Evaluation of Potential Water Conservation Using Site-Specific Irrigation

K. C. Stone[1], P. J. Bauer, and J. A. Millen

Abstract: *With the advent of site-specific variable-rate irrigation (VRI) systems, irrigation can be spatially managed within sub-field-sized zones. Spatial irrigation management can optimize spatial water use efficiency and may conserve water. Spatial VRI systems are currently being managed by consultants who use either the farmer's familiarity with the field or some other measure of field variability, such as soil maps or soil electrical conductivity. The goal of the research is to provide farmers and consultants a tool to evaluate the potential benefits of implementing VRI. The specific objective of this research is to evaluate the potential water savings using VRI management compared to uniform irrigation management. The 20-year simulation study was carried out on selected fields with varying degrees of soil and topographic variability. The simulated field had 12 soil mapping units with a 65% difference in soil water holding capacity. The 20-year simulation covering all weather conditions for each soil produced only 2 significantly different irrigation management zones. However, when the 20-year period was divided into periods with different ratios of evapotranspiration to rainfall, the simulations identified 5 to 6 management zoned with significantly different irrigation requirements. These results indicate that variable rate irrigation system systems design and management should not be based on long term average weather conditions. Using years with differing weather conditions should be used for potentially identifying management zones for VRI systems. Compared to uniform irrigation management, managing irrigation using multiple management zones saved between 21 and 42 mm of irrigation for specific zones.*

Keywords: Precision farming, Variable-rate irrigation, management zones, water conservation

Introduction

Variable rate irrigation (VRI) systems have the potential to conserve water by spatially allocating limited water resources. Spatial water applications attempt to overcome site-specific problems that include spatial variability in topography, soil type, soil water availability, and landscape features. The VRI systems can also provide differential water application to crops based on spatial crop requirements. Additionally, VRI systems would be an asset in fields that have

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highly variable soil with different water holding capacities. Furthermore, recent droughts throughout the US have highlighted the delicate balance that faces agricultural production in competition with urban, industry, and environmental water uses (Stone et al., 2010). Under these drought conditions, VRI systems can be utilized for water conservation. Sadler et al. (2005) outlined opportunities for conservation including situations where non-cropped areas exist in a field for which irrigation can be turned completely off; situations where a reduced irrigation amount provides specific benefits; and finally, situations where optimizing irrigation amount to adapt to spatial productivity provides quantitative benefits. In this research, we investigated the potential water conservation using VRI for crop production. Our specific objective is to evaluate the potential water savings using VRI management compared to uniform irrigation management using a simple water balance approach.

Methods

A field with highly variable soils and a history of spatial crop production was selected to simulate water requirements for a corn crop. Soil at this site had been mapped on a 1:1200 scale by USDA-NRCS staff in 1984 (USDA-SCS, 1986). Brief descriptions of the 12 soil map units are shown in table 1.

Table 1. Description of soils located under the variable-rate irrigation system at Florence, SC (after Sadler et al., 2002)

Symbol	Soil Classification
BnA	Bonneau loamy fine sand (lfs), 0% to 2% slopes
Cx	Coxville loam
Dn	Dunbar lfs
Do	Dunbar lfs, overwash
ErA	Emporia fine sandy loam (fsl), 1% to 2% slopes
GoA	Goldsboro lfs, 0% to 2% slopes
NbA	Noboco lfs, moderately thick surface, 0% to 2% slopes
NcA	Noboco lfs, thick surface, 0% to 2% slopes
NfA	Noboco fsl, 1% to 2% slope
NkA	Norfolk lfs, moderately thick surface, 0% to 2% slopes
NoA	Norfolk lfs, thick surface, 0% to 2% slopes
NrA	Norfolk fsl, 1% to 2% slopes

The water holding capacity for these soils were estimated using the soil properties in the DSSAT soils database (Jones et al., 2003) and from previous modeling research by Sadler et al. (2000). The soil had a wide range of water holding capacities (Figure 1). The water holding capacities of the top 12 inches of the soils ranged from approximately 42 mm to 70 mm.

These soils were then used to simulate a 20-year water balance under the VRI system. The water balance was accomplished in a Microsoft Excel spreadsheet. The equation for the simple daily water balance was:

$$S_{i+1} = S_i + Rain_i - ET_{ci} - Runoff_i - Drainage_i$$

Where S_i was the soil storage on day I, and ET_{ci} = crop evapotranspiration. When the soil storage exceeded saturation, the excess was defined as runoff. Drainage was calculated as the difference between the maximum soil water holding capacity and saturation. Crop evapotranspiration was calculated based on the ASCE standardized reference evapotranspiration equation (Walter et al., 2000) method and crop coefficients for a corn crop. The weather parameters were collected from on on-site weather station.

The simulated water balance was calculated for a corn crop grown under the VRI system. The four simulation scenarios were simulated: 1) a uniform irrigation using the soil with the largest area under the VRI system (NkA); 2) using the individual soils as management zones (ie. 12 management zones); 3) 2 management zone (zone 1: Bonneau, NcA, NrA,NoA, NkA, NfA, NnA; zone2: NbA, Emporia, Dunbar, Coxville, Goldsboro); and 4 management zones (zone 1: zone 1: Bonneau, NcA, NrA; zone 2: NoA, NkA, NfA; zone3: NnA, NbA; zone 4: Emporia, Dunbar, Coxville, Goldsboro).

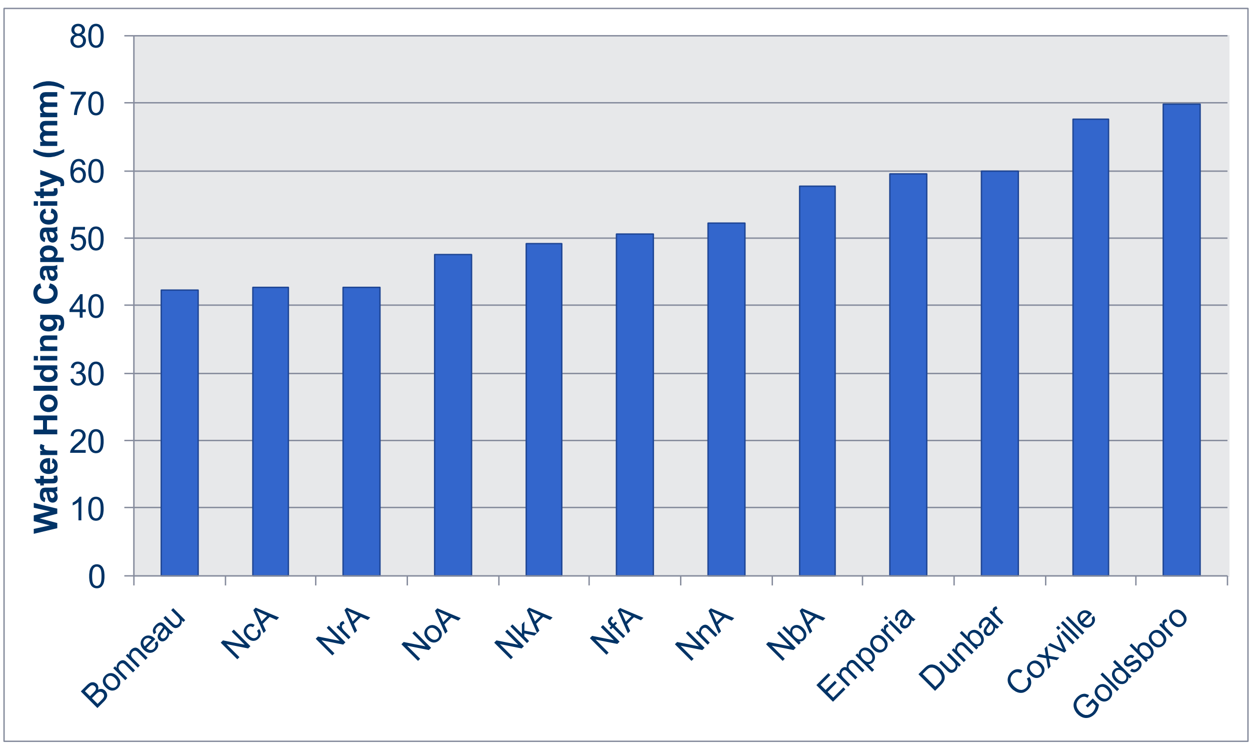

Figure 1. Soil water holding capacities for the 12 soil map units under the variable-rate irrigation system at Florence, SC.

The growing season rainfall was highly variable during the 20-year simulation period (figure 2) and encompassed both wet and drought years. The account for differing weather patterns, we calculated the ratio of growing season cumulative potential ET to rainfall. We then in addition to a simulation covering all years, we simulated the water balance for years with the ET-Rainfall ratios of <50%, 50 To 60%, 60 to 75%, and >75%. We referred to these ratios as drought years.

Results

The simulations of water balance over the 20-year simulation using the individual soils as management zone are shown in table 2. The simulation results for the entire 20-year period had average irrigation requirements ranging from 230 to 271 mm. The 20-year simulation produced only two significant groups of soil (or potential management zone). However, using long-term simulation may mask years where drought conditions existed. When the simulations were divided into drought years, the results were quite different (table 2). The drought years with ET/Rainfall ratio less than 50% required the greatest irrigation as expected with irrigation ranging from 303 to 318 mm. Similar distributions of irrigation requirement were seen in the other ET/Rainfall ratio categories. Overall these categories, there were from 5 to 6 significantly different management zones identified. This was in contrast to the simulation covering all conditions which only had 2 significant management zones.

Table 2. Simulated average irrigation requirements for the for 12 soil maps units for years with different levels of drought conditions and for a simulation over all years.

Soil	Drought (% of ET_{ref} / Rainfall)				All Years
	<50%	50 to 60%	60 to 75%	> 75%	
	Irrigation (mm)				
Bonneau	318 A*	290 A	277 A	213 A	271 A
Coxville	294 E	258 F	243 EF	177 E	240 B
Dunbar	301 D	268 E	249 DE	189 D	249 AB
Emporia	303 D	268 E	249 DE	189 D	249 AB
Goldsboro	294 E	258 F	241 F	177 E	239 B
NbA	303 D	271 DE	251 D	196 C	252 AB
NcA	318 A	290 A	277 A	213 A	271 A
NfA	313 BC	279 BC	260 BC	205 B	261 AB
NkA	313 BC	283 B	260 BC	207 AB	263 AB
NnA	311 C	275 CD	254 CD	205 B	259 AB
NoA	316 AB	283 B	264 B	208 AB	265 A
NrA	318 A	290 A	277 A	213 A	271 A
# of Zones	**5**	**6**	**6**	**5**	**2**

* Irrigation depths for a given drought condition with different letters were significantly different at the 95% level.

We then calculated the irrigation requirements with the water balance for a specific number of predefined management zones (table 3). The management zones used groups of soils with similar water holding capacities. The scenario with one management zone required the greatest overall irrigation. Under this scenario, some areas of the field may have been over or under irrigated. The scenarios with two and four management zones had differing irrigation requirements depending upon the average water holding capacity of that specific zone. Using a management zone approach as simulated could save or conserve from 21 to 42 mm of irrigation in specific management zone compared to a uniform irrigation.

Table 3. Simulated irrigation requirements for the one (uniform), two, and four management zones irrigation scenerios.

Mgt. Zone	Drought (% of ET_{ref})											
	<50%			50 to 60%			60 to 75%			>75%		
	# of Mgt. Zones			# of Mgt. Zones			# of Mgt. Zones			# of Mgt. Zones		
	One	Two	Four	One	Two	Four	One	Two	Four	One	Two	Four
	Irrigation (mm)											
1	313	316	320	283	285	293	260	269	283	206	211	215
2	.	295	313	.	259	279	.	242	259	.	181	206
3	.	.	300	.	.	268	.	.	248	.	.	194
4	.	.	293	.	.	256	.	.	241	.	.	174
Difference		21	27		26	37		27	42		30	41

Summary and Conclusions

The water balance of a corn crop was simulated using a 20-year weather record at Florence, SC. The simulated field had 12 soil mapping units with a large difference in soil water holding capacities. The 20-year simulation covering all weather conditions for each soil produced only 2 significantly different irrigation management zones. However, when the 20-year period was divided into periods with different ratios of evapotranspiration to rainfall, the simulations identified 5 to 6 management zoned with significantly different irrigation requirements. These results indicate that variable rate irrigation systems design and management should not be based on long term average weather conditions. Irrigation design should be utilize periods where irrigation demands are greater. Additionally, using this simulation approach may be useful in determining management zones for VRI systems.

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