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# Effect of agro-techniques on the performance of natural sweetener plant–stevia (*Stevia rebaudiana*) under western Himalayan conditions

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## ABSTRACT

Two separate field experiments were conducted during 2007, 2008 and 2009 to evaluate the effect of agro-techniques on the performance of natural sweetener plant–stevia (*Stevia rebaudiana* Bertoni) under western Himalayan conditions. In the first experiment during 2007 and 2008 two doses of farm yard manure (FYM) and seven inorganic fertilizers were compared with untreated plot (control). Application of 50:60:50 kg NPK/ha recorded significantly higher plant height, stem, flower and total weight/plant (dry) and consequently recorded higher dry leaf yield as compared to other treatments. However, stevioside and rebaudioside contents were found to reduce due to the application of manures/fertilizers. FYM application recorded higher marker compounds than inorganic fertilizers. Owing to higher dry leaf yield, 50:60:50 kg NPK/ha recorded highest steviol glycoside (stevioside and rebaudioside A) yield/ha than other treatments. In second experiment during 2008 and 2009, effect of land configuration and harvesting time on growth, yield and steviol glycosides of stevia was evaluated. Planting stevia in broad bed and furrow (BBF) recorded 31 and 23% higher leaf biomass over flat and camber bed methods, respectively. Steviol glycosides (stevioside and rebaudioside-A) concentration was higher when stevia was planted in camber bed as compared to flat and BBF. Significantly higher leaf biomass was obtained from stevia plants which were harvested once at 50% flower bud stage compared with those harvested once at the 60 and 90 days after transplanting (DAT). Rebaudioside -A content was higher when leaves were harvested at 50% flower bud stage. Owing to higher dry leaf yield, stevia planted in BBF and harvested at 50% flower bud stage recorded highest net return and B:C ratio than other treatments.

***Key words*** : Fertilizers, Harvesting stage, Land Configuration, Manures, Rebaudioside-A, Stevia, Stevioside

Stevia (*Stevia rebaudiana* Bertoni) is an important zero calorie natural sweetener plant. Worldwide, 32,000 hectares are covered under stevia cultivation, of which China has a major chunk of 75% area. Currently Japan is using stevia on large scale (Sumida, 1980). Stevioside and rebaudioside-A are the important sweet steviol glycosides, present in the leaves and are not absorbed by human body during digestion process. Further, the human body does not metabolise the sweet glycosides from the stevia leaf or any of its processed forms. Stevia can play an important role in India which tops the diabetic population in the world with 30 million patients, and this is expected to increase to 80 million by 2025. China ranks second in diabetic population followed by the US and Russia. Incorporation of this species in agricultural production and food system, however, depends upon a thorough knowledge of the plant and its agronomic potential (Ramesh *et al.*, 2006). The Indian farmers have also started taking up stevia cultivation following the large demand for diabetic market here. The country's total annual production is currently nearly 600 tonnes of dry leaf. The climatic conditions in most parts of India are quite favourable for stevia cultivation. In India farmers have started growing stevia in some parts of Rajsthan, Punjab, Uttar Pradesh, West Bengal, Madhya Pradesh, Karnatka, Chattisgarh and West Bengal etc. Stevia is safe for use by both diabetics and hypoglycaemics (Singh and Rao, 2005) due to its low glycaemic index. Food Standards Australia and New Zealand (FSANZ, 2008) has approved the use of steviol glycosides as a food additive, while in the USA the FDA has raised no objection regarding companies' self-affirma-

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tion of GRAS (generally regarded as safe) approval for rebaudioside A.

Nutrient requirements of stevia grown as an annual crop are low to moderate since it grows in poor quality soils in its natural habitat in Paraguay. When placed under commercial culture, for economic crop, manuring is necessary. At maximum dry matter accumulation, stevia plants consist of 1.4% nitrogen (N), 0.3% phosphorus (P), and 2.4% potassium (K) (Katayama *et al.* 1976). Since the leaf is the economic part of this crop, it is presumed that higher nutrient application may produce higher yield. But only few attempts have been made on nutritional aspects of this crop in relation to stevioside content. Ramesh *et al.* (2007) found changes in stevioside content due to intercropping of field crops, apparently due to nutrient additions through intercrops as well as microclimatic modification.

Heavy rainfall has drastic effect on the growth and yield, as stevia is extremely sensitive to water logging. It can rot the plant and result in poor crop stand. Prolonged water logging induces senescence which is harmful to the crop. Thus it is necessary to have proper water disposal system to ward-off adverse effects of sudden and heavy downpour and subsequent water logging. The excess moisture and water logging conditions during rainy season creates unfavourable conditions for growth *viz*., reduced aeration, hampered root development reduced nutrient uptake and conducive environment for disease incidence, finally leading to reduced crop stand in pearlmillet-mustard cropping system (Parihar *et al*., 2010). Modified land configurations, such as furrow irrigated raised bed (FIRB) have shown good promise in enhancing crop performance and water productivity in same crops (Singh *et al.*, 1996; Ahlawat and Gangaiah 2010).

Time of harvest at which maximum yield and quality can be obtained is another important requirement for profitable cultivation of this crop. It is also important to harvest the crop when both leaf biomass and steviol glycoside content are at their maximum. Time of harvest is one of the important non monetary agronomic factors that affect yield and quality of different crops (Prakasa Rao *et al*., 2000, 2005; Kumar and Gill, 2009). The information on nutrient management, effect of land configuration in association with harvesting time is lacking for stevia. In view of the above, the present investigations were undertaken to find out the impact of organic manure, inorganic fertilizers and land configuration on yield and quality of stevia under western Himalayan conditions.

## MATERIALS AND METHODS

Field experiments were conducted during 2007, 2008 and 2009 at the experimental farm of Institute of Himalayan Bioresource Technology (CSIR), Palampur (1,325 m amsl, 32º06´05"N, 76º34´10"E), Himachal Pradesh, India. In the first field experiment, effect of organic manure and chemical fertilizers evaluated during 2007 and 2008 on clay loam soils which was, acidic in reaction (pH 5.2), low in organic carbon content (0.65%), and available N (131.7 kg/ha), medium in available P (23.4 kg/ha), and high in available K (250.2 kg/ha). The experiment was laid out in a randomized complete block design with three replications. Stevia plants were seeded in sand beds and grown during January 2007 and January 2008. Three month old seedlings were transplanted in the field on 28 March, 2007 and 1 April, 2008 at a spacing of 30 × 30 $cm^2$. Well decomposed farmyard manure (FYM) was incorporated into the soil before transplanting every year. Farm yard manure on dry weight basis contained 0.35% N, 0.16% P, and 0.24% K. Inorganic nutrients were applied at the time of transplanting utilizing urea (N 46%), single super phosphate ($P_2O_5$ 16%), and muriate of potash ($K_2O$ 60%). Nitrogen was applied in two equal splits; half dose at the time of transplanting and the remaining half applied after first harvest, whereas, the full doses of phosphorus and potassium were applied at the time of transplanting. The experiment consisted of ten treatments *viz*., $T_1$ (control), $T_2$ (FYM 15 t/ha), $T_3$ (FYM 30 t/ha), $T_4$ (50:0:50 kg NPK/ha), $T_5$ (100:0:50 kg NPK /ha), $T_6$ (150:0:50 kg NPK/ha), $T_7$ (0: 60: 50 kg NPK/ha), $T_8$ (50:60:50 kg NPK/ha), $T_9$ (100: 60: 50 kg NPK/ha), $T_{10}$ (150:60:50 kg NPK /ha) replicated three times in randomised complete block design.

Second field experiment was conducted during 2008 and 2009 on silty clay soils which was acidic in reaction (pH 5.9), medium in available nitrogen (247.4 kg/ha), and phosphorus (24.7 kg/ha) and high in potassium (424.6 kg/ha) and organic matter (1.7%). Weekly maximum temperature ranged from 11.3 to 31.6 °C during 2008 and from 17.7 to 33.7 °C during 2009. The minimum temperature ranged from 3.4 to 20.3 °C during 2008 and 4.6 to 21.0 °C during 2009. During the crop growth season the mean relative humidity ranged between 40 to 89% in 2008 and 44 to 93% in 2009. Total of rainfall 2117.9 mm was recorded during 2008 and 1620.2 mm during 2009 in the crop season.

Three land configuration methods *viz*., broad bed and furrow (BBF), flat bed (FB) and camber bed (CB) (wide raised strips of land with open side drains between them), in the main plot and four harvest stages *viz*., harvesting at 60 days after transplanting (DAT), 90 DAT, 60 DAT and 50% flower bud stages (two harvests), and 50% flower bud stage (single harvest) in the sub plot in a split plot design. For determination of 50% flower bud stage, 10 plants were randomly selected in each plot and when flower bud appears in 5 plants the stage was considered as

50% flower bud stage. Stevia plant was spaced at 30 × 30 $cm^2$. Camber bed made by raising the bed with 30 cm open side drains. The experiment was replicated three times. Main plot size was 25.0 $m^2$ and sub plot size was 8.1 $m^2$. Broad-beds of 60 cm width with a furrow of 30 cm between beds were made and 84 plants were planted in each plot.

Nursery of stevia crop was raised during April 2008 and February 2009 in sand beds through seed. Two month old seedlings were transplanted in the field on 2 June, 2008 and 20 April, 2009.

Good quality well decomposed farmyard manure (FYM) @ 15 t/ha was incorporated into the soil before transplanting, every year. A common fertilizer dose of @100: 50: 50 kg N-P-K/ha was applied to supplement the nutritional demand of stevia crop. These were applied before transplanting in the form of single super phosphate ($P_2O_5$: 16%) and muriate of potash ($K_2O$: 60%). Nitrogen was applied in two equal splits through urea (N: 46%); half dose at the time of transplanting and remaining half applied after first harvest. Need based water management was adopted.

In both experiments biometric observations were recorded at harvest. Five plants/plot were selected for recording plant height, plant spread, number of branches/ plant, number of leaves/plant, leaf length and width. Plant height was measured from the ground level to tip of the top leaf. Stevia plants were cut from the bottom leaving 10 cm up to ground level. Five plant samples were partitioned to leaf, stem and root and the total biomass was calculated. The stem and root were dried at 60 °C, whereas, leaf samples were dried at 40°C in a hot air oven and data were taken when concordant values were obtained. Leaf: stem ratio was calculated on oven dry weight basis by dividing leaf dry weight (t/ha) with stem dry weight (t/ha).

Sweet glycosides from dried leaves of stevia plants were extracted using acetonitrile and water 80:20 and the content of stevioside and rebaudioside-A was calculated through HPLC using standards of stevioside and rebaudioside A. 50 mg air dried powdered leaves of stevia was extracted three times with 10 ml methanol for 6-8 hours. All the extracts were concentrated to dryness under reduced pressure. Dried extract was re dissolved in 5ml of HPLC mobile phase. Dried extract was filtered through 0.45 µm filter and degas for one minute (Kaul, 2009 personal communication). The price of stevia leaf was taken as ₹150/kg of dry leaf and cost of stevia seed was taken as ₹10/g. About 50g of stevia seed is sufficient for raising plantation for one hectare area. The trend of results was similar during both the years, and hence data was subjected to pooled analysis for results and discussion.

## RESULTS AND DISCUSSION

### *Effect of organic manure and chemical fertilizers*

*Plant growth*

Plant spread and number of branches was not affected by different levels of inorganic and organic manures (Table 1). Treatment $T_8$ (50:60:50 kg NPK/ha) demonstrated significantly taller plants than the untreated control. Treatment $T_6$ (150:0:50 kg NPK/ha) produced significantly higher number of leaves than $T_5$ (100:0:50 kg NPK/ ha), $T_{10}$ (150:60:50 kg NPK/ha), and control. Number of leaves in remaining treatments were remained at par with each other. The variation in plant height at harvest may also be responsible for the variation in number of branches/plant and number of leaves/plant. The results are in conformity with the findings of Lee *et al.* (1980). Application of 50:60:50 kg NPK/ha recorded significantly

**Table 1.** Effect of organic and inorganic manures on growth and yield of stevia (Pooled data of 2 years)

| Treatment | Plant height (cm) | Plant spread (cm) | | Leaves (No./ plant) | Branches (No./ plant) | Dry weight (g/plant) | | | Dry leaf weight (t/ha) | Dry stem weight (t/ha) | Dry biomass (t/ha) | Leaf: stem ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N-S | E-W | | | Leaf | Stem | Flower | | | | |
| Control | 71.3 | 25.9 | 23.8 | 183.3 | 3.8 | 3.9 | 7.3 | 1.2 | 0.35 | 0.41 | 0.76 | 0.73 |
| FYM 15 t/ha | 76.3 | 29.7 | 24.5 | 203.9 | 5.3 | 5.5 | 8.7 | 1.9 | 0.43 | 0.48 | 0.91 | 0.76 |
| FYM 30 t/ha | 67.8 | 30.0 | 25.9 | 204.7 | 4.4 | 5.3 | 10.5 | 1.1 | 0.47 | 0.43 | 0.90 | 1.14 |
| NPK 50:0:50 kg/ha | 76.1 | 29.5 | 25.8 | 216.2 | 4.5 | 5.8 | 10.1 | 1.6 | 0.43 | 0.52 | 0.95 | 0.63 |
| NPK 100:0:50 kg/ha | 74.2 | 28.5 | 28.8 | 181.8 | 3.9 | 4.3 | 9.3 | 1.7 | 0.41 | 0.52 | 0.93 | 0.73 |
| NPK 150:0:50 kg/ha | 76.0 | 26.6 | 26.6 | 228.7 | 4.7 | 4.5 | 10.4 | 1.8 | 0.37 | 0.64 | 1.02 | 0.48 |
| NPK 0:60:50 kg/ha | 77.6 | 28.5 | 28.2 | 196.4 | 4.2 | 5.8 | 11.5 | 1.6 | 0.40 | 0.48 | 0.88 | 0.76 |
| NPK 50:60:50 kg/ha | 80.6 | 28.3 | 27.2 | 219.9 | 4.8 | 10.0 | 14.0 | 1.9 | 0.67 | 0.67 | 1.35 | 0.94 |
| NPK 100:60:50 kg/ha | 78.1 | 26.5 | 25.9 | 223.4 | 4.4 | 5.3 | 9.0 | 2.4 | 0.52 | 0.55 | 1.07 | 0.75 |
| NPK 150:60:50 kg/ha | 78.0 | 24.9 | 24.9 | 189.6 | 4.1 | 4.7 | 9.6 | 1.4 | 0.45 | 0.55 | 0.99 | 0.72 |
| SEm± | 2.0 | 1.3 | 1.1 | 10.3 | 0.4 | 0.4 | 1.6 | 0.1 | 0.04 | 0.05 | 0.07 | 0.1 |
| CD (P=0.05) | 5.8 | NS | NS | 29.6 | NS | 1.2 | 7.3 | 0.4 | 0.12 | 0.14 | 0.21 | 0.3 |

higher leaf and stem dry weight/plant than the other FYM treatments and control. Dry flower weight was significantly highest in $T_9$ (100: 60: 50 kg NPK/ha) than the other FYM treatments and the untreated control. The dry matter accumulation of crop in different plant parts during the growth period is important for determination of economic yield. Leaf and stem dry weight production was highest due to addition of 50:60:50 kg NPK/ha. Application of nitrogen up to 50 kg/ha has helped for higher dry matter accumulation which is an absolute essential prerequisite and photosynthetic ability in a given canopy and in turn during the process of developmental sequence.

### *Yield*

Dry leaf weight was also significantly highest in treatment $T_8$ (50:60:50 kg NPK/ha) as compared to all other treatments (Table 1). $T_8$ recorded 91% higher dry leaf weight as compared to control and was followed by $T_9$ (100:60:50 kg NPK/ha), which recorded significantly higher leaf yield than $T_6$ (150:0:50 Kg NPK/ha) and $T_1$ (control) but remained at par with remaining treatments. As compared to untreated soil, stem dry weight was significantly higher in plots treated with $T_8$ (50:60:50 Kg NPK/ha), which was on par to $T_6$ (150:0:50 Kg NPK/ ha), $T_9$ (100:60:50 kg NPK/ha) and $T_4$ (50:0:50 kg NPK/ha). Likewise dry biomass was significantly higher due to $T_8$ as compared to other treatments. Leaf: stem ratio was statistically higher with $T_3$ (FYM 30 t/ha) treatment but it remained at par with $T_8$ and $T_2$ (FYM 15 t/ha) treatments. Chalapathi *et al.* (1999) reported that yield of stevia crop increased with levels of NPK up to 60:30:45 kg/ha under Indian conditions. Application of 40 kg N/feddan/cut (1 Feddan =0.42 ha) gave maximum values of fresh and dry leaf weight under Egyptian conditions (Attia *et al.* 2005). Gradual and significant increase in fresh and dry leaves, stem, biomass yields, total soluble carbohydrate and stevioside content in *S. rebaudiana* over and within cuts as nitrogen fertilizer increased upto 30 kg N feddan there was increase in dry leaves yield and stevioside content by 1.9% when compared with 10 kg N/feddan (Allam *et al.*, 2001).

Katayama *et al.* (1976) reported that to produce 7.6 t/ha biomass, stevia required 105 kg N, 23 kg P and 180 kg K both from soil and fertilizers. Maheshwar (2005) reported that application of 105:30:45 kg NPK/ha recorded significantly higher dry leaf yield due to maximum number of leaves and branches/plant as compared to lower doses of nitrogen under loamy soil in Karnataka, India. Similarly, Lima Filho *et al.* (1997) observed that, shortly before or at flowering, production of 1 t of dry leaves of *S. rebaudiana* required 64.6 kg N, 7.6 kg P and 56.1 kg K/ha. Lee *et al.* (1980) had also recorded increase in leaf yield with moderate application of N, P and K fertilizers in Korea. There are, however, reports that stevia crop show yield reduction at high rates of fertilizer.

### *Quality*

In contrast to the above, the untreated plot recorded significantly higher stevioside, rebaudioside A, and total glycosides than plots treated with chemical fertilizers (Table 2) but remained at par with $T_2$ (FYM 15 t/ha) in terms of stevioside content. FYM (15 and 30 t/ha) treated plots did not differ significantly from each other for stevioside, rebaudioside and total glycosides content but were significantly superior to the plots treated with inorganic fertilizers. Liu and Shi (2011) have also reported that glycoside content in stevia were higher in those plants which were supplied with organic manures as compared to chemical

**Table 2.** Effect of organic and inorganic manures on quality of stevia and chemical content of soil after harvest of stevia (Pooled data of 2 years)

| Treatment | St (%) | Rb (%) | St + Rb (%) | Total steviol glycoside in leaf (kg/ha) | Organic Carbon (%) | Available N (kg/ha) | Available P (kg/ha) | Available K (kg/ha) |
|---|---|---|---|---|---|---|---|---|
| Control | 6.99 | 3.55 | 10.53 | 36.85 | 0.86 | 138 | 26 | 278 |
| FYM 15 t/ha | 5.82 | 2.41 | 8.24 | 35.43 | 0.59 | 152 | 22 | 201 |
| FYM 30 t/ha | 5.38 | 2.60 | 7.98 | 37.51 | 0.85 | 133 | 30 | 345 |
| NPK 50:0:50 kg/ha | 4.76 | 1.95 | 6.71 | 28.85 | 1.03 | 156 | 24 | 208 |
| NPK 100:0:50 kg/ha | 3.74 | 1.29 | 5.03 | 27.51 | 0.80 | 135 | 26 | 305 |
| NPK 150:0:50 kg/ha | 3.58 | 1.64 | 5.22 | 19.31 | 0.95 | 121 | 25 | 311 |
| NPK 0:60:50 kg/ha | 2.83 | 1.08 | 3.91 | 15.65 | 0.66 | 133 | 44 | 238 |
| NPK 50:60:50 kg/ha | 4.35 | 1.85 | 6.20 | 41.54 | 0.45 | 136 | 25 | 258 |
| NPK 100:60:50 kg/ha | 3.58 | 1.52 | 5.10 | 26.53 | 0.66 | 145 | 21 | 263 |
| NPK 150:60:50 kg/ha | 4.08 | 1.74 | 5.82 | 26.19 | 0.99 | 152 | 26 | 381 |
| SEm ± | 0.42 | 0.14 | 0.48 | | 0.22 | 12.0 | 2.4 | 48.6 |
| CD (P=0.05) | 1.22 | 0.42 | 1.38 | – | NS | NS | 6.9 | NS |

fertilizer due to improved root activity and enhanced photosynthesis rate. $T_8$ recorded 12.71% higher total glycoside yield than control.

### *Available SOC, N, P and K content in soil*

A perusal of data presented in Table 2 reveal that the highest N content in soil was recorded due to treatment $T_4$ (50:0:50 NPK kg/ha) followed by $T_{10}$ (150:60:50 NPK kg/ha) and $T_2$ (15 t/ha) though the differences could not attain the level of statistical significance. The soil organic carbon content (%), after harvest, was highest in the treatments $T_4$>$T_{10}$>T6>T1>T3 but the effect of treatments was not significant. Controlled application of NPK and FYM alone resulted in highest soil organic carbon content. Increase in available N content with application of the organic manures might be due to release of nitrogen through decomposition of organic manures (Narwal and Antil 2005). Moreover, it could also be attributed to greater multiplication of soil microbes, which could convert organically bound nitrogen into inorganic form. These results are in agreement to those of Das *et al.* (2006). Available P content in soil was significantly higher with $T_7$ (0:60:50 kg NPK/ha). This might be due to the phosphorus availability through inorganic fertilizers. Available K content in soil was not affected by application of different fertilizers though it was higher in $T_{10}$.

## ***Effect of land configuration and harvesting stage***

### *Plant growth*

Land configuration had significantly influenced the plant height of the crop (Table 3). Stevia crop planted in flat bed (FB) produced significantly taller plants over broad bed furrow (BBF) planting method but remained at par with camber bed (CB) which in turn did not differ significantly from the latter methods of planting. Stevia crop planted in broad bed and furrow recorded significantly higher number of leaves/plant than flat bed method but remained at par with camber bed. In general ridges have more available sunlight and higher temperature than the furrow and flat soil conditions. Kumar and Koppad (2007) reported similar results for stevia in sandy loam soil in Karnatka and Haque *et al*., (2002) for garlic in sandy loam soils of Bangladesh. The higher number of leaves may be ascribed to higher number of branches produced in BBF method followed by CB and FB. Other yield attributes were not affected by land configurations.

Harvesting time of stevia had significantly influenced the yield attributes. Harvesting stevia at 50% flower bud stage recorded significantly taller plants and consequently higher number of leaves/plant than other stages of harvesting. This may be due to continuos growth of stevia plant without any cut. Number of branches/plant were significantly higher when the crop was harvested twice at 60 days after transplanting (DAT) and 50% flower bud stage than harvesting once i.e. at 60 DAT, 90 DAT or 50% flower bud stage alone.

Although stevia planted in BBF planting method recorded higher dry matter production in different plant parts but the effect of land configuration was not signifi-

**Table 3.** Effect of land configuration and harvesting time on yield attributes, marker compounds (%) and economics of stevia (Pooled data of 2 years)

| Treatment | Plant height (cm) | Leaves/ plant | Leaf width (cm) | Branches/ plant | Leaf dry weight (g/ plant) | Stem dry weight (g/ plant) | Root dry weight (g/ plant) | Total dry biomass (g/ plant) | St** | Rb*** | Total (St+ Rb) | Cost of cultivation (×10³ ₹/ha) | Net Return (×10³ ₹/ha) | Net B:C ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Land configuration* | | | | | | | | | | | | | | |
| Broad bed furrow | 56.1 | 166.4 | 3.1 | 4.8 | 13.2 | 14.3 | 4.2 | 31.7 | 3.07 | 1.35 | 4.41 | 55.6 | 121.9 | 2.19 |
| Flat bed | 63.7 | 147.7 | 3.3 | 4.5 | 12.1 | 13.3 | 4.0 | 29.3 | 2.91 | 1.59 | 4.50 | 53.9 | 66.6 | 1.24 |
| Camber bed | 60.4 | 162.8 | 3.2 | 4.6 | 13.2 | 14.3 | 3.8 | 31.3 | 3.72 | 1.83 | 5.55 | 54.8 | 81.5 | 1.49 |
| SEm± | 1.8 | 5.1 | 0.2 | 0.3 | 0.6 | 0.9 | 0.5 | 1.8 | 0.22 | 0.09 | 0.26 | | | |
| CD (P=0.05) | 5.0 | 14.4 | NS | NS | NS | NS | NS | NS | 0.63 | 0.26 | 0.78 | | | |
| *Harvesting time* | | | | | | | | | | | | | | |
| 60 DAT* | 33.7 | 66.0 | 3.4 | 3.1 | 3.7 | 2.2 | 1.0 | 6.9 | 3.23 | 1.84 | 5.07 | 38.5 | 3.4 | 0.09 |
| 90 DAT | 64.2 | 144.0 | 3.8 | 5.1 | 10.8 | 15.5 | 4.5 | 30.7 | 3.17 | 0.80 | 3.96 | 47.3 | 74.2 | 1.57 |
| 60 DAT & 50% flower bud stage | 51.5 | 196.2 | 2.7 | 5.4 | 18.2 | 6.9 | 1.8 | 26.9 | 3.06 | 1.71 | 4.77 | 67.9 | 135.0 | 1.99 |
| 50% flower bud stage | 91.0 | 229.6 | 2.9 | 4.9 | 18.7 | 31.2 | 8.7 | 58.6 | 3.48 | 2.01 | 5.49 | 65.4 | 147.4 | 2.25 |
| SEm± | 1.7 | 4.5 | 0.2 | 0.3 | 0.7 | 0.8 | 0.4 | 1.5 | 0.25 | 0.10 | 0.31 | | | |
| CD (P=0.05) | 5.5 | 15.0 | 0.6 | 1.0 | 2.2 | 2.6 | 1.5 | 5.0 | NS | 0.30 | 0.87 | | | |

*DAT: Days after transplanting; **St: Stevioside; ***Rb: Rebaudioside-A cant. Harvesting stevia crop at different stages has significantly affected dry matter production in different plant parts. Significantly higher dry matter production in leaves was recorded when single cut of stevia was harvested at 50% flower bud stage compared to other treatments but remained at par with stevia harvesting at two stages i.e. 60 DAT and 50% flower bud stage. Dry matter accumulation in stem, root and aboveground biomass was significantly higher when stevia was harvested at 50% flower bud stage.

### *Yield*

Leaf is the main economic part of stevia plant hence production of more leaf biomass with higher steviol glycosides (stevioside and rebaudioside-A) is the main criteria for crop performance. Data presented in Table 4 revealed that BBF method of planting recorded significantly higher leaf dry weight than camber and flat method. Planting stevia in broad bed and furrow resulted in 31% and 23% higher leaf dry yield as compared to flat and camber methods, respectively. This may be ascribed to maintenance of favourable moisture and avoidance of water logging conditions under broad bed and furrow planting. Similar findings were also reported by Kantwa *et al*. (2005) for pigeonpea. There may be higher removal of nutrients and more water use efficiency under BBF method. These results are in agreement to those of Singh *et al*., (1996) and Chalapatthi *et al*. (1997). Like leaf dry weight, aboveground biomass was significantly higher in broad bed furrow. This may be due to the better soil environments provided in case of broad bed and furrow methods. Malik *et al*. (2001) reported that loose soil surface is available in ridge sowing which enhances the root growth, nutrient and water uptake. Likewise in BBF method due to better surface drainage, evaporation losses are also reduced because of the slope developed by the furrow. These results are in agreement to those of Ahmad *et al*. (2000). Higher leaf and biological yield of stevia in broad bed and furrow methods was due to more branches and significantly higher leaf number/plant. Broad bed and furrow method also acts as drainage structure during heavy rainfall and conserve more moisture during light shower.

Harvesting stevia once at 50% flower bud stage recorded significantly higher leaf dry weight, above ground biomass than other treatments but remained statistically at par with harvesting stevia two times i.e. at 60 DAT and 50% flower bud stage for leaf dry weight (Table 3). This may be due to significantly higher branches and number of leaves/plant. Consequently leaf stem ratio was also significantly higher when the stevia was harvested at 50% bud-

**Table 4.** Dry biomass as influenced by interactive effect of land configuration and harvesting time of stevia (Pooled data of 2 years)

| Treatment | Harvesting time | | | | Mean |
|---|---|---|---|---|---|
| | 60 DAT* | 90 DAT | 60 DAT & 50% flower bud stage | 50% flower bud stage | |
| *Land Configuration* | | | *Total leaf biomass (t/ha)* | | |
| Broad bed and furrow | 0.27 | 0.94 | 1.65 | 1.79 | 1.16 |
| Flat bed | 0.31 | 0.69 | 1.09 | 1.12 | 0.80 |
| Camber bed | 0.24 | 0.74 | 1.31 | 1.27 | 0.89 |
| Mean | 0.27 | 0.79 | 1.35 | 1.39 | |
| SEm± for land configuration | | 0.07 | CD (P=0.05) for land configuration | 0.21 | |
| SEm± for harvesting stage | | 0.05 | CD (P=0.05) for harvesting stage | 0.17 | |
| SEm± for interaction | | 0.10 | CD (P=0.05) for interaction | 0.29 | |
| | | | *Total biomass (t/ha)* | | |
| Broad bed and furrow | 0.44 | 2.31 | 2.21 | 4.72 | 2.42 |
| Flat bed | 0.46 | 1.57 | 1.56 | 3.09 | 1.67 |
| Camber bed | 0.39 | 1.75 | 1.83 | 3.43 | 1.85 |
| Mean | 0.43 | 1.88 | 1.87 | 3.74 | |
| SEm± for land configuration | | 0.15 | CD (P=0.05) for land configuration | 0.43 | |
| SEm± for harvesting stage | | 0.09 | CD (P=0.05) for harvesting stage | 0.31 | |
| SEm± for interaction | | 0.19 | CD (P=0.05) for interaction | 0.54 | |
| | | | *Leaf: stem ratio* | | |
| Broad bed furrow | 1.63 | 0.84 | 2.26 | 0.61 | 1.33 |
| Flat bed | 1.92 | 1.09 | 1.88 | 0.63 | 1.38 |
| Camber bed | 1.68 | 1.25 | 2.15 | 0.67 | 1.44 |
| Mean | 1.74 | 1.06 | 2.10 | 0.63 | |
| SEm± for land configuration | | 0.02 | CD (P=0.05) for land configuration | NS | |
| SEm± for harvesting stage | | 0.01 | CD (P=0.05) for harvesting stage | 0.03 | |
| SEm± for interaction | | 0.18 | CD (P=0.05) for interaction | NS | |

*DAT Days after transplanting

ding stage. It is well established that dry-matter yield increases when the growth period before harvesting is extended. Interaction effect of planting methods and harvesting stage on leaf and total biomass was also significant (Table 4). The land configuration affected the dry leaf and total biomass yield at 90 DAT, 60 DAT and 50% flower bud and 50% flower bud stage and not at 60 DAT. Although land configurations could not bring any significant difference in leaf: stem ratio of stevia but it was higher in CB methods of planting which may be due to lower stem biomass.

### *Quality*

Stevioside and rebaudioside (steviol glycoside) are the main glycoside which are responsible for the quality of stevia. Their concentration in the plant determines the sweetness and bitterness. A perusal of data presented in Table 3 shows that harvesting time of stevia recorded significant effect on rebaudioside concentration and total glycosides. Stevioside, rebaudioside –A and total glycoside concentration was significantly higher when the plants were planted in camber bed as compared to BBF and FB. Harvesting stevia at 50% flower bud stage resulted in significantly higher concentration of rebaudioside-A and total glycosides as compared to other stages. Stevioside concentration was not affected by harvesting of the crop. Sumida (1980) also reported that stevia should be harvested just prior to flowering when steviol glycoside content in the leaves is at its maximum.

### *Economics*

Economics is the main parameter which finally decides the adoption of any recommended agrotechnology by the farmers or industrialist. The economical indicator indicated that planting stevia in broad bed and furrow recorded highest net return (₹1,21,900/ha) and benefit: cost ratio (2.19) (Table 3) which may be to due higher leaf yield under this method of planting. Harvesting stevia once at 50% flower bud stage recorded highest net return (₹1,47,400/ha) and benefit: cost ratio (2.25) than harvesting at two stages or at early stage of plant growth.

It can be concluded from these studies that the growth, development, yield and marker compounds (stevioside and rebaudioside-A) can be improved by agrotechniques. When stevia plants were given 50:60:50 kg NPK/ha they recorded significantly higher plant height, leaf, stem, flower, total weight/plant (dry), higher dry leaf yield (t/ha) and 12.71% higher total glycoside yield than control. Therefore, application of 50:60:50 kg NPK/ha has been beneficial for stevia. Planting stevia in BBF in high rainfall area is beneficial. The potential advantages of this method may be due to less trafficking for intercultural operations. While taking stevia as annual crop in high rainfall area harvesting can be done once at 50% flower bud stage.

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