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EFFECTS OF BLACK PLASTIC AND STRAW MULCH ON YIELD AND WATER USE EFFICIENCY OF CUCUMBER

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ABSTRACT. Field experiments were conducted during the 1995 and 1996 seasons to evaluate the yield and water use of cucumber (*Cucumis sativus* L. cv. 'Calypso', 1995 and 'Dasher II', 1996) grown with black plastic and grass straw mulch under 3 levels of drip irrigation. Cucumber was grown in replicated plots arranged in randomized complete block design and mulched with either black plastic (1.25 mil) or dry guinea grass (*Panicum maximum* L.) straw (5.0-6.5 cm thick). Plots were drip-irrigated at soil water tensions corresponding to 20, 40, and 60 kPa. Number of marketable fruits, fruit size, total weight of fruits and marketable yield were recorded for each harvest. In 1995, for all of the measures parameters, black plastic mulch resulted in significantly higher values than the straw mulch. Marketable yield (15.7 t ha^{-1}) in plots with black plastic mulch was significantly higher ($P<0.005$) than plots with straw mulch (11.9 t ha^{-1}). For both mulches, drip irrigation levels had no influence ($P>0.10$) on cucumber yield and yield components. Water use in straw-mulched plots was lower than plastic-mulched plots, but water use efficiency and economic returns to irrigation water were higher in plots with black plastic mulch. The incidence of fusarium wilt (*Fusarium* sp.) in plots with straw mulch was higher than plots with plastic mulch, a contributing factor for low yields in straw-mulched plots. In 1996, there were no significant differences observed between mulch treatments or irrigation regimes for any of the parameters measured. Production from the 'Dasher II' cultivar was much higher than the yields obtained in 1995 from 'Calypso'.

INTRODUCTION

The integration of mulch into microirrigation systems for vegetable production has gained popularity in the major vegetable growing regions in the U.S. and other parts of the world. The use of this technology has significantly increased yields and economic returns from vegetable production especially in areas where irrigation water is a scarce and limiting resource. In the Virgin Islands, drip irrigation has benefited the production of major vegetable crops by reducing water use, improving both the quantity and quality of yield, and increasing economic returns (Navarro, 1987; Navarro and Newman, 1989; Palada *et al.*, 1995a).

Cucumber is one of the major vegetable crops popularly grown by local farmers. Many local growers do in fact produce cucumbers year-round under the tropical climate of the Virgin Islands. However, during the dry season, production is limited by availability of irrigation water. Growers always experience shortage of irrigation water and water sources are not dependable during this season. Furthermore, irrigation water use is high due to high temperature and evapotranspiration during the hot dry season.

Many growers employ mulching as an effective technique in reducing evapotranspiration and water use in vegetable production. Several reports have indicated that drip irrigation in combination with mulching has benefited the production of melons, squash, and cucumbers (Bhella, 1978; Bhella and Kwolek, 1984; Briones *et al.*, 1995; Collingwood *et al.*, 1989; Fipps and Perez, 1995; Paterson, 1980; Schales and Sheldrake, 1966). These studies demonstrated that plastic mulch in conjunction with drip irrigation resulted in earlier and higher overall yields, reduced evaporation, fewer weed problems, and reduced fertilizer leaching (Lamont, 1993).

Although plastic mulch offers many advantages and benefits, it also has limitations. For example, removal and disposal are a problem in areas where waste disposal is restricted. Furthermore, the use of plastic mulch in vegetable production entails greater initial cost, which could be an economic burden to small-scale and limited-resource growers. An alternative to plastic mulch is an organic mulch such as grass straw or dry leaves. These materials are locally available and inexpensive. In the Virgin Islands, organic mulches such as grass straw and compost have been used in culinary herb production and resulted in yields comparable to or higher than herbs grown with synthetic (plastic) mulches (Palada *et al.*, 1995b). Few studies have been conducted on the effect of synthetic and organic mulches on cucumber yield in the Virgin Islands. The objective of this study is 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 regimes (levels) of drip irrigation.

MATERIALS AND METHODS

This study was conducted at the Agricultural Experiment Station, University of the Virgin Islands in St. Croix, USVI (lat. 17°42'N and long. 64°48W). The soil was a Fredensborg clay (loamy, fine carbonatic, isohyperthermic, shallow calciustolls). The average rainfall is 1015 mm, but evaporation exceeds precipitation 10 months of the year resulting in a negative water balance. The field experiments were conducted from 17 March to 5 June, 1995, and 26 March to 21 June, 1996.

Plots were established measuring 4.57 m wide and 4.06 m long. Each plot contained 3 rows spaced at 1.5 m. Cucumber cv 'Calypso' (1995) and 'Dasher II' (1996) was direct-seeded on 17 March using 2-3 seeds per hole at a spacing of 40.6 cm along the row. Treatments consisted of black plastic mulch and grass straw mulch. The black plastic mulch (21.35 m) was installed in plots after the final land preparation, whereas the straw mulch (dry guinea grass) was applied at 5.0-6.5 cm thick on 11 April (1995) and 16 April (1996) about 3 weeks after seeding. 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. 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 in each treatment on 2 replications to monitor 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. Insect pests and diseases were controlled by alternate spray applications of dipel, malathion, kocide, diazinon, M-Pede, rotenone and pyrethrum. In 1996, all plots were fertilized on 18 April with triple superphosphate and sulfate of potash to supply 120 and 60 kg ha^{-1} 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^{-1}. Weeds were controlled by hand-weeding when necessary during both years.

Cucumbers were harvested starting on 3 May and ending on 5 June for a total of 11 harvests during 1995 and from 29 March to 21 June 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. Data were analyzed using the General Linear Models (GLM) procedures by Statistical Analysis System (SAS).

RESULTS AND DISCUSSION

Fruit Number and Weight by Harvest:

Cultivar 'Calypso' - 1995 Trial. During the first four harvests, more fruits were harvested from the straw mulch compared to black plastic mulch, however, differences were small (Fig. 1). Starting at the fifth harvest, plants grown with black plastic mulch produced more fruits than plant under grass straw mulch. The highest number of fruits was recorded in plastic-mulched plots during the tenth harvest (Fig. 1). For each harvest, differences in fruit number between irrigation regimes were insignificant. This result does not agree with those previously reported, where black plastic mulch resulted in early harvest. In terms of earliness, straw mulch is as good as or comparable to plastic mulch in cucumber production. Similar result was observed in fruit weight, except that cucumber grown with plastic mulch produced heavier fruits than those under grass straw mulch starting on the fifth harvest (Fig. 2). This also resulted in a significantly higher ($P<0.0047$) cumulative total yield in plots with black plastic mulch compared to straw mulch (Table 1). The data would suggest that the harvest and productive season for cucumber can be extended with the use of black plastic mulch resulting in maximum yields.

Cultivar 'Dasher II' - 1996 Trial. The grass straw mulch treatment produced significantly more marketable cucumber fruits and higher yields than the black plastic mulch for the first three harvests (Fig. 3-4). The number of marketable fruits harvested and the yield from both treatments were statistically 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.

Cultivar 'Calypso' - 1995 Trial. Data in Table 1 show that fruits harvested from plots with black plastic mulch were larger than those grown with straw mulch. Average fruit size (306 g) from plots with black plastic mulch was significantly larger ($P<0.0554$) than fruits harvested from grass straw-mulch plots (261 g). The effect of irrigation regime on fruit size was not significant (Table 1). This result indicates that cucumber fruit quality is improved with the use of black plastic mulch and is consistent with results previously reported (Lamont, 1993).

Table 1. Cucumber (cv. 'Calypso') yield and yield components grown with black plastic and grass straw mulch under three drip irrigation regimes. UVI/AES, 1995.

Mulch	Irrigation Regime (kPa)	Total no. of fruits per plot	Fruit size (g)	Total fruit yield ($t\ ha^{-1}$)*	Marketable fruit yield ($t\ ha^{-1}$)*
Plastic	20	92	284	16.8	14.4
	40	107	270	18.8	15.9
	60	113	363	19.2	16.9
	Mean	104	306	18.3	15.9
Straw	20	94	265	16.1	13.7
	40	81	255	13.7	11.4
	60	74	264	13.1	10.5
	Mean	83	261	14.3	11.9

*Metric tons per hectare

Analysis of Variance by General Linear Model Procedure (Values for Prob.>F)

Parameter	No. of Fruits	Fruit Size	Total Yield	Marketable Yield
Replication	0.2727	0.5235	0.2204	0.2521
Mulch	0.0047**	0.0554*	0.0126**	0.0052**
Regime	0.9872	0.3765	0.9859	0.9582
Mulch x Regime	0.0590	0.8125	0.2692	0.1605

Fruit Size:

Cultivar 'Dasher II' - 1996 Trial. The mulch treatments did not significantly affect the fruit size of 'Dasher II' cucumber in 1996 (Table 3). The average size of 359 g from the black plastic mulch treatment was not significantly different from the 364 g fruit size in the grass straw-mulched plots. This result indicates that with cultivar 'Dasher II' both mulch type (organic vs. synthetic) has similar effect on yield.

Table 2. Estimated irrigation water use and efficiency by cucumber (cv. 'Calypso') grown under black plastic and grass straw mulch at three drip irrigation regimes. UVI/AES, 1995.

Mulch	IR[1] (kPa)	TWU[2] (l/plt)	TWU (cu.m/ha)	IWC[3] ($/ha)	WUE[4] (l/kg)	WCE[5] ($/kg)	RIW[6] ($/$)
Plastic	20	41.9	677	2864	47	0.20	11.06
	40	49.0	793	3354	50	0.21	10.43
	60	40.1	648	2741	38	0.16	13.56
	Mean	43.7	706	2986	45	0.19	11.71
Straw	20	48.6	786	3325	57	0.24	9.06
	40	41.7	674	2851	59	0.25	8.80
	60	35.6	576	2436	55	0.23	9.48
	Mean	42.0	679	2871	57	0.24	9.11

[1]Irrigation regime. [2]Total water use.
[3]Irrigation water costs, estimates based on irrigation water cost of $4.23/cu.m.
[4]Water Use Efficiency=lts of water used to produce a kg of fresh cucumber.
[5]Water Cost Efficiency=cost of irrigation water to produce a kg of fresh cucumber.
[6]Returns to irrigation water, calculated from gross returns divided by irrigation water cost using $2200/ton market value of cucumber.

Total Fruit Yield and Marketable Yield:

Cultivar 'Calypso' - 1995 Trial. The effect of mulch on total and marketable fruit yield was highly significant, but irrigation regime did not significantly influence fruit yield (Table 1). Total fruit yield from plots with black plastic mulch was significantly greater ($P<0.0126$) than those obtained from grass straw mulch. Black plastic mulch resulted in 22% more yield than grass straw mulch. Similar result was obtained for marketable fruits where plots under black plastic mulch produced yields which were significantly higher ($P<0.0052$) than plots with grass straw mulch. Overall, the average marketable fruit yield in plots with black plastic mulch was 25% higher than the grass straw mulch (Table 1). These data agree with those reported by Collingwood *et al.*, (1989) and Paterson (1980) where cucumber overall yields were much improved under black plastic mulch.

Table 3. Cucumber (cv. 'Dasher II') yield and yield components grown with black plastic and grass straw mulch under three drip irrigation regimes. UVI/AES, 1996.

Mulch	Irrigation Regime (kPa)	Total no. fruits per plot	Fruit size (g)	Total fruit yield ($t\ ha^{-1}$)*	Marketable fruit yield ($t\ ha^{-1}$)
Plastic	20	272	370	57.9	54.9
	40	263	353	54.4	51.2
	60	266	356	56.0	51.8
	Mean	267	359	56.1	52.6
Straw	20	295	352	63.1	57.6
	40	249	374	58.2	50.9
	60	247	367	55.4	49.8
	Mean	264	364	58.9	52.8

*Metric tons per hectare

Analysis of Variance by General Linear Model Procedure (Values for Prob.>F)

Parameter	No. of Fruits	Fruit Size	Total Yield	Marketable Yield
Block	0.0099**	0.9609	0.0192*	0.0314*
Mulch	0.867	0.6059	0.5644	0.9707
Regime	0.4666	0.9671	0.673	0.5826
Mulch x Regime	0.6531	0.2202	0.8715	0.9224

Cultivar 'Dasher II' - 1996 Trial. Yield of 'Dasher II' was not significantly influenced by either the type of mulch or the soil moisture level under which the crop was grown (Table 3). The yields from the black plastic mulch treatment were 56.1 and 52.6 $t\ ha^{-1}$ for total and marketable yield, respectively, while from the grass straw mulch, the yields were 58.9 and 52.8 $t\ ha^{-1}$ for total and marketable yield, respectively.

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. Lamont (1993) stated that plastic mulch prevents rain splashing that may carry disease organisms from the soil during heavy rainfall, thereby improving the quality of fruits. Furthermore, the edible product from mulched crop is clean and less subject to rots, because the soil is not splashed on the plants or fruits.

During the latter part of the growing season in 1996, it was also observed that plants under grass straw mulch were more susceptible to infestation by thrips compared to plants under plastic mulch, suggesting that straw mulch may provide a microenvironment which favors increased pest population.

Water Use, Efficiency and Economic Returns to Irrigation Water:

<u>1995 Trial - Cultivar 'Calypso'</u>. Total water use varied among irrigation regimes (Table 2). For a given mulch, water used decreased with increasing water tension regime. However, under plastic mulch treatment, highest water use was observed at the 40 kPa irrigation regime (Table 1). In general, water use of cucumber under grass straw mulch was lower than those under black plastic mulch. Examining weekly water consumption (data not shown), it was found that during the first 3 to 4 weeks, plots under plastic mulch utilized more irrigation water than those in straw mulch. During the last 3 weeks of the season, plots with straw mulch used slightly lower irrigation water than in plastic mulch. The amount of rainfall received during the season was 178 mm and was concentrated during the last 4 to 6 weeks. This partially explains for the lower irrigation water use in plots with straw mulch compared to plastic mulch. Straw mulch is permeable to rain water allowing water to penetrate below the soil surface. In contrast, plastic mulch is impermeable to rain water, thereby blocking water infiltration through the soil.

In spite of high irrigation water use in plots with plastic mulch, water use efficiency (WUE) is generally higher than plots with straw mulch (Table 2). On the average, plants grown in plastic mulch used only 45 liters of irrigation water to produce a kilogram of fresh cucumber compared to 57 liters in plots with straw mulch. This translates into reduced water cost in producing a kilogram of cucumber ($0.19 for plastic mulch vs. $0.24 for straw mulch). Thus, water cost efficiency (WCE) is much better with plastic than with straw mulch.

Economic returns to irrigation water were generally higher in plots with plastic mulch compared to straw mulch (Table 2). Because of relatively high yields, gross returns were higher in plastic mulch than in straw mulch. Using cucumber retail market price of $2.20 per kg ($1.00/lb), returns to irrigation water in plots with plastic mulch are higher than those in straw mulch. On the average, for every dollar spent on irrigation water, the grower gets $11.71 in return for using plastic mulch compared with only $9.11 with straw mulch (Table 2). This suggests that it is more profitable to produce cucumber using black plastic mulch in terms of returns to irrigation water. This is important for the economy of the Virgin Islands, since cost of irrigation water is one of the highest in the Caribbean. Use of irrigation water and plastic mulch is therefore justified by producing high value crops such as cucumbers.

1996 Trial - Cultivar 'Dasher II'. Overall, there was a tendency for the plastic mulch treatment to use more water than the grass straw mulch (Table 4). The only exception was the 40 kPa treatment where the grass straw mulch used more water than the plastic mulch. On a per plant basis the 20 kPa regime had the highest water use for both mulches (55.3 and 50.6 liters, respectively). The amounts used for both the 40 and 60 kPa regimes were similar. The water use efficiency (liters water used to produce a kg cucumber) followed a pattern that was similar to the water use data. Economic returns to irrigation water show that irrigation regimes which maintain higher soil water tension (40 and 50 kPa) gave better returns than treatment where irrigation regime was maintained at 20 kPa (Table 4). When mulches were compared, the returns from the grass straw mulch ($39.41 for every dollar spent for irrigation water) were higher than from the plastic mulch ($37.65). A factor which might have contributed to the better returns from the grass straw mulch is the fact that rainfall can be better utilized by this permeable mulch, but not by the plastic mulch which is impermeable to rainfall.

CONCLUSIONS

The two-year study has shown that the response of cucumber to black plastic and grass straw mulch depended on the cultivar. Using 'Calypso' in 1995, black plastic mulch increased yield, improved water use efficiency and increased economic returns to irrigation water. Cucumber grown in plots with black plastic mulch produced higher number of fruits, larger fruit size, and higher total and marketable fruit yields compared to those grown with grass straw mulch. The improved yields in plots with black plastic mulch resulted in more efficient water use and profitable returns to irrigation water than the straw mulch. The benefit of using straw mulch is shown by reduced total irrigation water use due to rain water infiltration, but this is offset by high incidence of soil-borne fungal disease, reducing total yield and crop quality. The 1996 study utilizing cultivar 'Dasher II', indicates that cucumber production is not affected by both types of mulch or irrigation regimes. Despite an infestation of thrips, cultivar 'Dasher II' continued to be more productive compared to cultivar 'Calypso'.

Table 4. Estimated irrigation water use and efficiency by cucumber (cv. 'Dasher II') grown under black plastic and grass straw mulch at three drip irrigation regimes. UVI/AES. 1996.

Mulch	IR[1] (kPa)	TWU[2] (l/plt)	TWU (cu.m/ha)	IWC[3] ($/ha)	WUE[4] (l/kg)	WCE[5] ($/kg)	RIW[6] ($/$)
Plastic	20	55.3	893	3778	16.5	0.07	31.97
	40	39.1	631	2671	12.5	0.05	42.14
	60	42.9	693	2931	13.6	0.06	38.84
	Mean	45.7	739	3127	14.2	0.06	37.65
Straw	20	50.6	817	3457	14.4	0.06	36.66
	40	40.5	654	2768	13.1	0.06	40.48
	60	39.0	630	2666	12.9	0.06	41.09
	Mean	43.3	701	2964	13.5	0.06	39.41

[1]Irrigation regime. [2]Total water use.
[3]Irrigation water costs, estimates based on irrigation water cost of $4.23/cu.m.
[4]Water Use Efficiency=lts of water used to produce a kg of fresh cucumber.
[5]Water Cost Efficiency=cost of irrigation water to produce a kg of fresh cucumber.
[6]Returns to irrigation water, calculated from gross returns divided by irrigation water cost using $2200/ton market value of cucumber.

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