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Determination of Optimal Soil Moisture Depletion Level for Lemongrass (*Cymbopogon citratus* L.)

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Abstract

The study was conducted at the 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 lemongrass (*Cymbopogon citratus* L.). Six level of soil moisture depletion level (20, 30, 40, 50, 60 and 100% of total available water of the soil (TAW) with three replication were used as treatments to evaluate the yield and yield component of lemongrass in randomized complete block design. Different level of soil moisture depletion level significantly (p<0.01) affected all recorded yield and yield components except number of tillers per hill and essential oil content. Significantly highest number of leaf per hill, fresh and dry aboveground biomass and essential oil yield were obtained as lemongrass was irrigated when 60% of the total available water in the soil was depleted. Moreover, the highest water use efficiency was obtained when the soil moisture depleted level was reached 60% of total available water. On the other hand, the minimum was obtained at 20% soil moisture depletion level. Therefore, lemongrass could be irrigated when the soil moisture content is depleted by 60% of the total available water content in the soil to enhance yield and water use efficiency.

Keywords: Depletion level; Essential oil; Lemongrass; Water use efficiency

Introduction

Lemongrass (*Cymbopogon citratus* L.) belongs to the family Germineae is a perennial grass mainly used as aromatic and medicinal purpose. Leaf part and essential oil extracted from the leaf is used as consumption for its different medicinal and aromatic uses. It is the most widely used aromatic crop in different foods, soft drink, alcohols and sanitation materials like soups and perfumes. Lemongrass is one of the most widely grown essential oil plants in the tropics and subtropics of India, Indonesia, Madagascar, and countries in Africa and South America [1-3]. Moreover, lemongrass is widely used as medicinal crop in many parts of the world. Its oil has been used as anti-bacterial and anti-fungal properties to cure various diseases like cough, cold, spitting of blood, rheumatism, lumbago, digestive problems, bladder problems, leprosy, and as mouth wash for the toothache and swollen gums. It is also been claimed to be stimulating, diuretic, anti-purgative and sudorific to reduce fever [4-7].

Lemongrass is grown as a perennial crop under either irrigated or non-irrigated conditions, but a large area is harvested from wild natural habitats such as in mixed forests or along banks of canals and rivers [8,3]. Its biomass is steam distilled for the extraction of essential oil, a natural product with wide application in the food and pharmaceutical industries, perfumery and cosmetics, and eco-friendly pesticides [2,3]. Lemongrass oil has a pleasant and refreshing aroma and antifungal and antibacterial properties [1,8-13].

Lemongrass can tolerate a wide range of soils and climatic conditions. However, vigorous growth could be obtained on well-drained sandy loam soil with high fertility and exposed to sunlight. As a medicinal plant, lemon grass has been considered as a carminative and insect repellent. Lemon grass is generally recognized as safe for human consumption as plant extract in the form of essential oil.

Water is a limited resource, which is widely used by different sectors like agriculture, domestic and industrial. The competition for this scarce resource is increasing from time to time due to increasing demand from sectors that utilize. Temporal and spatial variation of water resource and climate change is further exacerbating the problems [14]. Irrigated agriculture is the most inefficient and huge water-consuming sector, which accounts for 70% of water withdrawal from different, sources like aquifers, streams and lakes [15]. However, irrigated agriculture contributes for the production of 40% of world food and agricultural commodities within 16% of cultivated land [16].

The world is facing serious shortages of fresh water and growing competition for clear water, which makes less water available for agriculture. The great challenge for the coming decades will be the task of increasing food production with less water, particularly in countries with limited water and land resources. Serious water shortages are becoming worse and worse in the arid and semi-arid regions as existing water resources are being fully exploited [17].

Water stress is the most influential factor affecting the yield of important crops, it is necessary to get maximum yield in agriculture by using available water in order to get maximum profit form per unit area, because existing agricultural land and irrigation water are rapidly diminishing due to rapid industrialization and urban development [18]. The optimization of irrigation for the production of fresh herbs and essential oils is important, since water is a major component of the fresh produce and affects both mass and quality [19].

Study of soil moisture contents and the patterns of moisture depletion as the crop grows could help to sort out a suitable irrigation schedule for this objective. A lot of scientific work in this respect has been documented. Mohamed reported that irrigation at 60% ASMD (allowable soil moisture depletion) gave the highest grain yield and harvest index in wheat while WUE was the highest with 85% ASMD [20]. Ahmad et al. observed that increasing SMD from 50% to 75% for wheat production markedly reduced total yield [21]. Karim et

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al. reported that irrigation at 35% available soil moisture depletion (ASMD) gave highest yield (4.71 tha^{-1}) with the application of 120 kg N fertilizer while irrigation at 65% ASMD produced satisfactory yield (4.13 t ha^{-1}) with highest WUE (196.5 kg $ha^{-1}cm^{-1}$) with application of 80 kg N for wheat [22]. Similarly, Aydin and Kalaycl reported that irrigation at 66% ASMD was the most effective in terms of grain yield in wheat [23]. Tahmasabi and Fardad applied irrigation at 10, 25, 50 and 75% soil moisture depletion and observed that wheat grain yields were 3384, 3050, 3094 and 2273 kg ha^{-1}, while water use efficiency was 1.13, 1.05, 0.82 and 0.86 kgm^{-3}, respectively [24]. Narang et al. found that yield of all wheat cultivars studied decreased with increasing levels of SMD and water use efficiency was highest with 60% ASMD [25].

Although different studies have been conducted to evaluate different crops yield and yield component under different soil moisture depletion levels, little work was reported for aromatic and medicinal crops in general and for lemongrass in particular. For production of lemongrass under irrigated conditions, determination of the optimum soil moisture depletion level is crucial to recommend when and how much irrigation water to be applied under specified agro-ecology and soil type. This field experiment was initiated due to unavailability of information regarding soil moisture depletion level and irrigation scheduling for lemongrass. Therefore, the objective of the study is to determine the optimum soil moisture depletion (SMD) level for lemongrass (*Cymbopogon citratus* L.) at Wondo Genet area.

Materials and Methods

Experimental conditions

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. during 2013/14 and 2014/15 dry season to determine optimum soil moisture depletion level for the production of lemongrass (*Cymbopogon citratus* L.). The soil texture in the experimental site was clay loam with moisture content at field capacity and permanent wilting point of 30.8% and 19.0%, respectively. The bulk density of the soil was 1.1 g/cm^3.The available water holding capacity per unit meter of the soil profile in the root zone is 130 mm. The area gets total annual rain fall of 1121.80 mm (Table 1). From this 72.3% of the rainfall falls in the main rainy season (April to September).

Experimental design and procedure

The field experiment was carried out using randomized complete block design (RCBD) with three replications following the design procedure for RCBD by Gomez and Gomez [26]. The plot size used was 3.00 m × 3.00 m with spacing of 1.50 m between plots and 3.00 m between blocks. Six treatments of different soil moisture depletion levels (20, 30, 40, 50, 60 and 100% TAW) were randomly assigned for each plot in each block.

Lemongrass (*Cymbopogon citratus* L.) stem from one year old matured plant was taken and planted. Three tiller split was planted at a point with spacing of 60 cm both between raw and between plant/hill. The regular tillage and agricultural operations for lemongrass in the study area were followed during the experimentation. All other agronomic practices were kept normal and uniform for all plots regardless of the treatment variation. 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 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 treatment level for all harvesting cycle.

Data collection

Five plant hills were randomly selected for sample from the central part of the plot excluding the border for data collection on growth, yield and yield components of lemongrass. Data on number of tiller per hill, number of leaves per hill and number of leafs per tiller were counted at field. The selected five samples were harvested 120 days after planting for the first harvest and 60 days after the first harvest, the second harvest for both seasons were made. Fresh biomass of lemongrass (30 cm above the ground at the edge of leaf) was harvested manually using sickle. Data on moisture content and essential oil content were collected after the sample was extracted at Wondo Genet Agricultural Research Center, Natural Product Laboratory using hydro distillation method. Based on the oil content and moisture content, essential oil content and dry biomass yield were calculated. Moreover, based on the obtained yields and amount of irrigation used, water use efficiency was calculated using the following formula.

$$WUE = \frac{EOY}{TW}$$

Where: WUE is water use efficiency (kg m^{-3}); EOY: is the essential oil yield (kg ha^{-1}); TW: is the seasonal total water use (m^3 ha^{-1}).

Data analysis

The data collected were statistically analyzed using statistical analysis system (SAS) software version 9.0 using the general linear programming procedure (GLM). Mean comparison was carried out using least significant difference (LSD) at a 5% probability level to compare the differences among the treatments mean.

Month	T_{min} (°C)	T_{max} (°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

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

Result and Discussion

Different level of total available water depletion significantly affected all recorded yield and yield components except number of tillers per hill and essential oil content. Significantly highest number of leaf per hill, aboveground fresh and dry biomass, essential oil yield and water use efficiency yield were obtained as lemongrass was irrigated when 60% of the total available water in the soil was depleted.

Number of tiller and leaf per hill

The study revealed that number of tillers per hill of lemongrass was not significantly (p>0.05) affected by different levels of soil moisture depletion level and the value ranges between 73 and 62 tillers per hill. On the other hand, different levels of soil moisture depletion level on lemongrass had a highly significant (p<0.01) effect on number of leaf per hill.

The combined analysis revealed that maximum number of leaf per hill of 345 was obtained as lemongrass irrigated when 60% of the total available water in the soil depleted. However, the maximum leaf per hill recorded at 60% TAW treatment was statistically similar with 30 and 40% TAW treatments. On the other hand, the minimum leaf per hill of 278 was obtained when lemongrass irrigated after only 20% of the total available water in the soil depleted. The minimum leaf per hill recorded at 20% TAW was not statistically different with 40, 50 and 60% TAW treatments (Table 2). The study showed that as soil moisture depletion level increased and decreased from 60% number of leaf per hill was reduced. The maximum number of leaf per hill obtained at 60% TAW treatment was 23.8% higher than the least number of leaf per hill recorded at 20% TAW treatment.

Different studies revealed that different level of soil moisture depletion significantly affect growth, yield and yield components of different crops. This study revealed that the maximum yield component leaf per hill was recorded when lemongrass irrigated after 60% of total available water in the soil depleted. The finding is in line with FAO which recommend a 60% depletion level for production of grass species [27]. This might be due to the optimum depletion level lemongrass required is 60% of TAW both for optimum water and air circulation in the root depth. This could be as soil gets dried beyond 60% the crop experience stress in the growing season which leads to reduction in growth and yield components of the specified plant. Different studies revealed that moisture stress due to depletion to higher amount leads to reduction of growth parameters. Razmjoo et al. reported that drought stress in chamomile reduced some growth parameters [28].

Aboveground fresh and dry biomass

Different levels of soil moisture depletion had a significant (p<0.05) effect on aboveground fresh biomass during both the first the second (2013/14 and 2014/15) years experimentation. Whereas, the combined analysis (pooled mean) revealed that, different levels of soil moisture depletion had a highly significant (p<0.01) effect on aboveground fresh biomass of lemongrass. On the other hand, aboveground dry biomass was significantly (p<0.05) influenced due to different soil moisture depletion levels during the first experimental year (2013/14). However, during the second experimental year (2014/15) and the combined analysis revealed that aboveground dry biomass was highly significantly (p<0.01) affected due to different soil moisture depletion levels.

The pooled mean revealed that maximum aboveground fresh and dry biomass of 14662 and 4042 kg ha^{-1} were recorded when lemongrass irrigated at 60% of the total available water in the soil is depleted, respectively (Table 2). However, the maximum aboveground fresh and dry biomass obtained at 60% TAW treatment was statistically similar with 50, 40 and 30% TAW treatments. On the other hand, the minimum aboveground fresh biomass was obtained at 100% TAW treatment. Moreover, the minimum aboveground fresh and dry biomass was recorded at 100% TAW which was statistically inferior to all other treatments in both parameters. The study showed that as soil moisture depletion level increased and decreased from 60% TAW, aboveground biomass was reduced. The maximum aboveground fresh and dry biomass obtained at 60% TAW treatment were 65.9 and 64.0% higher than the least yield recorded at 100% TAW treatment, respectively.

Different studies revealed that different level of soil moisture depletion significantly affect yield and yield components of different crops. For example, Narang et al. found that yield of all wheat cultivars studied decreased with increasing levels of soil moisture depletion level [25]. As the depletion level increased the fresh biomass also increased on the contrary drought stress caused significant decrease in fresh and dry biomass, nutrient content and essential oil production of basil [29]. According to Singh et al. [30] a field experiment conducted on lemongrass (*Cymbopogon flexuosus*) soil moisture regime maintained at 0.75 irrigation water to cumulative pan evaporation ratio (IW:CPE) significantly increased herb yield compared with those having 0·25 and 0·50 IW:CPE ratios.

This study revealed that the maximum aboveground fresh and dry biomass yields were obtained when lemongrass irrigated after 60% of total available water in the soil depleted. This is in line with the findings of Singh who reported maximum herb yield of lemongrass (*Cymbopogon*

Treatments	Tiller per hill	Leaf per hill	Aboveground fresh biomass (kg ha^{-1})			Aboveground dry biomass (kg ha^{-1})		
	(Pooled)^{ns}	(Pooled)**	(2013/14) *	(2014/15)*	(Pooled)**	(2013/14) *	(2014/15)**	(Pooled)**
20% TAW	61.8	278.4^{c}	9468^{ab}	13727^{bc}	11597^{b}	2617^{ab}	3984^{b}	3301^{b}
30% TAW	66.7	315.8^{ab}	10165^{a}	15673^{ab}	12919^{ab}	2666^{a}	4299^{ab}	3482^{ab}
40% TAW	69.0	310.6^{abc}	10350^{a}	16181^{ab}	13266^{ab}	2757^{a}	4434^{ab}	3596^{ab}
50% TAW	66.9	301.8^{bc}	10365^{a}	15877^{ab}	13121^{ab}	2885^{a}	4474^{ab}	3679^{ab}
60% TAW	72.7	344.7^{a}	11164^{a}	18160^{a}	14662^{a}	3037^{a}	5047^{a}	4042^{a}
100% TAW	64.1	293.5^{bc}	7613^{b}	10059^{c}	8836^{c}	2130^{b}	2800^{c}	2465^{c}
$LSD_{0.05}$	ns	37.3	2151.5	3926.8	2311.6	510.9	913.1	570.7
CV (%)	12.9	11.9	14.5	17.4	14.4	12.6	14.5	11.0

^{abc}Means followed by the same letters with in columns does not differ significantly at p< 0.05 probability level.

*Significant at p<0.05, ** significant at p<0.01.

Table 2: Yield and yield components of lemongrass as influenced by different soil moisture depletion levels at Wondo Genet during 2013/14 and 2014/2015 dry season (two harvests).

flexuosus) was recorded around mid of the tested irrigation water levels (from 0.1 to 1.5 times cumulative pan evaporation) at 0.7 IW: CPE ratio on deep sandy soils [31]. Similar research on rosemary plant showed that the herb growth was influenced by different levels of irrigation intervals which lead to different soil moisture depletion level [32].

Ahmad also reported that increasing soil moisture depletion level from 50% to 75% for wheat production markedly reduced total biomass yield [21]. This finding is also in line with FAO which recommend 60% depletion level for production of grass species [27]. This might be due to the optimum depletion level lemongrass required is 60% of TAW both for optimum water and air circulation in the root depth. This could be as soil gets dried beyond 60% the crop experience stress in the growing season due to photosynthesis interruption due to shortage of water supply. This leads to reduction in biomass yield as more than 90% of biomass production is due to photosynthesis activity [33].

Essential oil content and yield

Maximum essential oil yield of 93.1 kg ha^{-1}was obtained at 60% of TAW treatment. However, the maximum essential oil yield recorded at 60% TAW was statistically similar with oil yield obtained at 50, 40 and 30% TAW treatments (Table 3). On the other hand, the minimum essential oil yield of 54.8 kg ha^{-1} was obtained when lemongrass irrigated after the total available water in the soil depleted to100%. The minimum essential oil yield obtained at 100% TAW was significantly inferior to all other treatments. The maximum essential oil yield obtained at 60% TAW improves essential oil yield by 69.9% than that obtained at 100% TAW treatment. The study showed that when the total available water in soil increased and decreased from 60% TAW, essential oil yield of lemongrass decreased. This is in line with the findings of Singh who reported maximum essential oil yield of lemongrass (*Cymbopogon flexuosus*) was recorded around mid of the tested irrigation water levels (from 0.1 to 1.5 times cumulative pan evaporation) at 0.7 IW:CPE ratio on deep sandy soils [30].

The study revealed that different depletion levels of total available water in the soil had no significant ($p>0.05$) impact on essential oil content of lemongrass. However, the value (weight in wet base) ranges between 0.63 to 0.66%. On the other hand, different soil moisture depletion levels significantly ($p<0.05$) influenced essential oil yield of lemongrass during both experimental years. Moreover, the pooled mean analysis revealed that different levels of total available water in the soil has highly significantly ($p<0.01$) influenced essential oil yield production of lemongrass.

According to Singh soil moisture regime maintained at 0.75 irrigation water to cumulative pan evaporation ratio (IW: CPE) significantly increases lemongrass (*Cymbopogon flexuosus*) essential oil yields [31]. The current finding is in line with the findings of Soha on rosemary plant who reported essential oil yield is influenced by different levels of irrigation intervals based on different soil moisture depletion levels [32]. Different reports also revealed that lemongrass responds differently under mild and moderate stress conditions and responses varied depending upon the level and duration of moisture stress [34]. Under water stressed conditions, lemongrass total essential oil yield remained the same in different varieties with increased levels of geraniol and citral content. The same author reported that mild and moderate moisture stress substantially increases major oil constituents like geraniol and citral in different lemongrass species. This could be a possible relevance for lemongrass as a drought stress adaptability tolerance for moisture stressed area.

Increasing soil moisture depletion means that reducing the frequency of irrigation and subjecting a little bit to stress. However, different studies on aromatic plants shows drought stress due to different irrigation regime leads to enhance some of yield and yield components. For example, essential oil and prolin contents of sweet basil increased in response to water stress by subjecting basil plant towards water stress just before harvesting by increasing soil moisture depletion level [35]. On the other hand some reported that the drought stress caused by increasing depletion level initiated significant decrease in the production of essential oil in basil plant [29]. Moreover, Razmjoo et al. reported that drought stress in chamomile reduced essential oil yield [28].

Water use efficiency

Maximum water use efficiency of 19.7×10^{-3} kg m^{-3} was observed when lemongrass irrigated after 60% of the total available water in the soil was depleted (Table 3). However, the maximum water use efficiency recorded at 60% of TAW depleted from the soil treatment was not statistically different with that of 50, 40 and 30% TAW depleted from the soil treatments. Contrary to this, the minimum water use efficiency of 12.4×10^{-3} kg m^{-3} was recorded when lemongrass irrigated after 100% of the total available water depleted from the soil. The minimum water use efficiency obtained at 100% TAW depleted from the soil was statistically similar with that of 20% TAW depleted from the soil. The study showed that irrigating lemongrass at 60% TAW depleted from the soil improved water use efficiency by 58.9% than the 100% TAW depleted from the soil treatment. Improving water use efficiency is an increasing concern through different irrigation practice to enhance yield of crop per irrigation water used. Different studies on different crops revealed that water use efficiency improved based on different irrigation practice like determining the optimum soil moisture depletion level before.

Treatments	Essential oil content (%)	Essential oil yield (kg ha^{-1})			Water use efficiency x10^{3} (kg m^{-3})		
	(Pooled)^{ns}	(2013/14) *	(2014/15)*	(Pooled)**	(2013/14) *	(2014/15)*	(Pooled)**
20% TAW	0.64	53.7^{bc}	95.5^{a}	74.6^{b}	10.8^{b}	19.8^{a}	15.3^{bc}
30% TAW	0.64	61.2^{abc}	103.8^{a}	82.5^{ab}	12.6^{ab}	21.7^{a}	17.2^{ab}
40% TAW	0.66	67.8^{a}	104.7^{a}	86.2^{ab}	15.0^{a}	21.7^{a}	18.4^{ab}
50% TAW	0.64	65.2^{ab}	102.8^{a}	84.0^{ab}	14.6^{a}	21.0^{a}	17.8^{ab}
60% TAW	0.64	70.6^{a}	115.6^{a}	93.1^{a}	15.4^{a}	24.0^{a}	19.7^{a}
100% TAW	0.63	49.3^{c}	60.3^{b}	54.8^{c}	11.5^{b}	13.3^{b}	12.4^{c}
$LSD_{0.05}$	Ns	13.4	27.5	15.2	2.9	5.7	3.19
CV (%)	8.7	14.5	18.8	12.7	14.7	18.7	12.6

^{abc}Means followed by the same letters with in columns does not differ significantly at p< 0.05 probability level.

*Significant at p<0.05, ** significant at p<0.01.

Table 3: Yield and yield components of lemongrass as influenced by different soil moisture depletion levels at Wondo Genet during 2013/14 and 2014/2015 dry season (two harvests).

The different soil moisture depletion levels significantly ($p<0.05$) influenced water use efficiency of lemongrass during both experimental years. Moreover, the pooled mean of two year analysis revealed that water use efficiency was highly significantly ($p<0.01$) influenced due to different levels of soil moisture depletion levels on lemongrass based on its essential oil yield per irrigation water used.

Irrigation for specific crop, variety and agro ecology for example, Mohamed and Karim et al. reported higher water use efficiency at higher soil moisture depletions on wheat [20,22]. On the contrary, Tahmasabi and Narang et al. reported higher water use efficiency associate with lower soil moisture depletion levels on wheat [24,25]. The current finding is in line with the findings of Singh [31] who reported maximum water use efficiency of lemongrass (*Cymbopogon flexuosus*) recorded around mid of the tested irrigation water levels (from 0.1 to 1.5 times cumulative pan evaporation) at 0.7 IW:CPE ratio on deep sandy soils.

Conclusion and Recommendation

Irrigating lemongrass at 60% of the total available water improves not only the herbal and oil yields, but also enhances the water use efficiency of lemongrass under Wondo Genet condition. Therefore, based on the finding of the current study it could be concluded that the optimal soil moisture depletion level for lemongrass (*Cymbopogon citratus* L.) is 60% of total available water depleted from the soil. Hence, before irrigating lemongrass depleting the moisture content in the soil to 60% of the total available water is vital to improve yield and water productivity at Wondo Genet and similar agro ecology.

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