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 (24-29ºC) 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**