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Determination of Optimal Soil Moisture Depletion Level for Stevia (*Stevia Rebaudiana Bertoni*) at Wondo Genet, South Ethiopia

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Abstract

The study was conducted based on the objective to evaluate the optimal soil moisture depletion level of stevia (*Stevia rebaudiana Bertoni*). Six levels of soil moisture depletion (20, 30, 40, 50, 60, and 100%) with four replications were used in a randomized complete block design. Different levels of total available water depletion significantly ($p<0.05$) affected all recorded yield and yield components. Significantly highest plant height, fresh and dry leaf weight, fresh and dry stem weight, aboveground fresh and dry biomass, and water productivity were obtained as stevia was irrigated below 40% TAW depletion level. However, water productivity was decreased both at higher and lower depletion levels and higher was at 30 and 40% depletion levels. The pooled mean revealed that irrigating stevia under different soil moisture depletion levels had a significant ($p<0.05$) effect on fresh leaf weight, fresh stem weight, dry stem weight, fresh biomass, and water productivity. Moreover, plant height, dry leaf weight, and dry biomass of stevia were also highly significantly ($p<0.01$) affected due to different soil moisture depletion levels. The maximum plant height (23.95 cm), fresh leaf weight (3300.3 kg/ha), fresh stem weight (1213.3 kg/ha), fresh biomass (4513.6 kg/ha) and water productivity (1.92 kg/m3) were recorded at 30% TAW. Moreover, the maximum dry leaf weight (1155.8 kg/ha), dry stem weight (869.0 kg/ha) and dry aboveground biomass (2024.7 kg/ha) were recorded at 40% TAW. On the other hand, the minimum growth, yield and yield component, and water productivity were recorded at 100% TAW. The current study revealed that irrigating stevia after 40% of the total available water in the soil depleted could be practiced in the study area and similar agroecology and soil type as the wider irrigation interval could be achieved without significantly affecting yield and water productivity.

Keywords: Essential oil • Soil moisture depletion • Stevia • Water productivity

Introduction

Stevia (Stevia rebaudian Bertoni) is an herbaceous perennial plant that belongs to the family Asteraceae which is originated from Paraguay. Leaves of the stevia plant contain low-calorie sweetening agents that can be used as a natural alternative to sweetening different products. Moreover, the leaves are consumed in special human diets and for the treatments of various diseases. The sweetness level of fresh leaves stevia reported as 15 – 30 times than common sugar and the leaf extracts as 250 – 330 times the common sugar. The plant is adaptive to the Ethiopian climate for the production of sweet leaves and stevioside under different agroecology even though yield varies considerably from highest 3034 to lowest 992 kg/ha within a year [1].

Stevia yield was reported to range from 2.85 t/ ha to 3.48 t/ha for different varieties under different irrigation conditions including reduced irrigation in central Greece [2]. Reducing irrigation water application to 33 and 66% refill to field capacity level leads to a significant reduction in yield and yield component. However, application of full irrigation to field capacity level leads to 40% higher leaf dry yield than irrigated with 33% irrigation to field capacity level [3]. However, Vasilakoglou et al. (2016) reported that satisfactory dry leaf biomass yield could be achieved even when stevia is grown under reduced irrigation to the level of 75% of evapotranspiration [4] reported that water stresses significantly reduced stevia yield and yield components as compared with the full irrigation based on 100% evapotranspiration. Moreover, the same author reported that total steviol glycosides yield reduced by 37.66% when the irrigation level reduced to 50% than the full irrigation despite the total glycosides content increased by 24.71% due to the moisture stress than the full irrigation.

Stevia is a shallow-rooted crop in which the plant obtains soil moisture and nutrient in the limited upper soil profile. This leads to being considered an inefficient root system and the applied irrigation water is at risk of leaching below the shallow rooting zone [5,6]. Different studies also recommend that stevia should be irrigated with shallow irrigation as its main roots tend to be located close to the surface of the soil surface [7]. Similarly, different research reports revealed that stevia is sensitive to water deficit which mainly affects its growth and yield despite it improves the content of steviol glycosides [4]. Beyond leaching of irrigation water below the root zone, shallow root in crops leads to leaching of essential nutrients like nitrogen, especially under high irrigation depth [8]. Reported that water productivity is affected by water dose and nitrogen level, as higher water dose leads to leach both water and nutrient from the shallow-rooted crops to affect yield.

Therefore, like many crops, stevia production could be affected by different agronomic practices like population density and agroecology [9,10]. Availability of soil moisture is among the major factor that affects crop yield including stevia which the yield is affected under different irrigation level [3] Different findings revealed that optimum irrigation scheduling based on soil moisture depletion levels varies for different crops. Determination of the optimum level of soil moisture before the next irrigation leads to maximize crop yield and water productivity. This is important especially for shallow-rooted crops as the effect of low moisture content in the topsoil leads to reduced yield, since moisture below the root zone will not be available for crops. However, there is a limitation of information regarding optimum soil moisture depletion level for irrigation scheduling of stevia in the study area. Therefore, the current study was initiated to identify the optimum soil moisture depletion level of stevia for better yield and water productivity.

Materials and Methods

The Study Area

A Field experiment was carried out at Wondo Genet Agricultural Research Center, Ethiopia latitude 8°25'59", longitude 39°01'44" and altitude of 1800 m. a. s. l. for three years during 2016/17 to 2018/19 dry season to determine

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optimum soil moisture depletion level for stevia (Stevia rebaudian Bertoni). Clay loam is the dominant soil texture in the study area in which the field capacity and permanent wilting point of the soil in the rooting depth were found to be 30.8 and 19.0%, respectively. The bulk density of the soil was 1.1 g/cm^3. This lead to a volumetric available water holding capacity per unit meter of the soil profile in the root zone to be 130 mm. The study area receives a mean annual rainfall of 1121.80 mm from which the majority, 72.3% of the annual rainfall, falls in the main rainy season which is April to September (Table 1).

Experimental Design and Procedure

The field experiment was carried out using randomized complete block design (RCBD) with four replications following the design procedure for RCBD by Gomez and Gomez (1984). The plot size used was 3.00 m × 3.00 m with a spacing of 1.50 m between plots and 3.00 m between blocks. Six levels of soil moisture depletion (20, 30, 40, 50, 60, and 100% TAW) were used as treatments and each treatment were assigned randomly for each plot in each block. Stevia (Stevia rebaudian Bertoni) seedling was prepared in nursery raising for two months before plantation time during the rainy season. For seedling preparation, a top cutting position with three nodes was used as per the recommendation for the area for better seedling using stem cuttings from one-year-old stevia collected from multiplication plots at Wondo Genet Agricultural Research Center [11].

After the good establishment of seedling at nursery with an average height of 15 cm, it was transplanted to the field with population density recommended for the area which was 40 cm between rows and 20 cm between plants in the row. Before planting the land preparation was done with plowing, land leveling, and layout according to the experiment. During the study period, regular tillage and agricultural operation for stevia in the study area were followed beyond the irrigation level as it is applied as treatment.

Irrigation water depth and irrigation interval were different for all treatments as the irrigation amount and interval governed by the soil moisture depletion levels were used as treatment. Accordingly, irrigation depth that brings the soil to field capacity was applied for each treatment when the specified soil moisture depletion attained. All other agronomic practices were similar for all plots as per the recommendation for the area. The calculated gross irrigation depth for each treatment was applied using a Parshall flume of size 2-inch when the specific depletion level of each treatment was attained. Soil samples before irrigation were taken to determine the moisture content of the soil using the gravimetric method. Next irrigation applied when the moisture depletion level from the total available water in the soil attain the treatment depletion level for all season.

Data Collection

Yield and yield component data was collected from the randomly selected five central plants from each plot. Border rows and plants were excluded from the sampling to minimize the border effect on yield and yield components of stevia. The selected five samples were harvested 120 days after planting for the first year harvest and 60 days after the first year harvest, only during the dry season, as the crop is perennial. Harvesting was done manually by cutting the samples 5 cm above the ground level using a sickle. Then after the collected samples were punched to separate leaf and steam and weighted separately for each plot. Finally, the samples were submitted to Wondo Genet Agricultural Research Center, Natural Product Laboratory for analysis of leaf and steam moisture content using oven dry. Based on the leaf yield and amount of irrigation used for each plot, water productivity was calculated using the following formula.

$$WUE\left(\frac{kg}{m^3}\right) = \frac{Leaf\ fresh\ yield\ \left(\frac{kg}{ha}\right)}{Irrigation\ water\ applied\ \left(\frac{m^3}{ha}\right)}$$

Data Analysis

The data collected were statistically analyzed using statistical analysis system (SAS) software version 9.3 using the general linear programming procedure (GLM). Mean comparison was carried out using the least significant difference (LSD) at a 5% probability level to compare the differences among the treatment means.

Result and Discussion

Different levels of soil moisture depletion levels significantly affected all recorded yield and yield components of stevia including its water productivity. Significantly higher yield and yield components were associated with frequently irrigated treatment under lower soil moisture depletion levels before irrigation. As per the results of these studies, irrigation of stevia when 40% TAW depleted associated with better yield and yield components and water productivity as well as compared with higher depletion levels. Yield and yield components, as well as water productivity, reduced as the depletion level increased. Therefore, a better yield with a longer irrigation interval due to higher total available soil water at 40% TAW depletion could be selected as a better irrigation strategy for the production of stevia.

Plant Height

The study revealed that plant height of stevia was highly significantly ($p<0.01$) affected by different levels of soil moisture depletion levels. The study showed a decreasing trend in plant height as the soil moisture depletion level increased. The maximum plant height (23.95 cm) was recorded at a 30% TAW depletion level (Table 2). However, this was statistically similar to that of 20 and 40% TAW depletion levels. On the other hand, the minimum plant height (15.98 cm) was recorded at 100% TAW depletion level which is statistically similar to that of 50% TAW depletion level (Table 2). Increasing soil moisture depletion level to 100% TAW leads to a reduction of 33.3% as compared with the maximum plant height recorded at 30% TAW depletion

Table 1. Long-term monthly climatic data of the experimental area.

Month	T_{min} (˚C)	T_{max} (˚C)	RH (%)	Wind speed (m/s)	Sunshine (%)	RF (mm)
January	9.7	28.0	51	1.26	75	29.4
February	11.2	28.2	50	1.27	71	55.5
March	12.0	28.4	55	1.50	66	91.0
April	12.5	27.0	62	1.31	60	121.8
May	12.5	26.2	70	1.30	60	135.7
June	12.4	24.8	72	1.54	54	107.5
July	12.8	23.3	53	1.12	38	158.4
August	12.9	23.8	71	1.11	42	152.0
September	12.2	24.7	73	0.92	46	135.6
October	11.2	26.0	65	0.91	78	80.4
November	9.3	27.3	54	1.06	77	38.6
December	9.8	26.9	69	1.21	62	15.9

Source: Wondo genet college of forestry metrology station.

level. Different studies revealed that higher soil moisture depletion before the next irrigation leads to reduced different plant growth conditions including plant height due to drought stress experience during the growth stages beyond the threshold level of soil moisture depletion level of different crops.

The current finding is in line with the report of [3] who reported that plant height was affected due to moisture stress due to reduced irrigation beyond the full application. Similarly, [4] reported that a reduction of irrigation amount by 50% from the full irrigation leads to a reduction of stevia plant height by 22.44%. The reduction in plant height might be associated with stress in the crop at higher soil moisture depletion levels which reduces photosynthesis products as water is its major component. Moreover, reduced cell enlargement might be due to low turgor pressure resulted in drought stress conditions in plants [12].

Fresh and Dry Leaf Weight

Different levels of soil moisture depletion significantly ($p<0.05$) affected fresh leaf weight production of stevia. Similarly, dry leaf weight was highly significantly ($p<0.01$) influenced by different level of soil moisture depletion levels. A decreasing trend was observed both in fresh and dry leaf weight production of stevia due to increasing levels of soil moisture depletion. The maximum fresh and dry leaf weight (3300.3 and 1155.8 kg/ ha) was recorded at 30 and 40% TAW depletion levels, respectively (Table 2). Both maximum fresh and dry leaf weight was statistically similar when stevia irrigated under lower depletion level at 20, 30, and 40% TAW. On the other hand, the minimum fresh and dry leaf weight (2463.1 763.6 kg/ ha) was recorded at a 100% TAW depletion level. These minimum yields on fresh and dry leaf weight were statistically similar to that of 50 and 60% TAW depletion levels in both parameters (Table 2).

Increasing soil moisture depletion level to 100% TAW leads to a reduction of 25.4 and 33.9% as compared with the maximum fresh and dry leaf weight recorded at 30 and 40% TAW depletion levels, respectively. Similar findings were also reported by [4] that stevia is sensitive to water deficit that affects growth and yield of the crop. These could be due to moisture stress due to low irrigation depth below optimum or longer irrigation interval due to higher soil moisture depletion level which creates seasonal drought stress during the growth stages [3]. Also reported that stevia leaf dry weight showed an increasing trend when full irrigation applied than lower irrigation water applied. As a major component of photosynthesis, soil moisture deficit in the growth stages of different crops could affect the final growth and yield of a crop [13] also reported that irrigation of lemongrass, an aromatic and medicinal plant, at different depletion levels significantly affected yield, and the higher yields were associated with lower depletion levels below 60% total available soil moisture depletion. That is due to the low production output of inefficient photosynthesis leads to lower production of biomass. Higher soil moisture depletion has a great effect on the yield of crops due to the drought stress developed especially for moisture-sensitive crops like stevia [4] A similar finding was also reported by [12] that irrigation application at 60% FC (field capacity of the soil) which is equivalent to 40% TAW depletion had no negative effect on stevia leaf yield dry weight. These indicated that the crop should be frequently irrigated with shallow irrigation as its roots are mainly concentrated near to the soil surface [7].

Fresh and Dry Stem Weight

Different soil moisture depletion levels significantly ($p<0.05$) affected both fresh and dry stem weight production of stevia. Similar to leaf weight, steam weight also showed a decreasing trend as the moisture depletion levels increased. The maximum fresh and dry stem weight (1213.3 and 859.2 kg/ ha) was recorded at 30 and 40% TAW depletion levels, respectively (Table 2). However, both parameters were statistically similar with that of 20% TAW depletion levels. On the other hand, the minimum fresh and dry stem weight (791.6 and 560.9kg/ ha) was recorded at a 100% TAW depletion level (Table 2). Fresh stem weight was statistically similar to that of 60, 50, and 40% TAW depletion levels and dry biomass was statistically inferior only with that of 30 and 40% TAW treatments. Similar findings were also reported by [4] that stevia is sensitive to water deficit that affects growth and yield of the crop [7]. Also reported that application of irrigation beyond 60% FC (field capacity of the soil) affects plant growth in stevia. The reduction in plant growth including stem of stevia at higher soil moisture depletion level might be associated with low turgor pressure response of crops during the drought in their growth stages which reduce cell enlargement (Table 2).

Fresh and Dry Aboveground Biomass

Pooled means of the three-year study revealed that different levels of soil moisture depletion significantly ($p<0.05$) affected fresh biomass production of stevia in the study area. Similarly, dry biomass was highly significantly ($p<0.01$) influenced by different levels of soil moisture depletion. Both fresh and dry aboveground biomass showed a decreasing trend as the moisture depletion levels increased from 20 to 100% TAW of the soil. The maximum fresh and dry aboveground biomass (4513.6 and 2024.7 kg/ ha) was recorded at 30 and 40% TAW depletion levels, respectively (Table 2). However, statistically, both fresh and dry aboveground biomass at 20, 30 and 40% TAW depletion levels are similar. On the other hand, the minimum fresh and dry aboveground biomass weight (3254.7 and 1324.4 kg/ ha) was recorded at 100% TAW depletion level. The minimum fresh aboveground biomass was statistically similar to that of 60, 50, and 40% TAW depletion levels. On the other hand, the minimum dry aboveground biomass was statistically similar to that of 60 and 50% TAW depletion levels (Table 2). The current finding revealed that increasing soil moisture depletion levels to 100% TAW of the soil before the next irrigation leads to a reduction of fresh and dry aboveground biomass by 27.9 and 34.6% as compared with the maximum fresh leaf weight recorded at 30 and 40% TAW depletion levels, respectively.

Similar findings were also reported [4] that stevia is sensitive to water deficit that affects growth and yield of the crop. The current finding is also in agreement with the findings of [7] who reported that increasing soil moisture depletion level to 45% FC which leads to a longer irrigation interval of 12 days significantly affected growth reduction of stevia. Different studies showed that as the soil gets dried beyond some threshold level crops experience

Table 2. Response of stevia yield and yield component for soil moisture depletion levels.

Treatments	PH (cm)**	FLW (kg/ha)*	DLW (kg/ ha)**	FSW (kg/ ha)*	DSW (kg/ ha)*	FAgBM (kg/ ha)*	DAgBM (kg/ ha)**	WP (kg/ m^3)*
20% TAW	22.55^{ab}	3088.9^{ab}	1032.5^{ab}	1137.4^{ab}	694.3^{ab}	4226.3^{ab}	1726.8^{ab}	1.47^{bc}
30% TAW	23.95^{a}	3300.3^{a}	1152.3^{a}	1213.3^{a}	859.2^{a}	4513.6^{a}	2011.5^{a}	1.92^{a}
40% TAW	20.75^{abc}	3056.9^{ab}	1155.8^{a}	998.3^{abc}	869.0^{a}	3931.0^{abc}	2024.7^{a}	1.84^{ab}
50% TAW	18.90^{cd}	2603.0^{bc}	920.8^{bc}	900.7^{bc}	600.5^{b}	3490.3^{bc}	1521.3^{bc}	1.36^{c}
60% TAW	19.35^{bc}	2591.9^{bc}	911.2^{bc}	887.3^{c}	708.8^{ab}	3492.6^{bc}	1619.8^{bc}	1.50^{abc}
100% TAW	15.98^{d}	2463.1^{c}	763.6^{c}	791.6^{c}	560.9^{b}	3254.7^{c}	1324.4^{c}	1.28^{c}
CV (%)	10.78	11.9	11.1	16.5	17.5	13	12.1	18.5
$LSD_{0.05}$	3.29	512.6	165.13	246.1	188.72	746.1	310.15	0.4

Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at $p<0.05$ level of significance; ns: non-significant at $p<0.05$; *significant at $p<0.05$; **significant at $p<0.01$; PH: plant height; FLW: fresh leaf weight; DLW: dry leaf weight; FSW: fresh stem weight; DSW: dry stem weight; FAgBM: fresh aboveground biomass; DAgBM: dry aboveground biomass; WP: water productivity; CV: coefficient of variation; $LSD_{0.05}$: Fisher's least significant difference at 5% probability level.

stress due to photosynthesis interruption due to water supply shortage. As more than 90% of the biomass production of different crops is due to photosynthesis activity, limitation in moisture as soil moisture depletion level increase might lead to reducing biomass production. To overcome such conditions, stevia, a shallow-rooted crop, should be irrigated frequently when 40% of the TAW in the soil is depleted [14].

Water Productivity

Pooled means of three-year results revealed that different levels of soil moisture depletion significantly ($p<0.05$) affected the water productivity of stevia in the study area. The study revealed that water productivity showed a decreasing trend both as the moisture depletion levels increased and decreased from 30% TAW of the soil. The maximum water productivity (1.92 kg/ m^3) was recorded at a 30% TAW depletion level (Table 2) which was statistically similar to that of 40 and 60% TAW depletion levels. On the other hand, the minimum fresh biomass weight (1.28 kg/ m^3) was recorded at 100% TAW depletion level which is statistically similar to that of 60, 50, and 20% TAW depletion levels (Table 2). Increasing soil moisture depletion levels to 100% TAW of the soil before the next irrigation leads to a reduction of water productivity by 33.3% as compared with the maximum water productivity recorded at 30% TAW depletion level. These indicated that part of the water used under 100% TAW depletion level leads to inefficient utilization of the irrigation water by the crop [15].

The current study is in agreement with [3] who reported that water productivity was decreased with the increase in irrigation regime. However, this study also revealed that beyond 60% TAW depletion level water productivity showed a decreasing trend with the decrease in irrigation regime. These might be due to the lower yield obtained at 100% TAW soil water depletion level. Moreover, reported that soil water stress leads to an improvement of antioxidant and soluble sugar content in stevia due to the physiological and biochemical response of stevia plants for drought stress. Such conditions might be important when statistically similar yields are observed at 40% TAW as compared with lower depletion levels like 20 and 30% TAW.

Conclusion and Recommendation

The current study revealed that stevia yield and yield components showed a decreasing trend when it is irrigated above 40% of TAW depletion levels. However, yield and yield components were statistically similar when irrigated at 20, 30, and 40% TAW depletion levels. However, water productivity showed a decreasing trend when stevia irrigated below 30 and above 40% TAW depletion levels. The finding indicated that irrigation of stevia should be practiced at 40% TAW depletion levels or below to improve yield and yield components. However, under limited water resource conditions, the main aim is to improve water productivity through minimizing water wastage and enhancing the crop water productivity through different practices that 40% TAW could be practiced than the lower depletion levels. Besides improving water productivity practicing longer irrigation interval at 40% TAW than frequently irrigation at 20% TAW, it will minimize the labor requirement especially for furrow irrigation methods where smallholder farmers practicing irrigation in the area. Therefore, irrigating stevia after 40% of the total available water in the soil depleted could be practiced in the study area and similar agro-ecology and soil type as the wider irrigation interval could be achieved without significantly affecting yield and water productivity.

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