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Research Article

Effect of Soil Moisture and Fertility on Growth and Yield of *Stevia* in a Sandy Clay Loam Soil of Odisha

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ABSTRACT

Field experiments were carried out at the Central Experimental Farm of the ICAR-Indian Institute of Water Management, Bhubaneswar, Odisha on a sandy clay loam soil for two consecutive *rabi* seasons of 2005-06 and 2006-07 to ascertain the effect of drip irrigation and fertigation treatments on *Stevia* (*Stevia rebaudiana*, *Bertoni*) grown in rice fallow. Treatments comprised of three drip irrigation regimes (I_1- irrigation at 100% PE, I_2 – irrigation at 80% PE and I_3 – irrigation at 60% PE), three fertility levels (F_1 -100%, F_2 – 75% and F_3 - 50% of recommended dose of 110-45-45 kg N-P_2O_5-K_2O ha^{-1}) and the control (treatment with surface irrigation and soil application of fertilizer) were applied in a Factorial Randomized Block Design with three replications. It was observed that I_1 maintained the most favourable soil moisture and produced maximum dry leaf yield of 2,738 kg ha^{-1} in *Stevia*, and the highest water use efficiency. The highest fresh leaf (8,952 kg ha^{-1}), dry leaf (2,738 kg ha^{-1}) and total biomass yield (34,451 kg ha^{-1}) were achieved with I_1. Similarly, the highest yields of fresh leaf (8,207 kg ha^{-1}), dry leaf (2,525 kg ha^{-1}) and biomass (33,503 kg ha^{-1}) were recorded with F_1. The I_1-F_1 combination produced 9,131 kg of fresh leaf, 2,903 kg dry leaf and 3,500 kg biomass yield. Stevia responds best under the 100% drip irrigation, as it remains the soil moisture most favourable for the growth and development of the crop.

Key words: Soil moisture, drip irrigation, water use efficiency, pan evaporation, *Stevia*

Introduction

Plant sweeteners have attained high significance in the recent years due to their demand for industrial use and higher market price (Lubbe and Verpoorte, 2011). *Stevia* is a small sweet perennial shrub with green leaves that belongs to the family Compositae. It was originated in South America (Paraguay and Brazil). About 85% of the global supply of the fluffy white crystalline *Stevia* extracts are consumed by the markets in Asian continent itself. It was estimated that the present market demand for *Stevia* leaf extract is 1.5 million kg, processed from 12 million kg of *Stevia* leaf (*Stevia* Facts, 2008). Main reason for the huge demand for this plant is the presence of stevioside as an active constituents in the leaf (~5-10% on dry weight basis) which is sweeter than sucrose by not less than 300-350 times (Geuns, 2003; Lemus-Mondaca *et al*., 2012). *Stevia* acts as a flavour enhancer and in medicinal field, it has hypoglycemic, oral contraceptive, cardiovascular, antimicrobial activity. It is also used for weight loss, digestive and skin problems (Puri *et al.,* 2011). It has wide application in agriculture also. The main habitat of *Stevia* includes low-lying areas on poor sandy acidic soils nearer to swamps

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which generally have shallow water tables. The previous studies revealed that *Stevia* responds positively to irrigation given at frequent intervals which is mainly attributed to constant supply of soil moisture above wilting point, even up to 80% of field capacity (Lavini *et al.,* 2008). The present experiment was therefore conducted to study the effect of drip fertigation on yield and quality of *Stevia* in the rice fallow where drip irrigation keeps soil in moist condition.

Materials and Methods

The experiment was conducted at the ICAR-Indian Institute of Water Management, Bhubaneswar, Odisha during the *rabi* (winter) seasons of 2005-06 and 2006-07 to assess the performance of *Stevia* grown in rice fallow under different irrigation and fertility levels. The experiment was laid out in Factorial Randomized Block Design with three replications. Treatments comprised of three irrigation regimes (I1 - drip irrigation at 100% PE, I2 at 80% PE and I3 at 60% PE) and three fertility levels of (F1 -100%, F2 – 75% and F3 - 50% recommended dose of fertilizers), plus the control with surface irrigation and soil application of fertilizers. The soil was sandy clay loam in texture with pH 5.7, low in organic C (0.46%) and N (159 kg ha^{-1}); medium in available phosphorus (21 kg ha^{-1}) and potassium (183 kg ha^{-1}) in the plough layer (0-15 cm).

Stevia was propagated vegetatively consisting of 3-4 nodes with the terminal bud and 3-4 crown top leaves were planted in polythene bags containing a mixture of soil and sand (1:1) in October during both the seasons. Forty-five days old seedlings of variety “SRB-126” were planted in crop geometry of 60 cm x 30 cm. The recommended fertilizer dose was 110-45-45 kg $N\text{-}P_2O_5\text{-}K_2O$ ha^{-1}. Required amount of urea and potash was dissolved in water and fed to the drip system using ventury. Fertigation was given in 10 equal splits at fortnightly interval starting from 15 days after planting (DAP) up to 30 days before the final harvest.

Different irrigation levels were imposed on the basis of pan evaporation (Jenson *et al*., 1961). The depth of water in surface irrigation was 60 mm. First irrigation was given one day prior to planting. Subsequent irrigations were given at two days interval in drip system. If rainfall event occurred between irrigation cycles, then the rainfall amount was deducted and irrigation water was applied accordingly. The crop coefficient values of 0.70, 1.10 and 0.70 were taken as standard during vegetative, full growth and later part of the growth stages, respectively. Water was pumped from a well through a 3 HP diesel pump and conveyed to the field using PVC pipes of 63 mm diameter after filtering through a screen filter. Ventury was installed for fertigation ahead of the screen filter in the main line. Water was taken to the field through sub mains PVC pipes (50 mm diameter). In each plot, four laterals were placed at a spacing of 0.90 m. Drippers were fixed at 0.60 m spacing. In each plot (gross plot size-5.0 m × 3.60 m and net plot size-4.20 m × 2.70 m), there were 32 drippers (4 laterals × 8 drippers/ lateral). A tap was fixed at the head of each lateral in order to regulate the water supply. Sub mains were closed with end caps and laterals were closed with end plugs. The mean discharge rates were 3.0 lh^{-1} with standard deviation of 0.19 lh^{-1} and coefficient of variation 6.34%, respectively. Based on the above discharge rates, emission uniformity was found to be 96.3%. The plants were sun-dried and thereafter oven dried at 80^0 C for 48 h till constant weight was achieved. The dry weight so obtained from five plants was averaged out to get dry matter per plant in g. The leaves were separated from the plant by beating with wooden stick, sun-dried and the weight was expressed on oven-dry basis as dry leaf yield in kg ha^{-1}. The plants in the net plot were cut from the base and fresh total biomass yield was expressed in kg ha^{-1}.

Results and Discussion

Soil moisture changes

Irrigation at 100% PE through drip system recorded higher soil moisture content than 80 and 60% PE at all the soil depths during non-rainy days (Table 1 & 2). However, during rainy days, soil moisture profile remained uniform in all the

Table 1. Effect of drip irrigation on soil moisture depletion (%) in *Stevia* in 2006

Date of observation	Drip irrigation at											
	100% PE				80% PE				60% PE			
	Soil depth (cm)				Soil depth (cm)				Soil depth (cm)			
	20	40	60	80	20	40	60	80	20	40	60	80
2.2.06	8.89	1.51	3.39	16.72	11.6	15.2	3.4	13.3	16.2	1.7	3.4	-9.9
9.2.06	12.55	0.15	1.69	15.86	15.3	17.6	1.7	12.4	19.9	3.0	5.1	-9.0
16.3.06	18.97	2.12	5.08	14.40	21.7	21.6	8.5	9.9	25.4	5.3	18.6	-6.4
23.3.06	22.63	23.18	14.39	10.72	24.5	25.6	17.8	7.3	29.1	29.6	20.3	-3.9
28.3.06	3.94	1.21	5.92	13.29	1.2	20.0	9.3	9.9	3.4	4.4	11.9	-6.4
1.4.06	9.80	1.21	1.69	20.15	12.6	20.8	5.1	16.7	16.2	4.9	8.5	13.3
12.4.06	18.97	5.31	5.08	15.00	22.6	28.8	8.5	11.6	26.3	9.4	11.9	-8.1
19.4.06	8.89	18.38	8.46	10.72	12.6	21.6	11.9	7.3	16.2	5.3	15.2	-3.9
26.4.06	19.89	4.40	14.39	1.28	23.6	26.4	17.8	2.1	28.1	8.0	21.2	5.6
3.5.06	1.55	16.78	19.47	0.42	4.3	20.0	22.9	3.0	8.9	4.4	25.4	6.4
11.5.06	2.47	1.66	13.54	4.71	5.2	21.6	16.9	1.3	8.9	24.8	19.5	2.1
18.5.06	3.39	0.75	14.39	2.14	6.1	20.0	17.8	1.3	10.7	23.2	15.2	3.9
25.5.06	6.14	15.18	8.46	3.00	8.9	16.0	11.9	6.4	12.6	19.2	15.2	10.7
1.5.06	8.89	19.18	5.92	5.57	11.6	21.6	9.3	9.0	16.2	24.8	11.0	13.3
8.6.06	13.47	19.98	11.00	10.72	16.2	23.2	14.4	14.2	20.8	26.4	16.1	17.6

Table 2. Effect of drip irrigation on soil moisture depletion pattern (%) in *Stevia* in 2007

Date of observation	Drip irrigation at											
	100% PE				80% PE				60% PE			
	Soil depth (cm)				Soil depth (cm)				Soil depth (cm)			
	20	40	60	80	20	40	60	80	20	40	60	80
5.2.07	8.9	12.8	-3.4	-16.7	10.7	10.4	-3.4	-13.3	16.2	18.4	3.4	-9.9
11.2.07	12.6	15.2	-1.7	-15.9	15.3	17.6	1.7	-12.4	19.9	20.8	5.1	-9.0
18.3.07	16.2	16.0	5.1	-14.4	18.1	19.2	8.5	-9.9	25.4	24.8	18.6	-6.4
25.3.07	19.9	16.8	11.0	-10.7	19.9	19.2	9.3	-7.3	29.1	29.6	20.3	-3.9
30.3.07	18.1	19.2	15.2	-13.3	16.2	20.0	9.3	-9.9	21.7	23.2	11.9	-6.4
3.4.07	9.8	17.6	1.7	-20.2	12.6	23.2	5.1	-16.7	16.2	24.0	8.5	-7.3
15.4.07	19.0	24.8	5.1	-15.0	14.4	24.0	8.5	-11.6	26.3	25.6	11.9	-8.1
21.4.07	8.9	18.4	8.5	-10.7	12.6	26.4	11.9	-7.3	16.2	24.8	15.2	-3.9
28.4.07	10.7	23.2	14.4	-1.3	10.7	26.4	17.8	2.1	28.1	29.6	21.2	5.6
5.5.07	11.6	16.8	19.5	-0.4	9.8	27.2	19.5	3.0	18.1	23.2	25.4	6.4
13.5.07	12.6	18.4	13.5	-4.7	11.6	16.8	16.9	-1.3	16.2	24.8	19.5	2.1
20.5.07	8.9	16.8	14.4	-2.1	13.5	20.0	17.8	1.3	24.5	23.2	15.2	3.9
27.5.07	12.6	15.2	8.5	3.0	19.9	16.0	11.9	6.4	25.4	19.2	15.2	10.7
3.5.07	13.5	19.2	5.9	5.6	19.0	16.0	9.3	9.0	25.4	24.8	11.0	13.3
10.6.07	11.6	17.6	11.0	10.7	16.2	17.6	14.4	14.2	28.1	26.4	16.1	17.6

treatments. With subsequent irrigation cycles, more depletion of soil moisture occurred when less amount of irrigation water was applied at 60% as compared to 100% PE irrigation schedule.

In case of 100% PE irrigation schedule, the depletion of available soil moisture was 1.5-22.6% in 0-20 cm soil depth, while in case of 80% PE and 60% PE, the depletion ranged from 4.3 to 24.5% and 3.4 to 23.1%, respectively. Soil moisture depletion from deeper layers (60-80 cm) was almost negligible during early crop growth period. Soil moisture depletion happened continuously as the penetration of roots progressed into deeper layers. In the month of April and May, when the crop ET demand was very high, the soil moisture depleted from greater depths. Drip irrigated crop received same amount of water regularly, which had been depleted through evapotranspiration process. This type of situation occurred when advective energy had influenced the demand to meet the requirement of the crop and the atmosphere.

The *Stevia* crop was irrigated by surface irrigation method at 60 mm PE and before each irrigation, the soil moisture status was determined to assess the magnitude of moisture stress. The result revealed that during 2006, the actual soil moisture content at 20 cm soil depth was 13.6 to 14.5%. The soil moisture content increased with soil depth and was found to be 19.3 to 20.3% at 40 cm, 21.1 to 22.5% at 60 cm and 22.6 to 23.6% at 80 cm depth. Similar trend was also observed during 2007. The depletion of available soil moisture from the surface layer was more than that of lower soil depth. It was estimated to be 44.6 to 52.9% from 20 cm, 28.8 to 39.2% from 40 cm, 14.4 to 26.2% from 60 cm and 14.2 to 21.9% from 80 cm soil depth. The depletion of soil moisture in 2007 also behaved in a similar pattern. The atmospheric demand was reduced after the receipt of the rainfall in June, which caused reduction in the depletion of available soil moisture.

Fresh leaf yield

The fresh leaf yield was affected significantly by the method and level of irrigation and the fertility level (Table 3). The leaf yield was 1.2 to 2.1% higher in 2006 than 2007. Irrigation through drip method increased the yield by 4.4 to 5.3% compared to furrow irrigation. The mean yield was maximum (7873 kg ha^{-1}) in case of drip irrigation, which was 4.9% more than the furrow irrigation (7508 kg ha^{-1}).

The effect of irrigation levels differed significantly between themselves. Application of irrigation at 100% PE increased the yield by 18.1 to 28.2% in 2006 and 16.0 to 26.7% in 2007 compared to that of 80% PE and 60% PE. Maximum yield of 8952 kg ha^{-1} was recorded with the former and lowest yield (7021 kg ha^{-1}) with 60% PE. The yield increased by 17.1 to 27.5% as compared with 80% and 60% PE. The crop that received irrigation at 80% PE gave 8.6 to 9.3% higher yield than 60% PE during both the seasons.

Table 3. Effect of irrigation regimes and fertility levels on yield of *Stevia* (kg ha^{-1})

Treatment	Yield (kg ha^{-1})		
	Fresh Leaf	Dry Leaf	Biomass
Method of irrigation			
Control	7508	2339	32011
DF	7873	2433	32665
SE (m)±	12.96	24.40	22.49
CD (p=0.05)	38.51	72.51	66.83
Irrigation			
I_1 = 100% PE	8952	2738	34451
I_2 = 80% PE	7647	2368	33015
I_3 = 60% PE	7021	2194	30531
SE (m)±	22.45	42.27	38.96
CD (p=0.05)	66.70	125.59	115.75
Fertility			
F_1 = 100% RD	8207	2525	33503
F_2 = 75% RD	7846	2429	32751
F_3 = 50% RD	7567	2345	31743
SE (m)±	22.45	42.27	38.96
CD (p=0.05)	66.70	125.59	115.75
Interaction (I×F)			
SE (m)±	38.89	73.22	67.48
CD (p=0.05)	115.52	217.53	200.48
CV (%)	0.78	0.52	0.51

Application of full dose of fertilizer (100% recommended dose, RD) produced maximum yield of 8239 kg and 8174 kg ha^{-1} in 2006 and 2007, respectively. The yield increased by 4.4 to 8% in the first year and 4.7 and 8.9% in the second year compared to75% and 50% RD. The mean yield was also higher in case of 100% RD (8207 kg ha^{-1}), which was 4.6 to 8.7% higher than 75% RD (7846 kg ha^{-1}) and 50% RD (7567 kg ha^{-1}). Reduction of 25% decreased the yield by 4.6% and that of 50% by 8.5%. The former (75% RD) gave 3.7% more yield than the latter (50% RD). The interaction effect of irrigation and fertilizers was significant. Application of irrigation at 100% PE and 100% RD produced maximum fresh leaf yield. The coefficient of variation ranged from 0.30 to 1.55%.

Dry leaf yield

The dry leaf yield was significantly affected by the method and level of irrigation and the fertility level (Table 3). The yield was 0.3 to 2.1% higher in 2006 than 2007. Drip irrigation produced maximum quantity of dry leaf (2433 kg ha^{-1}) as compared to furrow irrigation method (2339 kg ha^{-1}). There was 3.6% to 4.5% increase in yield during both the seasons by the former. The mean yield increased by 4% through drip irrigation and decreased by 3.9% through surface flow.

Application of irrigation at 100% PE produced highest yield (2709 to 2766 kg ha^{-1}) and 60% PE lowest yield (2184 to 2204 kg ha^{-1}). The former gave 16.7 to 25.5% higher yield in 2006, and 14.6 to 24.0% higher yield in 2007 as compared to 80% PE and 60% PE. It produced 15.6% higher yield than 80% PE, and 24.8% than 60% PE in case of the mean yield. Irrigation at 80% PE gave 3.6% more dry leaf yield than 60% PE.

The yield decreased with reduction in fertilizer dose. Maximum yield (2515 kg to 2535 kg ha^{-1}) was recorded through application of 100 % RD followed by 75% RD (2416 kg to 2442 kg ha^{-1}) and 50% RD (2327 kg to 2363 kg ha^{-1}). The yield increased by 4.0 to 7.7% as compared to the latter two treatments. Reduction of 25% fertilizer from the full dose decreased the yield by 3.9% and that reduction of 50% decreased yield by 7.1%. Application of 75% RD gave 3.6% higher yield than 50% RD. The interaction effect of irrigation and fertilizers was significant. Application of irrigation at 100% PE with 100% RD produced 2903 kg dry leaf per hectare. The coefficient of variation was very low (0.06-0.99%).

Total biomass yield

Drip irrigation produced more biomass (32665 kg ha^{-1}) than the surface irrigation (32011 kg ha^{-1}) method, which was 2.04% higher. Irrigation at 100% PE produced maximum quantity of biomass (33950 to 34952 kg ha^{-1}) with a mean yield of 34451 kg ha^{-1}. Reduction in yield was observed with decrease in the supply of irrigation water. The crop receiving irrigation at 100% PE produced 4.3 to 8.5% more yield than that of 80% PE and 60% PE. Application of irrigation at 80% PE gave 8.1% more yield than 60% PE.

Application of full dose of fertilizer (100% RD) helped to produce maximum biomass yield of 33085 kg to 33920 kg ha^{-1} as compared to 75% and 50% RD. It gave 2.3 to 5.5% higher yield than the latter two treatments. Application of 75% RD gave 3.2% more yield than that of 50% RD. Reduction of 25% fertilizer from the full dose (100% RD) decreased the yield by 2.2% and that of 50% by 5.3%. The interaction effect of irrigation and fertilizer was significant. Application of irrigation at 100% PE with 100% RD produced maximum biomass yield, which was superior to other treatments. The coefficient of variation ranged from 0.49% to 0.74%.

Highest dry leaf yield of 2433 kg ha^{-1} was recorded in case of drip irrigation due to better availability of soil moisture in adequate amounts. Fresh leaf yield showed similar trend. Drip irrigation produced 12% more fresh leaves than surface flow because of better height, number of branches and leaves plant^{-1} and leaf area index. It helped to double the crop growth rate with higher relative growth rate.

Table 4. Regression analysis between dry leaf yield and growth parameters of *Stevia* during 2006 and 2007

Parameter	Intercept		Slope		t-statistic		R^2	Intercept		Slope		t-statistic		R^2
	Coefficient	SE	Coefficient	SE	Intercept	Slope		Coefficient	SE	Coefficient	SE	Intercept	Slope	
Branch	1131.48	825.88	26.34	16.34	1.37	1.61	0.25	1131.78	583.83	24.90	11.15	1.94	2.23	0.38
Height	1352.03	710.21	11.47	7.32	1.90	1.57	0.23	1038.89	569.96	13.66	5.57	1.82	2.45*	0.43
DMP	2113.44	240.90	14.03	9.28	8.77*	0.51	0.22	2059.22	210.99	14.07	7.63	9.76*	1.84	0.29
Leaf no.	905.12	354.13	5.26	1.19	2.55*	4.43*	0.71	638.59	372.50	6.13	1.27	1.71	4.83*	0.74
Leaf area	1710.40	233.17	1006.99	304.34	7.34*	3.31*	0.58	1707.46	203.74	928.59	254.79	8.38*	3.64*	0.62
Biomass	586.89	363.62	0.08	0.02	1.61	5.18*	0.77	796.92	249.28	0.07	0.01	3.19*	6.59*	0.86

t-value at 8 df at 5% probability level (p=0.05) is 2.302, SE = Standard error

Regression analysis

There was positive and significant relation between dry leaf yield with growth parameters. Buana (1989) reported significant relation of dry and fresh weight of leaves with plant height, leaf number and branches in *Stevia* at harvest, but it had no correlation during first four-week period. Chalapathi *et al*. (1999) found that the yield of *Stevia* was significantly influenced by plant height, number of branches, leaves plant^{-1} and dry matter production.

Total dry leaf yield of *Stevia* was highly influenced due to leaf number, leaf area and biomass production as t-statistics computed was 4.43, 3.31 and 5.18 for respective parameters ($t_{0.05}$ = 2.302) (Table 4). The contribution of leaf number, leaf area and biomass production to leaf yield was 71%, 58% and 77%, respectively during 2006. However, the contribution of branches, height and dry matter production was very low in 2007, whereas plant height, leaf number, leaf area and biomass (fresh) significantly contributed to herbage yield and their contribution was 43, 74, 62 and 86%, respectively. Rest of the parameters did not contribute much towards herbage yield as it is expressed in R^2 values, except branches at harvest as this parameter contributed 38% to total leaf production.

Conclusion

It could be concluded that medicinal crop *Stevia* gave maximum fresh leaf (9.13 t ha^{-1}), dry leaf (2.90 t ha^{-1}) and biomass (3.5 t ha^{-1}) yields with drip irrigation at 100% PE and application of 100% RD of fertilizer. More depletion of soil moisture occurred from top layers with frequent irrigations at 100% PE in case of drip than surface irrigation. The regression analysis revealed branches followed by height, dry matter production, number of leaves, leaf area and biomass as major direct contributors to dry leaf yield.

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