + (.00615 x DU_{LQ})). One advantage of the RTM equation limits how much extra water will be applied compared to using the DU_{LQ} that has no upper limit. On excellent systems the differences are not great, but as the uniformity deteriorates the differences get much larger. By using the RTM with the measured DU_{LQ} in the equation helps account for the lateral movement of water in the soil. On well-managed sites the soil moisture uniformity is greater than what can be measured using catch cans. Another advantage of using the RTM is the end user can more easily see the impact of poor uniformity on the irrigation schedule that is programmed into the controller. For example if the DU_{LQ} is 70 and to account for the lack of uniformity the chart will quickly show that the RTM will increase the number of minutes to program by 23% to help compensate for the lack of uniformity. This is in contrast to the 43% increase in time that would be calculated using DU_{LQ} to modify the run time.

Conclusion

The Run Time Multiplier method based upon data collected from an irrigation audit will help create irrigation schedules that will adequately irrigate the turfgrass and also result in substantial water savings over the current methodology. It can be shown in statistical analysis as well as in the field that this concept works. The recommendation to continue to “trim back” the schedule is still advised, but the amount of trimming will be greatly reduced and water savings can happen more quickly. This concept has worked well and more closely matches the run times that experienced managers use in maintaining the landscape. This will aid in creating meaningful irrigation schedules that are more realistic especially on systems that have poor uniformity measurements. The RTM combined with irrigation management efficiency will also have an impact upon water budgeting or water allocations which a water purveyor may use.

Evaluating how well a sprinkler system performs by using the DU_{LQ} is still very valid and should continued to be used. Reasonable expectations of how well individual sprinkler zones should perform needs to be emphasized and taught to water purveyors. However, being able to use the DU_{LQ} to calculate the RTM will save water for other applications.

Table 1. **Run Time Table based on Catch DU_{LQ}**

Catch Can DU_{LQ}	Run Time Multiplier RTM	Using DU_{LQ} to modify times
100	1.00	1.00
98	1.01	1.02
96	1.03	1.04
94	1.04	1.06
92	1.05	1.09
90	1.07	1.11
88	1.08	1.14
86	1.09	1.16
84	1.11	1.19
82	1.12	1.22
80	1.14	1.25
78	1.16	1.28
76	1.17	1.32
74	1.19	1.35
72	1.21	1.39
70	1.23	1.43
68	1.25	1.47
66	1.26	1.52
64	1.28	1.56
62	1.30	1.61
60	1.33	1.67
58	1.35	1.72
56	1.37	1.79
54	1.39	1.85
52	1.42	1.92
50	1.44	2.00
48	1.47	2.08
46	1.50	2.17
44	1.53	2.27
42	1.58	2.38
40	1.58	2.50
39	1.60	2.56
36	1.65	2.78
33	1.70	3.03
30	1.76	3.33
27	1.81	3.70
24	1.88	4.17
21	1.94	4.76
18	2.02	5.56
15	2.10	6.67
12	2.18	8.33
9	2.27	11.11
6	2.37	16.67
3	2.48	33.33

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Figure 1.

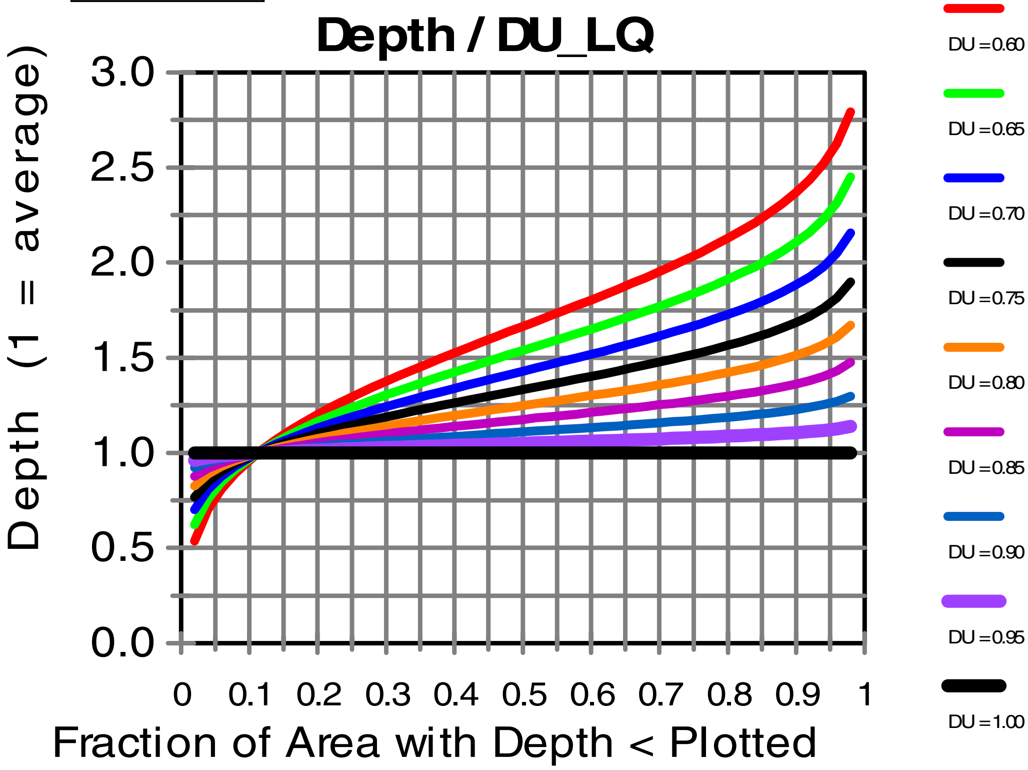


Figure 2.

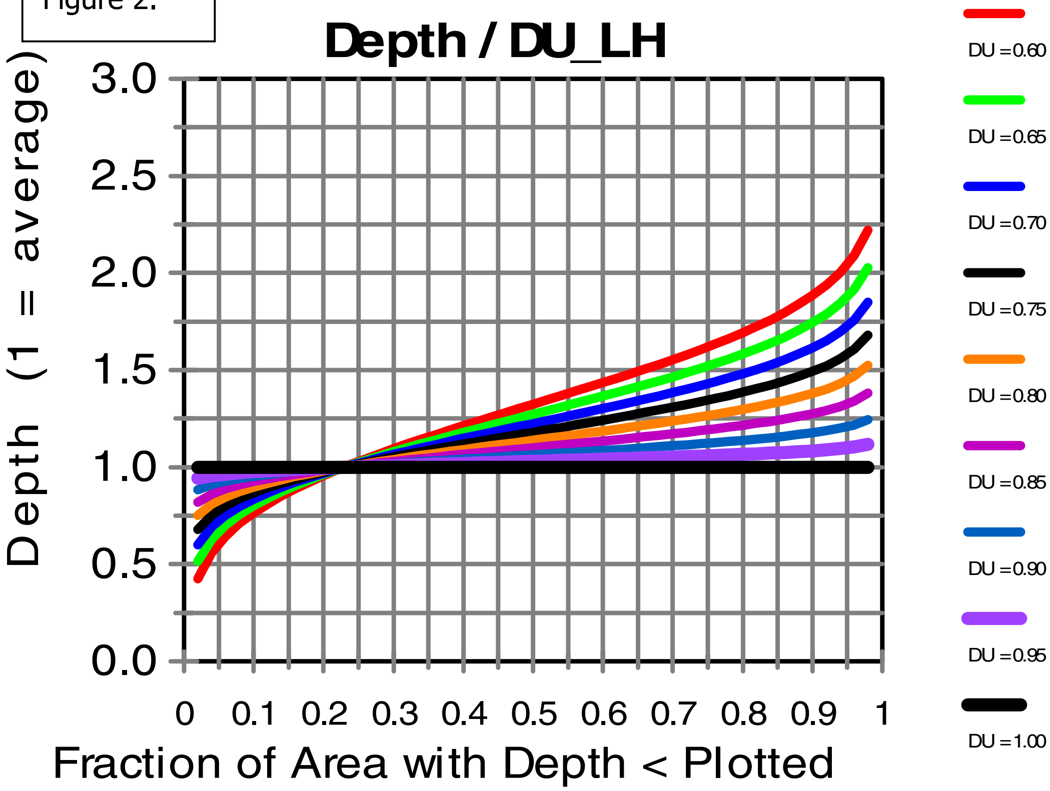
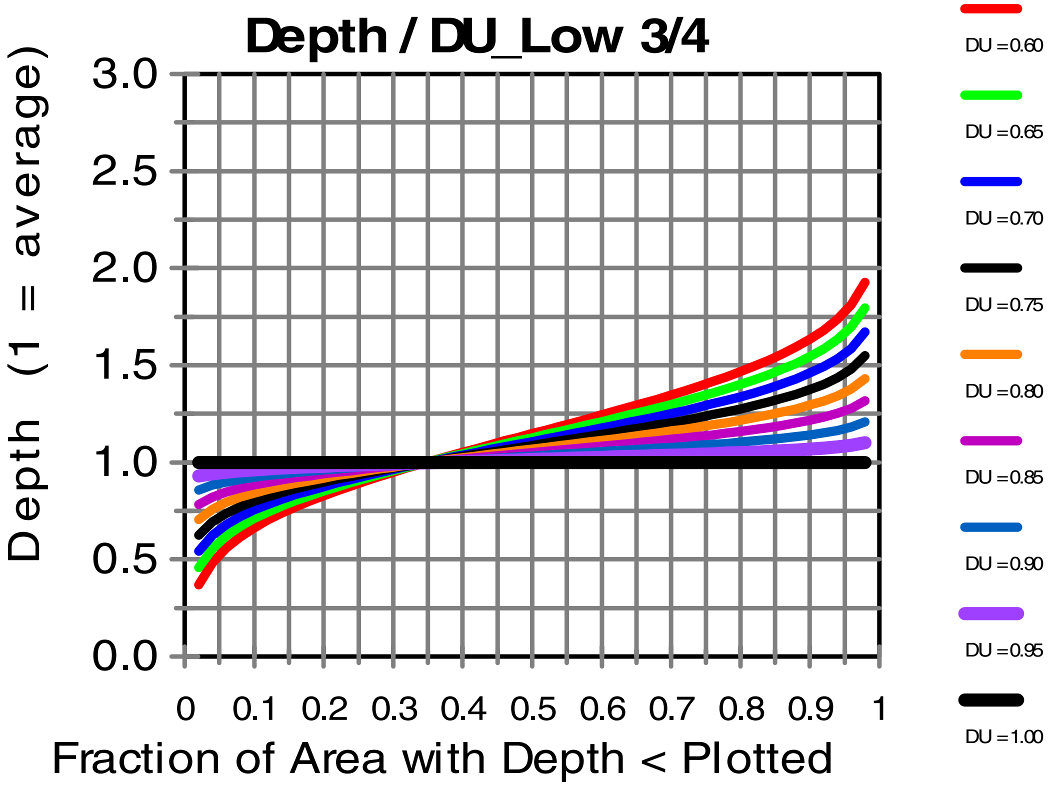


Figure 3.


Depth / DU_Low 3/4
Depth (1 = average)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Fraction of Area with Depth < Plotted
DU =0.60
DU =0.65
DU =0.70
DU =0.75
DU =0.80
DU =0.85
DU =0.90
DU =0.95
DU =1.00

Irrigation Construction Management:

Capital Projects Irrigation Design and Installation Quality Control

By Brian K. Davis

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Overview

Intense scrutiny of irrigation, landscaping and related subject matter during the entire Capital Projects planning and construction cycle is a vital component of the University of Washington's (UW) Landscape Irrigation Water Conservation Program. The goal of this paper is to empower irrigation and landscape workers, and enlighten planners, managers, policy makers, designers, and project personnel, with a critical aspect of irrigation water conservation: Irrigation Construction Management – Capital Projects Irrigation Design and Installation Quality Control.

Background Information

The UW is the top water user in the Seattle Public Utilities District. Of the UW's 700 acres, 54 are ornamental landscapes and athletic fields serviced by over 100 automatic irrigation systems, close to 1000 valves, over 6 miles of subsurface drip, and about 13,000 sprinkler heads and rotors. About forty percent of the systems are centrally controlled and include water conservation and control features.[1] On average, the Seattle area requires 15 inches of supplemental water per summer.

Irrigation is a small slice of the UW pie, but is significant, nonetheless, in supporting the amazing blend of structure and landscape for which the UW is renown. Landscapes surround buildings, are on buildings, in courtyards within buildings, border the many connecting paths and roads, and frame the open spaces and campus perimeter.

This blend, indeed, is a relevant component to the greater mix that is the UW – excellence in academics, research, medical services, libraries, arts, galleries and museums, park-like grounds and horticultural center, a lecture and conference venue, a collegiate/professional sports and athletics facility, and a public sports and entertainment complex.

The combination of architecture and landscape provides a healthy, soothing, and exhilarating experience for students, faculty, staff, the surrounding community and visitors. It is the job of UW Irrigation to support the slice of the pie that is a part of the aforementioned mix.

With a limited staff, dramatic growth,[2] and an increasing need for water conservation, we have no choice but to be efficient and effective operationally to ensure efficient and effective water conservation. Design and installation quality control is but one of many responsibilities comprising the duties of the UW Irrigation Specialist.[3] Thus, balancing the construction management function with the other responsibilities is indeed challenging.

<u>Why Is Design and Installation Quality Control Important?</u>

Ensuring sound designs and quality installations directly contributes to water conservation. These are the first steps and essential elements for new irrigation water conservation efficiency and effectiveness.

Both proper selection and correct installation of products with respect to plant water requirements and microclimate variables[4] are key to irrigation water conservation. Quality designs and installations significantly minimize costly Change Orders, minimize rework, reduce future maintenance costs, and contribute to system longevity.

If we get the opposite, countless hours often go to correcting poor designs and installations. Not only is there poor water conservation, poor plant health, rework, reduced goodwill from the ever observant public, and reduced aesthetics during the interim, but there is the opportunity cost of the time and resources that could have been used for the maintenance, alteration, and improvement of other irrigation systems.

<u>Elements of a Successful Installation</u>

- Quality design, product and installation information
- Quality construction documents
- Quality execution of plans via irrigation construction management

<u>Design, Product and Installation Information</u>

The UW Facilities Design Information (FDI) for Irrigation is given to irrigation designers and landscape architects early in a project. The FDI is a set of design, product and installation specifications and details. The FDI for Irrigation is updated annually by UW Irrigation and UW Engineering.

The idea is simple – quality input parameters improve the likelihood of quality output.

The UW Capital Projects Planning and Construction Cycle, Entities, Players, and Procedures

The UW Capital Projects planning and construction cycle is organized by strictly defined phases, steps, and procedures. It consists of the following phases: Programming/Pre-Design, Schematic, Design Development and Construction Documents, Installation, and the Warranty Period.

From an irrigation perspective, the following UW entities and players are involved: Capital Projects (Project Manager, Construction Manager, Construction Coordinator, Campus Landscape Architect); Engineering Services (Mechanical, Utility, and Other Engineers); Design Services (CAD); and Shops (Grounds, Irrigation, Plumbing, Electrical, Computing & Communications, Control Technicians, Heavy Equipment, Utilities, Masons, and Roofers).

The following outside/contracted entities and players are involved: General Contractors, Subcontractors (Landscape/Irrigation, Demolition and Earthwork, Utilities), Landscape Designers, Landscape Architects, Engineers, Consultants, Seattle Public Utilities, Manufacturers/Technical Support, and Suppliers.

Irrigation construction management is challenging. It requires that the Irrigation Specialist learn the construction phases, procedures, protocols, and terminology used by project personnel. The specialist must interface appropriately, via emails and attachments, blueprints and details, typed punch lists, digital photos, written documents and renderings, faxes, scheduled and unscheduled meetings, and cell phone calls while in the field.

The following outline identifies the main project phases (boldface) and associated procedures.

Programming/Pre-Design: scope assessment; FDI to landscape architects & irrigation designers
Schematic: simple layout of irrigated landscape areas; general plant types
Design Development and Construction Documents: details, specifics, major problems solved

- Respond to Requests for Information (RFI) (e.g. existing field conditions, As-Built Drawings)
- Document Review
  - Irrigation, Landscape, and to a lesser extent, Electrical, Telecommunications, Demolition, Drainage, Earthwork, Utilities, and Field Furnishings
  - Final Comment Resolution: formal recommendations and feedback for alternative designs, products, and specifications via the Project Manager
  - Document Sets: Permit, Contract, and Construction Documents

Installation

- Pre-Construction Conference (general/overall project scope): Construction Schedule, meetings, procedures, coordination issues, Q&A, troubleshooting and problem solving
- Pre-Installation Meeting (for each discipline): introduction of General Contractor and Landscape/Irrigation Subcontractor; review Product Submittal; discuss Construction Schedule, phasing, and coordination issues; discuss scope of work, red-flags, non-entitlement (no cost) adjustments, and entitlement (additional cost) Change Orders
- Weekly Progress Review/Site Inspection Meetings: review installation work and As-Built Drawings; troubleshoot field problems and design anomalies; document work (e.g. prepare Site Observation Reports with corrective work punch lists, print notation, digital photo support, field notation via paint and marking flags).

- Random Site Inspections: periodic site visits to monitor and inspect installation quality control and troubleshoot problems
- Crisis Meetings: often necessary to deal with time sensitive and/or entitlement issues
- Consult, review, and inspect Architectural Supplemental Information (ASI) and Change Order Proposals (COP)
- Performance Testing: formal testing of key irrigation system components
  - Mainline and lateral line static pressure
  - Coverage and working pressure – adjust primary and zone pressure regulating valves
  - Electronic valve operation via controller, remote and central control
  - Master valve, flow sensor, and moisture sensor operation via controller and central control
  - Communications Loop Testing for Central Control
- Performance Testing Activities
  - Pressure Testing: ongoing as construction permits
  - Pre-walk: this site inspection is conducted unilaterally by UW Irrigation prior to the Preliminary and Final Punch Lists. This offers more thorough findings and better preparation for formal site inspections
  - Preliminary Punch List: formal meeting and site inspection procedure to identify installation and design problems, and to determine corrective actions
  - Final Punch List: formal meeting and site inspection procedure to identify status of Preliminary Punch List and other corrective work. When the contractor has satisfied these obligations, the status of Substantial Completion is granted, initiating the warranty period and final payment to the contractor.

Warranty: ensure product, installation, and plant quality for a specified warranty period (one or two years) started at Substantial Completion; follow-through on problems

<u>Access, Reality of the Construction Cycle, Engaging the People and Process</u>

In-depth project involvement is often not available to irrigation specialists, but should be, as a means of adding value to projects by increasing success in terms of promoting quality irrigation and landscape design and installation with respect to water conservation.

In addition to the difficulties presented by lack of access, the typical position of landscape and irrigation work at the end of the construction cycle can result in problems. For examples:

- Contingency budgets are often depleted; thus, additional dollars for landscape and irrigation needs are not available
- The backlog of other project activities can result in the compression of work at the end of the cycle, especially considering firm completion deadlines; thus, the lack of time, stumbling over others, and the pressure to meet deadlines can decrease quality
- The project entities and players may be tired at this stage of the game; thus, don't have comparable energy or interest in addressing landscape and irrigation issues
- Project personnel are often preoccupied with completion and moving onto the next project; thus, important details tend to get pushed under the rug

Activities for successfully engaging the people and process follow.

- Preparation; comprehension of design info, construction documents and procedures
- Develop quality support materials (e.g. design information, details, product and performance specifications, punch list format)
- Have confidence in one's expertise; facilitate interpretation of irrigation issues in layperson terms
- Get funding for consulting and inspection work
- Follow procedures
- Manage multiple projects, at various stages, simultaneously
- Understand the politics unique to each project; develop and cultivate relationships; assertiveness; picking and choosing battles; professionalism; compromising; teamwork
- Meet deadlines; follow through with commitments; consistency; cope with deadline pressure
- Documentation and record keeping; prepare and present information
- Anticipate problems and develop solution alternatives; be proactive
- Willingness to get "bloody noses;" learn from mistakes
- Earn trust of project personnel; get limited non-entitlement decision making authority

Examples of Project Installation Problems: ICA Indoor Practice Facility (OPF Phase 1), Project 2498

For digital photos – Figures 1 through 8, please see below. The photos were taken in the spring of 2001; the installation occurred in the summer of 2000. All of the following project photos illustrate improper installations that result in poor water conservation. In addition to wasted water, the contractor incurred corrective time and materials costs, not to mention looking bad excavating some 128 heads and swing assemblies. And of course, we all looked bad. UW Irrigation was not "invited" to inspect this installation until after back filling. A lateral static pressure test was not performed prior to back filling. The project had been put on a "fast track" with NFL and NCAA football dates approaching in the adjacent Husky Stadium.

The following leakage problem was discovered during the spring 2001 system activation and pre-audit. Figures 1 and 2 show leakage from both upstream and downstream connections between fittings and polyethylene piping. The polyethylene piping was defective – pitted and incapable of making a seal. The piping also exceeded specified depths and run lengths. Furthermore, the upstream connection lacked a Marlex ell to give 3-way directional control. The resulting "bend" stress and the lack of Teflon tape further aggravated already poor connections, further contributing to leakage. Each bad swing assembly resulted in about 50 ounces of leakage per minute. Note that the worst leakage from the upstream connections was far below the root zones of the planting, thus, this water, more than half of the total leakage, was completely wasted. Note that this deep leakage was not obvious. Downstream swing assembly leaks can often result in undermining the stability, and thus pitch and elevation, of sprinkler heads over time, which typically results in high maintenance costs to "true" numerous heads during spring system activation and pre-audits. Given a Northwest irrigation season (6 months), had the leaks not been corrected, the collective leaks, considering an irrigation schedule adjusted monthly for ET, would have amounted to 317.34 hundreds of cubic feet (CCF), and at the commercial peak rate of $2.75/CCF, would have equaled $872.69 per year. Through the 2002 irrigation season, 772.66 CCF would have been lost, amounting to $2,124.82.[5]

Figure 3 shows a sprinkler head that was not installed per spec. The spec notes that heads must be installed at a grade perpendicular to the average slope. This head, despite the nozzle's 23-degree trajectory, cannot achieve head-to-head coverage with its not-in-picture counterpart to the right. This resulted in a lack of coverage/poor distribution uniformity – areas that were too wet and too dry, resulting in unhealthy and unsightly turf grass.

Figure 4 shows an improperly installed valve box. The box is above grade, and would likely impede and/or get damaged by mowing. Note the valve was installed too high, and that reinforcing cells on the underside of the lid have been cut out to make room for it, thus, weakening the lid, as well as putting pressure on the solenoid as in the case of equipment driven over the box.

Figure 5 shows a rotary sprinkler head installed incorrectly – it is too high and too close to the extruded curb. It should be flush with finish grade with placement starting at 1¼ to 1½-inches perpendicular from the hardscape. This is a likely candidate for mowing and/or edging damage.

Figure 6 shows another improperly installed valve box. Note that it's resting on a lateral pipe. Figure 7 shows a close-up of this lateral pipe – already broken, probably from pedestrian/equipment weight. All piping should have ample clearance between valve boxes. Not completely visible is a mainline directly under the lateral, or "stacked," which is a spec violation due to the difficulty in making future maintenance repairs. Pipes should be installed side by side with adequate clearance between.

Figure 8 shows signal wiring above the specified depth of 18-inches (mainline depth). Shallow wiring is vulnerable to landscape and utility work. Note that the metallic warning tape was installed by UW Irrigation, not the contractor, as a post-installation damage countermeasure.


Figure 1


Figure 2


Figure 3


Figure 4

Figure 5

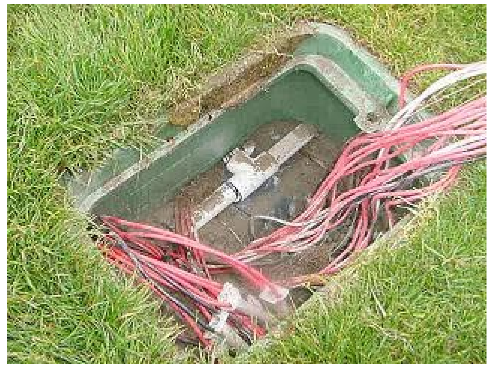

Figure 6

Figure 7

Figure 8

Future Irrigation Construction Management Issues

- Term Contracts for irrigation subcontractors instead of the quo “low bid” format; research legality, apply
- Contractor Performance Evaluations; research legality, apply
- Require that contractors have training credentials (e.g. Irrigation Association Certifications); research legality, apply
- Continuous Improvement of the UW FDI; also, research new issues: impact of the use of reclaimed water on irrigation products and designs; impact of district, state and federal water policy on irrigation products and designs

Concluding Remarks

The previous examples of irrigation design and installation quality control issues are merely the tip of the iceberg. It should be apparent that such shortcomings, collectively, can significantly reduce project quality, increase project costs, and increase future maintenance costs. Scrutiny and involvement by Irrigation Specialists during the entire Capital Projects planning and construction cycle can improve project quality, reduce project costs, and reduce future maintenance costs.

Footnotes

[1] Rain Master central control via radio and phone modem. Conservation and control features include integrated flow sensors, master valves and soil moisture sensors.

[2] Over $700 million worth of capital project development since 1996 ("The price of civic pride," Seattle Times, A12-13, 07/18/99). Most included landscape and irrigation. Note impact on existing systems (e.g. construction damage, existing and new system interfaces). A 1999 UW Irrigation Automatic Irrigation Growth Study showed the following increases since 1991: 122 percent in systems, 101 percent in valves, 94 percent in sprinklers, and over 6 miles of drip which was nonexistent in '91.

[3] Administration/Infrastructure, Central Control, Maintenance/Preventative Maintenance, Planning, Projects, Research & Development, Training & Information, and Water Conservation

[4] Microclimate variables: plant water requirements; hydro-zones; density, canopy and growth/maturity density; soil texture; soil structure; drainage; on-structure plantings; raised planters; effective seasonal sun path, exposure, reflective heat, and shading; wind exposure and average prevailing wind; rain exposure and rain shadows

[5] Calculation Tables

Program	Zone Run Times/min								Program tot min/ start time	Start times/ day	Total min/day	Days/ wk	Total min/wk
	Z6	Z7	Z8	Z9	Z10	Z11	Z16	Z17					
1	6	6	6	6	6	5			35	2	70	3	210
2							4	4	8	2	16	3	48
Total run time for the listed zones in minutes per week													**258**

Monthly Scheduling Adjustments (100% = full base schedule)						
Irrigation Months/%	April/May 50%	June 80%	July 100%	August 100%	Sept./Oct 70%	**Total Adjusted min/yr**
Adjusted min/wk	129	206.4	**258**	258	180.6	
Adjusted min/mo	774 (129)(6wk)	825.6 (206.4)(4wk)	1,032 (258)(4wk)	1,032 (258)(4wk)	1083.6 (180.6)(6wk)	**4747** (sum mo)

Yr	Tot Adj min/yr	Leakage (50 oz/min)(128 heads)	Total leakage oz/yr (adj min/yr)(leakage)	Tot leak gal/yr (tot oz/128oz)	Tot leakage CCF/yr (gal)(.001337CCF/gal)
'02	**4,747**	6,400	30,380,800	237,350	317.34
'01	4,747	6,400	30,380,800	237,350	317.34
00	2,064*	6,400	13,209,600	103,200	137.98
Water loss due to leakage from '00 through '02 if problem not corrected					**772.66 CCF**
Water loss in dollars @ peak rate of $2.75/CCF					**$ 2,124.82****

* Installed 09/00, new planting operated at 100% for two months prior to fall rain/winterization
** Not including time and materials costs

Denver Parks Irrigation System Inventory Project

Donna Pacetti, Water Conservation Specialist, Denver Water

Introduction

Denver Water and Denver Parks jointly funded the research and development of an irrigation system replacement plan for the entire Parks system. A RFP was released October, 2001, and a contractor was selected December, 2001. The replacement plan report was completed July, 2002. Denver Parks has 2258 acres of irrigated parkland. Some of these irrigation systems are over 40 years old and have never been renovated or replaced. Over 222 acres of these irrigated parks are still watered with quick-couplers or manual valves. Denver Parks uses close to 2 billion gallon of water annually to irrigate these parks. This paper outlines all the methods used to collect and analyze the condition of the systems, the criteria used in the analysis and the final recommendations from the contractor.

Request for Proposals

Denver Water developed a RFP in October of 2001 that was sent to seven irrigation/engineering consulting firms in the Denver area. The language from the RFP is inserted below.

> ***Objective***
> Denver Parks needs a replacement plan developed for their Parks irrigation systems. This plan will include information on current systems, an estimation of the remaining life of each system, an estimation of replacement costs for the systems and the development of a 10-15 year Capital Improvement replacement plan. The final plan is due June 3, 2002.
>
> ***Scope of Work***
> Develop a report of existing irrigation systems for each of the Denver Parks locations. This excludes Mt. Parks and Golf Courses.
>
> The final report must include the following information for each irrigation system:
>
> - Overall analysis of current system
> - Estimation of the remaining life of the system
> - Costs and recommendations for replacement, if necessary
>
> Develop a 10-15 year Capital Improvement replacement plan for Denver Parks' irrigation systems that are in need of replacement. This plan will be presented to the Denver City Council at a date not yet determined.

Collection of the following information will be necessary to determine the condition of each system:

1. Date of installation
2. Date of major renovations or system improvements
3. History of problems, repairs and leaks
4. History of water use

(The information can be obtained by performing record searches, field tests and interviewing Denver Parks' employees.)

Determining the type of system and the condition of the six irrigation components listed below will be necessary to develop a plan for replacement:

1. Backflow prevention
2. Water meter
3. Mainline
4. Valve clusters
5. Valves
6. Controllers

The proposals were due Friday, November 23rd by 10:00 am. We received two proposals, but only one was qualified to complete this project in the short time frame.

The Proposal

The selected contractor was a team of two engineering firms, Aqua Engineering and Black and Veatch. Their project approach is outlined below.

The scope of work was divided into five tasks:
Task 1.0 was the kick-off meeting. The goal of the meeting was to set the strategy and establish replacement priorities for the study.
Task 2.0 included the interviews with the maintenance technicians in all eleven Park Districts within Denver. The park employees were to provide information on the existing conditions at each of the park sites. This information included information on the condition of all the main components of the system and repair history.
Task 3.0 was the development of a database to collect and sort all the information collected during the interviews.
Task 4.0 was the development of a capital improvement replacement plan that would become part of the final report.
Task 5.0 included the preparation of the final report and presentations to the Denver City Council and/or other interested parties. The proposal was accepted and Denver Water developed and signed a contract with the two Engineering firms in December 2001.

Project Approach

During the kick-off meeting dates were set for District interviews, monthly meetings and final report completion. The Owners (Denver Water and Denver Parks) had monthly meetings with the Consultants to keep the project on tract by answering questions, giving direction and gathering necessary data.

The Maintenance District interviews were scheduled starting in January 2002. A questionnaire was sent to each Maintenance District outlining information that was to be collected prior to the interviews. A sample of the type of questions was included in the questionnaire. Each interview took a day to complete and these were scheduled from January through March. The purpose of the interviews was to identify maintenance problems with the irrigation systems and to get an understanding of the excessive water use.

The collection of data and development of the database was the main portion of this project. All the data collected at the interviews and by the Owners had to be entered into an Access database that was constantly under development.

The Report

The report broke the information into the following major categories, and each of these will be discussed in detail.

- Interview Findings
- Database Documentation and Use
- Replacement Plan
- Replacement Costs
- Potential Water and Labor Savings
- Capital Improvement Replacement Plan
- Findings and Recommendations

Interview Findings

During the interview process, a common thread of problems became apparent. These problems either in combination or alone, account for the high amount of water used in the parks to keep them green. Some of the typical findings that were common among the Districts are listed below.

1. Age of the irrigation system – especially apparent in older park Districts.
2. Soil Conditions – Corrosive soils require replacement of metal components as often as every two years.
3. Mixture of sprinklers on laterals.
4. Vandalism.
5. Winter Sand – This creates a build-up along the curb edges which eventually blocks the spray from sprinklers.
6. Lack of adequate funding – Insufficient funds over the years have created additional repair issues due to them not being done properly in the first place i.e. the “Band-Aid”effect.
7. Breakage caused by new utility construction.
8. Failure to embrace new technologies.
9. Failure to embrace new equipment.
10. Abandonment of centralized irrigation control.
11. Continued maintenance budget pressure.

12. Employees are not given the time to repair and find obvious leaks.
13. Pressure from the public to have perfect quality turf in parks.
14. Failure to hold outside contractors accountable for poor quality workmanship.
15. Failure to repair broken components especially in medians.
16. Failure to properly design irrigation systems to site requirements.
17. Failure by Denver Parks planning group to get input from maintenance technicians.
18. Maintenance technicians are not given water consumption information to know how much water they are using.

Replacement Plan Priority Assignments

A priority assignment of 1-4 (1 being the highest ranking) was given to every irrigated site.

Priority 1

Sites that fell into priority 1 were in need of immediate replacement to improve irrigation efficiency and reduce labor requirements. The criteria used to determine if a site was a priority 1 are:

- ♦ Perceived useful life left in system is less than 5 years.
- ♦ Original date of irrigation system installation was more than 25 years.
- ♦ Date from last complete or partial renovation is more than 15 years.
- ♦ Manually operated systems
- ♦ Large and/or highly visible site.
- ♦ High water use or implied inefficient water use.
- ♦ Persistent, recurring, documented problems.
- ♦ Mixed equipment on site.
- ♦ Site identified as high maintenance

Priority 2

Sites that fell into priority 2 will be replaced in 5 years. The criteria used to determine if a site was a priority 2 are:

- ♦ Perceived useful life in the system is less than 10 years.
- ♦ An older system, more than 15 years old, that is in fair condition.
- ♦ A system that has been partially renovated in the last 10 to 15 years.
- ♦ Larger or visible or highly used sites.
- ♦ High water use or implied inefficient water use.
- ♦ Mixed equipment on site.

Priority 3

Priority 3 systems are to be replaced in third 5 years of the program. These are systems that have more than half of their useful life remaining. The criteria used to determine if a site was a priority 3 are:

- ♦ Perceived useful life left in system is less than 15 years.
- ♦ Newer system, less than 15 years old.
- ♦ Minor operational problems.

- Lower water use on site.

Priority 4

Priority 4 includes systems that have been built in the last 5 years. The criteria used to determine if a site was a priority 4 are:

- New irrigation systems.
- Perceived useful life left in system is more than 20 years.
- Original date of irrigation system installation is less than 5 years.
- Sites that have low water use.

The table below shows how many sites fell into each priority for all the Districts.

Maintenance District	Number of Priority 1 Sites	Number of Priority 2 Sites	Number of Priority 3 Sites	Number of Priority 4 Sites
Northwest	4	17	8	**2**
Southwest	2	4	13	**0**
East	8	8	11	**4**
Central	14	10	15	**1**
Montclair	13	3	6	**2**
Northeast	6	4	14	**1**
Southeast	8	9	6	**1**
South	7	6	6	**2**
West	8	14	14	**2**
Platte	6	2	7	**4**
Lowry	2	0	2	**9**
Totals	**78**	**77**	**102**	**30**

The number of acres per District is as follows:

Maintenance District	Acreage of Priority 1 Sites	Acreage of Priority 2 Sites	Acreage of Priority 3 Sites
Northwest	130	80	80
Southwest	5	20	120
East	240	40	10
Central	160	30	20
Montclair	90	20	60
Northeast	20	40	50
Southeast	60	70	80
South	190	40	30
West	170	90	60
Platte	20	10	40
Lowry	30	0	30
Totals	**1,115**	**440**	**580**

The estimated replacement costs are as follows:

Maintenance District	Cost of Priority 1 Sites	Cost of Priority 2 Sites	Cost of Priority 3 Sites
Northwest	$3,204,000	$2,883,000	$2,001,000
Southwest	$146,000	$635,000	$3,689,000
East	$5,892,000	$1,083,000	$421,000
Central	$4,744,000	$914,000	$647,000
Montclair	$2,903,000	$468,000	$1,567,000
Northeast	$482,000	$1,503,000	$1,380,000
Southeast	$1,677,000	$1,851,000	$2,072,000
South	$4,816,000	$1,032,000	$616,000
West	$4,239,000	$2,356,000	$1,939,000
Platte	$488,000	$228,000	$1,140,000
Lowry	$913,000	$0	$790,000
Totals	**$29,504,000**	**$12,953,000**	**$16,262,000**

The total cost for priorities 1, 2, and 3 is $58,719,000.

Capital Improvement Replacement Plan

The report identified several future funding options. They are as follows:

1. General Obligation Bonds. The City and County of Denver occasionally issues general obligation bonds to finance major capital improvements. A portion of the proposed irrigation system improvements could be financed from the next bond issue. The timing of this issue is uncertain but may occur within the next five years.

2. Certificates of Participation. The City and County of Denver typically funds its capital projects using certificates of participation. This funding instrument is a capital lease backed by a pledge of City and County assets. The certificates usually have a 15-year term and are currently being issued at annual interest rates ranging from 4% to 5%. In order for this to be a viable instrument, a determination of appropriate collateral assets will be needed.

3. Conservation Incentive Programs. Denver Water provides incentives for certain conservation programs. The ability and applicability of this program to funding Denver Parks irrigation system improvements is being evaluated.

4. State Revolving Fund loan. The Colorado Water and Power Development Authority provide low-interest loans to eligible utility improvement projects. Loans typically have a 20-year term and currently are being issued at annual interest rates between 3% and 4%. The eligibility of Denver Parks irrigation improvements for these funds is being evaluated.

5. Permit Fee Increases. The highest irrigation requirements are generally associated with athletic fields. There is a nominal fee currently charged to users of these facilities. Park user fees for athletic fields might be increased to help offset costs of irrigation system improvements.

6. Grants for Sustainability. The Poudre Valley School District in the northern Front Range region has obtained a sustainability grant to fund irrigation projects. This may be a viable funding option for Denver Parks irrigation system improvements.

There are three funding sources that are available to the Parks and Recreation Department. The first is CIP monies (Capital Improvement Program). Parks receives annually $150,000 for irrigation infrastructure improvements. If this level of funding continues for the 15 years of the study, it will total $2.3 million. The two other sources of funding that became apparent through data analysis, water and labor savings.

The total potential water savings for all 257 sites is about 325 million gallons annually. At the current water rate of $1.09 per thousand gallons, the potential water cost savings is over $350,000 per year. The total direct annual labor cost associated with repair and maintenance of the irrigation systems is $1,372,400. If a 60% reduction in the labor cost were realized by the improvements to the irrigation systems, as suggested by the maintenance technicians, the potential annual labor savings is $823,000. The 60% reduction in labor costs may not be achievable. Conservatively, the analyses indicate that a 40% reduction in labor costs or an annual savings of $550,000 is a more reasonable and achievable savings

Total Savings

The total potential annual savings in water and labor costs is $900,000. Obviously, it is not possible to realize the full annual savings immediately for the 15-year project. All the improvements must be completed before the full annual savings can be realized. But, as the improvements are made some savings will be realized.

To estimate the potential savings realized during the 15-year project, it is assumed that 1/15 of the total savings is realized for each year of the project and that the savings is cumulative. For example, 1/15 of the potential annual savings is $60,000. Therefore, in year 1, the potential annual savings is $60,000. In year 2, the potential annual savings is $120,000 and the cumulative savings is $180,000. By year 15, the full potential annual savings of $900,000 will finally be achieved and the cumulative savings that has accrued during the course of the project is in excess of $7 million. The growth of the potential savings over the course of the project is illustrated in Figure 1.

It should be noted that these savings do not account for increases in the cost of water and inflation of labor cost over the 15-year project.

Summary

Interviews with Maintenance District irrigation technicians identified problems that affect the amount of water applied and the level of water conservation possible. The age of the existing irrigation systems was the primary problem identified.

Of the 287 irrigated sites, 257 sites covering 2,135 irrigated acres are in need of improvements in the next 15 years. Priority assignments were made to these 257 sites to understand the phasing of potential improvements and the probable construction costs.

Priority 1 sites are in immediate need of replacement to improve irrigation system efficiency, and reduce water wastage and labor requirements. The irrigation systems in this category would ideally be replaced in the first 5 years of the program. The costs for the Priority 1 sites are over $29 million. Priority 2 systems will be replaced in the second 5 years of the program. These systems are old but are currently more efficient than those in Priority 1. The costs for the Priority 2 sites are almost $13 million. Priority 3 systems are to be replaced in the third 5 years of the program. These systems have more than half of the useful life remaining and are currently reasonably efficient. The costs for the Priority 3 sites are over $16 million. The total replacement costs would exceed $58 million in 15 years.

The total potential water savings for all 257 sites is about 325 million gallons annually. At the current water rate of $1.09 per thousand gallons, the potential water cost savings is over $350,000 per year.

The annual direct labor cost associated with repair and maintenance of the irrigation systems is $1.37 million. If a 40% reduction in labor cost were realized by the improvement of the irrigation systems, the annual labor savings is $550,000. The total annual savings resulting from improvements to the irrigation systems is $900,000.

There are three probable funding sources that are applicable to the Plan: City and County Parks and Recreation Department capital improvement program, savings in water costs, and savings in labor costs. These sources are projected to generate a total of $10.1 million during the study period. However, this amount is not adequate to meet irrigation system capital costs of $58.7 million, creating a shortfall in funds that accumulates to $48.6 million at the end of the study period. Additional options for funding the remaining $48.6 million of irrigation system improvements include general obligation bonds, certificates of participation, conservation incentive programs, state revolving fund loan, permit fee increases, and grants for sustainability.

It is recommended that Denver Parks develop an ongoing funding mechanism that is realistic for the 2500 acres (and growing) of irrigated area. The current $150,000 per year falls far short of the funds needed to properly maintain the systems.

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