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Determination of Optimal Soil Moisture Depletion Levels for Sweet Basil (*Ocimum basilicum* L.) at Wondo Genet, Ethiopia

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Abstract

Determining allowable soil moisture depletion level is critical for determining proper irrigation scheduling. The study was conducted at Wondo Genet Agricultural Research Center, Ethiopia, latitude 8°25'59", longitude 39°01'44"and altitude of 1800 m.a.s.l to determine optimal soil moisture depletion level for sweet basil (*Ocimum basilicum* L.). Six levels of soil moisture depletion (20, 30, 40, 50, 60 and 100% of total available water (TAW) of the soil), with three replication were used as treatments to evaluate the yield and yield component of sweet basil in randomized complete block design. Different levels of soil moisture depletion levels significantly affected all recorded yield and yield components of sweet basil including its water productivity. Significantly higher yield and yield components were associated with frequently irrigated treatment under lower soil moisture depletion levels before irrigation. However, when sweet basil was irrigated beyond 40% TAW lowest yield and yield components were recorded. Therefore, sweet basil could be irrigated when the soil moisture content is depleted by 40% of the total available water content in the soil to enhance yield and water use efficiency in the study area and similar agro ecologies.

Keywords: Depletion Level, Essential Oil, Sweet Basil, Water Use Efficiency

Introduction

Basil (*Ocimum basilicum* L.) is an aromatic plant belonging to the *Lamiaceae* family that is used in the food, pharmaceutical, cosmetics, ornamental and pesticide industries (Daza-torres *et al*., 2017) [3]. *Ocimum basilicum* is an erect, almost glabrous herb, which grows to between 30 and 90 cm high. The leaves are ovate, lanceolate, cucuminate, toothed or entire, glabrous on both surfaces and glandular (Pushpangadan *et al*., 2012) [8]. It is also a culinary herb and its essential oils used for in the flavoring of confectionary and baked goods, condiments (like ketchups, tomato pastes, chili sauces, pickles, and vinegars), sausages and meats, salad dressings, nonalcoholic beverages, ice cream, and ices (Suppakul *et al*., 2003) [10].

The flowers of basil are white or pale purple and are borne in long terminal racemose inflorescences, in simple or many branched racemes. The flowers yield an average of 0.4 % oil while the whole plant contains 0.1–0.25 % oil. By taking the initial three to four harvests of flowers (including main and sub inflorescences) and final harvest of the whole herb, approximately 3–4 t of flowers and 13 t of whole herb per hectare can be obtained, corresponding to about 13 kg of the flower oil and about 27 kg of whole herb oil, a total of 40 kg of oil per hectare (Pushpangadan *et al*., 2012) [8].

The oils of basil are conventionally extracted by steam distillation from leaves and flowering tops and an alternative to the conventional steam distillation method is carbon dioxide (CO2) extraction, under liquid or supercritical conditions (Suppakul *et al*., 2003) [10].

Plant response to irrigation is influenced by the physical condition, fertility and biological status of the soil. Soil condition, texture, structure, depth, organic matter, bulk density, salinity, sodicity, acidity, drainage, topography, fertility and chemical characteristics all affect the extent to which a plant root system penetrates into and uses available moisture and nutrients in the soil (Savva & Frenken, 2002) [9].

The importance of water in plants arises from its role in supporting photosynthesis, regulating temperature via evaporative cooling, maintaining structure through cell turgor pressure, and transporting nutrients into and throughout the plant, thereby supporting its growth. While irrigation guarantees crop growth in regions where rainfall is insufficient to support crop growth and yield, it must be scheduled properly (Gu *et al*., 2020) [4]. Determining allowable soil moisture depletion level is critical for determining proper irrigation scheduling. In the study area allowable soil moisture depletion levels were determined for Stevia by Meskelu *et al*., 2021 [6] and Lemongrass by Tesfaye *et al*., 2017. However, there is a limitation of information regarding optimum soil moisture depletion level for irrigation scheduling of Sweet basil in the study area. Therefore, the current study was conducted to identify the optimum soil moisture depletion level of Sweet basil for better yield and water productivity.

Materials and Methods

Description of the experimental site

The study was carried out at Wondo Genet Agricultural Research Center, Ethiopia, 8°26' N latitude, 39°02' E longitude and mean altitude of 1800 m.a.s.l. for three dry seasons (2020/21, 2021/22 and 2022/23) based on an objective to determine the optimum irrigation scheduling based on the soil moisture depletion levels for sweet basil (*Ocimum basilicum* L.). The soil at the experimental site was sandy clay loam in textures with moisture content at field capacity and permanent wilting point of 30.8 and 19.0%, respectively. The pH of the soil was found to be 6.9. The bulk density was found to be 1.1g/cm^3 and the total volumetric available water in the root zone was 130mm/m. The climate of the area is characterized as semi-humid with a total annual rainfall of 1121.8 mm among which 72.3% of the rain falls from April to September which is the main cropping season for the area. The mean maximum temperature varies from 23.3 to 28.4^{O}C; while the mean minimum temperature varies from 9.3 to 12.5^{O}C (Table 1).

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

Month	T_{min} (^{O}C)	T_{max} (^{O}C)	RH (kpa)	Wind speed (m/s)	Sunshine hours (%)	RF (mm)
January	9.68	27.97	1.27	1.26	75	29.42
February	11.15	28.22	1.29	1.27	71	55.53
March	11.97	28.38	1.44	1.50	66	91.00
April	12.49	26.98	1.55	1.31	60	121.76
May	12.48	26.21	1.69	1.30	60	135.74
June	12.37	24.81	1.64	1.54	54	107.50
July	12.77	23.32	1.14	1.12	38	158.38
August	12.85	23.75	1.57	1.11	42	151.96
September	12.24	24.69	1.66	0.92	46	135.55
October	11.15	25.99	1.52	0.91	78	80.42
November	9.32	27.34	1.29	1.06	77	38.61
December	9.76	26.89	1.64	1.21	62	15.93

Source: Wondo Genet College of Forestry Metrology Station

Experimental design and procedure

The field experiment was carried out using the design procedure set by Gomez and Gomez (1984) for a randomized complete block design with three replications. Each experimental unit was 4.00 m × 3.00 m with spacing of 1.50 m between plots and 3.00 m between blocks. Six treatments of total available water (20, 30, 40, 50, 60, and 100% TAW) were randomly assigned for each plot in each block.

Basil seed were sown in a polyethylene tube and all necessary cultural practices were carried out when seedlings were raised in nursery. After the experimental land prepared well for better performance of the crop, uniformly growing seedlings were selected, hardened and transplanted to the experimental fields after 60 days of planting in the polyethylene tube depending on their performance with in 40 cm by 60 cm between plant and row of plant spacing respectively. Regular agricultural management like weeding and hoeing in the study area were common during the experimental period for all plots uniformly.

Irrigation water was applied based on the treatment soil moisture depletion level to bring the soil to field capacity. The calculated gross irrigation depth was applied for each plot by measuring the irrigation water using 2-inch Parshall flume. Soil sample before and after irrigation was taken to determine the moisture content of the soil until the soil moisture depletion level approached to treatment level for all harvesting cycle.

Data collection and analysis

Basil yield and yield components were collected from central five plants in the plot excluding border rows. Field data on plant height was collected from these samples by measuring their height using tape and the mean was calculated. For other yield and yield component data, the selected five samples were harvested by using sickle. Harvesting was done 90 days after planting for essential oil yield production. The collected sample was then submitted to Wondo Genet Agricultural Research Center, Natural Product Laboratory for extraction of essential oil using hydro distillation method and determination of moisture content using oven dry as illustrated by Guenther (1972). Dry leaf weight, dry stem weight, Essential oil yield and dry biomass yield were calculated based on the results of oil content and moisture content from the laboratory. Moreover, based on essential oil yield and amount of irrigation used for each treatment, water use efficiency was calculated using the following formula.

$$\text{Water use efficiency (kg/m}^3\text{)} = \frac{\text{Essential oil yield}\left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Net irrigation water applied}\left(\frac{\text{m}^3}{\text{ha}}\right)}$$

The collected data were analyzed using statistical analysis system (SAS) version 9.3 procedure of general linear model for the variance analysis. Mean comparisons were carried out to estimate the differences between treatments using Fisher's least significant difference (LSD) at 5% probability level.

Result and Discussion

Different levels of soil moisture depletion levels significantly affected all recorded yield and yield components of basil including its water productivity.

Significantly higher yield and yield components were associated with frequently irrigated treatment under lower soil moisture depletion levels before irrigation.

Plant Height

The study showed that plant height of basil was highly significantly ($p<0.01$) affected by different levels of soil moisture depletion levels. Maximum plant height (50.2 cm) was recorded at a 20% TAW depletion level (Table 2). However, this was statistically similar to that of 30, 40 and 50% TAW depletion levels. On the other hand, minimum plant height (41.4 cm) was recorded at 100% TAW depletion level which is statistically similar to that of 60% TAW depletion level (Table 2).

The study showed that plant height decreased when soil moisture level increased beyond 40% TAW. Different studies showed that higher soil moisture depletion leads to shortened plant height due to drought stress experience during the growth stages beyond the threshold level of soil moisture depletion level of different crops. The finding is in line with Meskelu *et al.* (2021) [6] who reported that Stevia plant height was decreased when the soil moisture depletion level increased beyond 40% TAW. Muleta *et al.* (2017) [7] also reported plant height of Vernonia decreased when soil moisture level increased beyond 40% TAW which is in lined with the current finding.

Fresh and Dry Leaf Weight

Different levels of soil moisture depletion highly significantly ($p<0.01$) affected fresh and dry leaf weight production of basil. Maximum fresh and dry leaf weight (10.7 and 1.7 t / ha) was recorded at 30% TAW depletion level, respectively (Table 2). Statistically fresh leaf weight was similar with that of 40% TAW and dry leaf weight with that of 20 and 40% TAW. On the other hand, minimum fresh and dry leaf weight (5 and 0.8 t/ha) was recorded at a 100% TAW depletion level. Statistically fresh leaf weight was differing from all other treatments and dry leaf weight was similar with that of 50 and 60% TAW depletion levels (Table 2).

The result showed that frequent irrigation interval or small soil moisture depletion level gives better fresh and dry leaf weight. When the soil moisture depletion level increased beyond 40% TAW fresh and dry leaf weight were decreased due to the presence of moisture stress on higher depletion level. Similar finding was reported by Karimi *et al.* (2015) [5], who reported that optimum dry leaf weight was obtained from 60% FC or 40% TAW. Meskelu *et al.* (2021) [6] also reported the same finding on Stevia production.

Fresh and dry stem Weight

Different levels of soil moisture depletion highly significantly ($p<0.01$) affected fresh and dry stem weight production of basil. Maximum fresh and dry stem weight (7.5and 1.8 t / ha) was recorded at 40 and 30% TAW depletion level, respectively (Table 2). Statistically both fresh and dry stem weight was similar with in 20, 30 and 40% TAW depletion levels. On the other hand, minimum fresh and dry leaf weight (5 and 1.1t/ha) was recorded at a 100% TAW depletion level. Statistically fresh stem weight was similar with that of 50 and 60% TAW and dry stem weight was similar with that of 60% TAW depletion levels (Table 2).

The result showed that frequent irrigation interval or small soil moisture depletion level gives better fresh and dry stem weight. When the soil moisture depletion level increased beyond 40% TAW fresh and dry stem weight were decreased due to the presence of moisture stress on higher depletion level. The current finding was in lined with Benhmimou *et al.* (2017) [2], who reported that stem weight was decreased as soil moisture deficit increased.

Fresh and dry biomass

Different levels of soil moisture depletion highly significantly ($p<0.01$) affected fresh and dry biomass production of basil. Maximum fresh and dry biomass (17.8 and 3.5 t / ha) was recorded at 40 and 30% TAW depletion level, respectively (Table 2). Statistically fresh biomass was similar with that of 20 and 30% TAW depletion levels and dry biomass was similar with that of 40% TAW depletion levels. On the other hand, minimum fresh and dry biomass (10 and 1.9 t/ha) was recorded at a 100% TAW depletion level. Statistically fresh biomass was similar with that of 50 and 60% TAW and dry biomass was differing from all treatments (Table 2).

The result showed that irrigating basil when the soil moisture depletion level reaches to 40% TAW gave highest fresh and dry biomass. This showed that basil requires frequent irrigation intervals. Tesfaye *et al.* (2017) [11] on lemongrass and Meskelu *et al.* (2021) [6] on stevia reported the same finding from the current finding. The finding was also in lined with Benhmimou *et al.* (2017) [2], who reported that biomass of stevia was decreased as soil moisture deficit increased.

Table 2: Response of basil yield and yield components for soil moisture depletion levels

Treatments	PH (cm)**	FLW (t/ha)**	FSW (t/ha)**	FBM (t/ha)**	DLW (t/ha)**	DSW (t/ha)**	DBM (t/ha)**	EOY (Kg/ha)**	WP*1000 (Kg/m3)**
20%TAW	50.2a	8.9bc	6.7a	15.6a	1.4ab	1.6ab	2.9bc	11.6abc	2.3bc
30%TAW	47.3ab	10.7a	6.6ab	17.2a	1.7a	1.8a	3.5a	12.8ab	2.7ab
40%TAW	48.6a	10.3ab	7.5a	17.8a	1.6a	1.6ab	3.2ab	14.4a	3.1a
50%TAW	46.7ab	7.4cd	5.5bc	12.9b	1.1bc	1.5b	2.6c	9.5bc	2.0cd
60%TAW	44.1bc	6.7d	5.5bc	12.2b	1.1bc	1.4bc	2.5c	9.4c	2.1bcd
100%TAW	41.4c	5.0e	5.0c	10.0b	0.8c	1.1c	1.9d	6.0d	1.4d
CV	4.7	11.1	9.6	9.8	16.9	11.1	11.5	17.4	17.4
LSD 0.05	3.9	1.6	1.1	2.5	0.4	0.3	0.6	3.4	0.7

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; FBM: Fresh biomass; DBM: Dry biomass; EOY: Essential oil yield; WP: Water productivity; CV: Coefficient of variation; LSD0.05: Fisher's least significant difference at 5% probability level.

Essential oil yield

Different levels of soil moisture depletion highly significantly ($p<0.01$) affected essential oil yield of basil. Maximum essential oil yield of (14.4 kg/ha) was recorded at 40 TAW depletion level (Table 2). Statistically essential oil yield was similar with in 20, 30 and 40% TAW depletion levels. On the other hand, minimum essential oil yield of (6 kg/ha) was recorded at a 100% TAW depletion level. Statistically it differs from all other treatments (Table 2).

The result showed that irrigating basil with soil moisture depletion level below 40% TAW gave highest essential oil yield. Ade-Ademilua *et al*. (2013) [1] reported that water stress reduces essential oil yield production of basil which is in lined with the current finding. Tesfaye *et al*. (2017) [11] on lemongrass also reported the same finding.

Water productivity

Different levels of soil moisture depletion highly significantly ($p<0.01$) affected water productivity of basil. Maximum water productivity of (3.1 kg/m^3) was recorded at 40 TAW depletion level (Table 2). Statistically maximum water productivity was similar with in 30 and 40% TAW depletion levels. On the other hand, minimum water productivity of (1.4 kg/m^3) was recorded at a 100% TAW depletion level. Statistically it was similar with that of 50 and 60% TAW depletion levels (Table 2).

The current finding showed that water productivity was also higher for the treatments that were irrigated frequently and which is in agreement with Meskelu *et al*. (2021) [6] who reported that water productivity of stevia was decreased with the increase in irrigation regime. Tesfaye *et al*. (2017) [11] on lemongrass, Benhmimou *et al*. (2017) [2] on stevia, Karimi *et al*. (2015) [5] on stevia and Muleta *et al*. (2017) [7] on vernonia reported also the same finding.

Conclusion

Based on the results of this study, irrigation of basil when 40% TAW depleted associated with better yield and yield components of basil 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 basil.

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