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Lemongrass (Cymbopogoncitratus(DC.)Stapf) Response for Supplementary Irrigation in Rain-fed Agriculture at Wondo Genet, South Ethiopia

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Abstract

The study was conducted at Wondo Genet Agricultural Research Center, SNNP Region, Ethiopia, 7°05' N latitude, 38°37' E longitude and 1785 m.a.s.l for two years (2013/14 to 2014/15) based on the objective to evaluate the response of lemongrass (Cymbopogoncitratus (DC) Stapf) to supplementary irrigation (SI) at different levels and different growth stages. Five levels of SI (100, 75, 50, 25% and no SI) and three supplementary irrigation at growth stages (one SI at mid-season, one SI at maturity and two SI at mid-season and maturity stages) with three replications were used in randomized complete block design. Application of supplementary irrigation to lemongrass had a highly significant ($p<0.01$) effect on fresh biomass, essential oil content and water use efficiency during the first year. Significant ($p<0.05$) effect was also observed in dry biomass and essential oil yield. However, no significant ($p>0.05$) effect was observed on number of tiller per hill. Highly significant ($p<0.01$) influence was observed on fresh biomass, dry biomass and water use efficiency during the second year. Though essential oil content affected significantly ($p<0.05$), no significant ($p>0.05$) variation was observed in essential oil yield due to supplementary irrigation during the second year. Maximum (43.4 and 60.1 t/ha) and minimum (29.7 and 51.1 t/ha) annual fresh biomass production were recorded at 100% ETC SI and rain-fed treatment both years, respectively. Similarly, maximum (9.15 and 13.8 t/ha) and minimum (5.74 and 11.4 t/ha) annual dry biomass production were recorded at 100% ETC SI and rain-fed treatments both years, respectively. Maximum (0.55 and 0.64%) essential oil content was observed at application of two SI at mid-season and late season stage and rainfed treatment during the first and the second year, respectively. Conversely, minimum (0.44 and 0.55%) essential oil content was observed at 100% ETC SI both years. Maximum annual essential oil production of 219.8 and 219.7 kg/ha were recorded at 75% ETC and two SI at mid-season and maturity stage during the first year. Minimum annual essential oil production of 152.2 kg/ha was recorded at rain-fed (no supplemental irrigation) treatment during the first year. The maximum (0.59 and 1.47 kg/mm) and minimum (0.19 and 0.28 kg/mm) water use efficiency was recorded at rain-fed treatment and 100% ETC SI during both years, respectively.

Keywords: Essential oil • Lemongrass • Supplementary irrigation • Water use efficiency

Introduction

Supplemental irrigation has been widely reported as one of the different strategies used for crop yield improvement in rain fed agriculture in areas where moisture availability for the crop is a limiting factor [1]. Though the effect varies from crop and soil types, application of additional amount of irrigation water to rain-fed crops during the moisture deficit due to lack of rainfall improves yield of crop [2]. Besides improvement on crop yield, effectiveness of supplemental irrigation on water productivity was reported with application at different growth stage or with different deficit levels application of parts of the crop water requirement [1,3]. In areas where rain-fed crop is important, application of supplemental irrigation has a benefit of reducing short-term risk on crop yield especially in the climate change era in areas where lower and more variable rainfall amount is expected [4].

On the other hand, even though full irrigation is not possible application of some deficit level for crops especially those that are tolerant for drought leads to compete with the full irrigation on yield and even improve the water use efficiency better than the one that received full irrigation. Different research findings on different crops leads to an improvement of yield and water use efficiency of a crop when moisture stress avoided by supplying irrigation only at some of the growth stages. For example, Elias *et al*., [5] reported that when irrigation applied for maize during only in development and mid-season growth stage of maize yield and water productivity was improved. Elias *et al*. [6] also reported that both essential oil yield production and water use efficiency of spear mint affected due to different irrigation levels during practicing deficit irrigation. This might be due to different tolerance levels of crops for moisture stress and as well nature of the product, essential oil content in this case, might be even improved due to stress as different reports showed that secondary metabolites improved due to stress [7].

Application of supplemental irrigation to some level is similar with that of deficit irrigation which both are aimed to improve yield per amount of irrigation water applied than only concerning to improve yield per hectare. This leads to improve total food production of the water scarce area as the water saved is used to irrigate additional land as the main aim is to stabilize rather than maximize yield [8,9].

Application of supplemental irrigation need a clear information on the timing and amount of supplemental irrigation to be applied as the nature and variability of crops for moisture stress tolerance varies from season to season and with seasonal rainfall levels of the a particular area [1]. Beyond it effect on improvement of water productivity, application of small amount of supplemental irrigation at the correct time and level can greatly increase yield of a particular crop. For example, Oweis and Hachum[1] reported that wheat yield was improved from 2.2 to 4.6 t/ha with addition of 63 mm supplemental irrigation in an area where season rainfall is 236 mm. Different former finding revealed that, supplemental irrigation play a key role in increasing water productivity in different part of the world especially when integrated with other management options like application of adequate other inputs and improved crop management methods. Moreover, this need timely application of supplemental irrigation for better utilization of the limited resource for better water productivity and yield improvement of the crop.

Water productivity improvement strategies requires precise knowledge of crop response to drought stress as the level of tolerance varies considerably based on crop type and its growth stage [8]. Therefore, site specific field research is vital to recommend water productivity improvement strategies like supplemental irrigation practice. Application of supplemental irrigation is somewhat challenging due to its unpredictable situation since actual

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rainfall and planned irrigation time might not be similar. Therefore, timings and amount of supplemental irrigation scheduling is needed for better crop management under supplemental irrigation condition.

Moreover, availability of irrigation water is inadequate in most of the cases to irrigate all land with full irrigation due to scarcity of water in different part of the world. In additional to this, farmers might consider the benefit of utilizing sub optimal supplemental irrigation than full irrigation in order to save some water so that additional land could be irrigated [1,8]. This could improve the efficient utilization of water resource with minimum yield reduction per hectare and improving the total crop production of a particular area, as water resource is limited and its availability is decreasing due to different factors like over exploitation, pollution and climate change [10].

On the other hand, lemongrass (*Cymbopogoncitratus* (DC.) Stapf), a perennial grass belongs to the family Poaceae or Gramineae, mainly cultivated in tropics and sub tropics for its aromatic and medicinal purpose with annual world production of 1000 tone from an area of 16000 ha [11,12,13]. The essential oil extracted from its leaf widely used in different foods, soft drink, alcohols, sanitation and perfumes as aromatic purpose. Moreover, it has an anti-oxidant, an anti-bacterial and anti-fungal properties to be used as a medicinal purposes for different diseases like cough, spitting of blood, digestive problem, leprosy, fever and toothache, and as carminative and insect repellent [14,15]. Production of lemongrass widely done as wild natural habitats along banks of canals and rivers and both as irrigated and in rain-fed condition for a purpose including soil and water conservation [13].

In areas where water scarcity is common and full crop production potential is not expected, supplemental irrigation during the rainy season leads to a better investment than full irrigation during the dry season. Therefore, research based policy recommendations are essential to utilize the available irrigation water resource efficiently for maximizing the output and profitability of rain-fed agriculture. This needs a critical information in order to apply crop and site specific supplemental irrigation in water scarce areas where availability of soil moisture is the main limiting factor for crop production. Different research results has been reported on the importance of supplemental irrigation on yield and water productivity of different food crops. However, on aromatic and medicinal plant, there is a limitation of information regarding the effect of supplemental irrigation on essential oil yield in general and on lemongrass in particular. Therefore, this field experiment was conducted based on an objective to evaluate the response of lemongrass (*Cymbopogoncitratus* (DC.) Stapf) to supplementary irrigation at Wondo Genet area.

Materials and Methods

Description of experimental site

This experiment was carried out at Wondo Genet Agricultural Research Center, Ethiopia, 7°05' N latitude, 38°37' E longitude and mean altitude of 1785 m.a.s.l. for two years during 2013/14 and 2014/15 based on an objective to maximize crop productivity of rain-fed agriculture, determine the effect of supplementary irrigation on crop yield and water use efficiency on Lemongrass (*Cymbopogoncitratus*(DC.) Stapf.). The physical soil characteristics of the experimental site is classified as sandy clay loam in textures with moisture content at field capacity and permanent wilting point of 30.8 and 19.0%, respectively with bulk density of 1.1 g/cm^3. Based on these physical parameters total water holding capacity of the soil was calculated as 130 mm/m. On the other hand, the soil in the experimental field was found as neutral with pH of 6.9.

Climatically, the study area is classified as sub-humid with 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 annual minimum temperature varies from 9.3 to 12.9 ^oC and maximum temperature varies from 23.3 to 28.4 ^oC (Table 1).

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

Month	T_{min} (^oC)	T_{max} (^oC)	RH (%)	Wind speed (m/s)	Sunshine hours (%)	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

Experimental design and procedure

The field experiment was carried out using the design procedure set by Gomez and Gomez (1984) for randomized complete block design (RCBD) with three replications. Each experimental units had 3.60 m length and 3.00 m width with spacing of 1.60 m between each units and 3.20 m between blocks. Eight treatments, four level of irrigation water (100, 75, 50 and 25% ETc), irrigating only some of the growth stages (full irrigation only during development stage, full irrigation only during mid-season stage and full irrigation only during development and mid-season stages) and rain-fed as control were used for this particular study. All treatments were randomly assigned in each experimental units based on the procedure used for RCBD.

Before planting the lemongrass, the experimental land was plowed with disc harrow using tractor. Then after the land was leveled and divided into three blocks across the slope of the land and each blocks were divided into eight experimental units to handle each treatment in each block. Then after, lemongrass (*Cymbopogoncitratus* (DC) Stapf) bulbous stems were collected from well grown clumps of one year matured plant. The tops of these bulbous stems were cut off 25 cm form the root and the lower brown sheath removed to expose young roots to enhance its performance. After land leveling and layout, ridge and furrow were prepared and pre-irrigation of uniform amount was applied for each plots. In addition to this planting hole of depth 10 to 15 cm were prepared on the top of the ridge for planting the lemongrass.

Following this, three bulbous stems were planted in a single planting hole with a spacing of 60 cm between plant and between rows of plant in the ridge. During the experiment, irrigation water requirement was estimated using CropWat 8.0 model for initial design and then after, it was monitored the moisture continent in the soil using gravimetric method before each irrigation period. Supplementary irrigation was applied thought the two year for the perennial lemongrass based on the deficit of soil moisture levels whenever rainfall is not enough to refill the soil moisture to field capacity level for the full supplementary irrigation treatment (100% ET_c). The soil sample for moisture content monitoring was collected from 100% ET_c supplemental irrigation treatment.

Moreover, rainfall of each time is collected from a rain gauge only 100 m away for the experimental land. Based on the rainfall amount, the effective rainfall during two successive irrigation events was estimated using FAO dependable rain method to subtract from the crop water requirement and apply the deficit amount using supplemental irrigation. Once after the amount of supplemental irrigation depth to refill the soil to field capacity for the full supplemental treatment known, each of the other treatments received based on their percent levels.

Finally, the calculated gross irrigation depth for supplementing the rainfall was applied using two inch Parshall flume for measuring the discharge of irrigation water using furrow irrigation method. Since planting, common crop management practice like weeding and hoeing for the particular plant were followed during the experimental period uniformly for all plots.

Data collection and analysis

Five representative plant hills from the central three rows were randomly selected excluding the border two rows including plant hills at both ends for the central rows. Lemongrass growth, yield and yield component parameters were collected from the selected plants 120 days after planting for the first harvest and then 60 days after harvest for other harvests. Data on number of tiller per hill was collected from these sample hills by manually counting the number of tillers within the sample hills directly at field before harvest and the mean was calculated for each plot per hill basis.

Data for other parameters were taken after the lemongrass harvested manually using sickle 30 cm above the ground at the edge of the leaf. Each harvested plant hills were collected carefully separately and each five sample were weighed using sensitive balance of 0.01g reading digit for recording fresh biomass. Then after recording the fresh biomass, composite sample of 300 g from each plot for essential oil extraction and other for moisture content determination was prepared from the five sample and submitted to Wondo Genet Agricultural Research Center, Natural Product Laboratory.

The sample was then used for extraction of essential oil using hydro distillation method in the laboratory. Then essential oil yield per hectare was calculated based on the essential oil content in percent obtained from laboratory and the fresh biomass per hectare collected. The moisture content was determined by calculating the weight difference before and after the sample is oven dried at 105 ^{o}C for 3 hours in laboratory. Accordingly, dry biomass was calculated based on the moisture content data and the fresh biomass data. Moreover, based on the calculated essential oil yield per hectare and amount of total net water applied per harvest (both rainfall and supplementary irrigation) for each treatment, water use efficiency was calculated using the following formula.

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

Data of all collected parameters 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.

Results and Discussions

Summary of findings

The study revealed that application of supplementary irrigation had a significant effect on yield and yield components of lemongrass except number of tillers per hill. Generally, higher biomass yield was associated with application of higher level of supplemental irrigation and lower biomass associated with rain-fed and lower supplemental irrigation treatments. On the other hand, application of higher supplemental irrigation to lemongrass resulted in lower water use efficiency. Higher water use efficiency was observed with application of lower supplemental irrigation level in which maximum attained with rain-fed (no supplemental irrigation). Based on this study, application of full supplemental irrigation for lemongrass leads to higher fresh biomass production. However, water use efficiency based on essential oil yield was maximized due to no supplemental irrigation. Therefore, in view of essential oil yield production with higher water use efficiency, application of supplemental irrigation at mid and maturity stage of lemongrass could be taken as better supplemental irrigation water management practice at the study area and similar agro-ecology and soil type.

Number of tiller per hill

The analysis of variance revealed that number of tiller per hill was not significantly ($p>0.05$) affected due to application of supplemental irrigation at different levels and on different crop growth stages of lemongrass (Tables 2 and 3). Although there was no statistical difference observed among supplemental irrigation at different levels and on different crop growth stages of lemongrass, the average number of tiller per hill varied from 26.8 to 30.6 and 47.9 to 53.1 during 2013/14 and 2014/15, respectively (Table 4 and 5). This might be due to most of the tillering activity performed during well watered seasons during the early planting stage of lemongrass during the rainy season. Similar results were reported on lemongrass number of tiller per hill that different deficit level and soil moisture depletion level has no effect on number of tiller per hill of lemongrass [16].

Fresh biomass

Application of supplemental irrigationat different irrigation levels and on different crop growth stages highly significantly ($p<0.01$) influenced fresh biomass production of lemongrass both the study years (Table 2 and 3). Maximum annual fresh biomass production of 43.4 and 60.1 t/ha were recorded at 100% ET_c (full supplemental irrigation) treatment both during 2013/14 and 2014/15, respectively (Table 4 and 5). On the other hand, minimum annual fresh biomass production of 29.7 and 51.1 t/ha were recorded at rain-fed (no supplemental irrigation) treatment both during 2013/14 and 2014/15, respectively (Table 4 and 5). The study revealed that application of full supplemental irrigation on lemongrass at the study area leads to improvement of fresh biomass by 46.1 and 17.6% as compared with the rain-fed system during 2013/14 and 2014/15, respectively. The decrease in fresh biomass production in lower supplemental irrigation water applied treatments might be due shortage of adequate moisture supply to the crop from the soil which affects the biomass production. Moreover, the high variation between the first and the second year is that since lemongrass is a perennial grass, the biomass production is lower during the first year, increased then after during the second year and then it will decrease considerably as lemongrass gets older [17].

Different research findings revealed that shortage of moisture during the growth stages of crops affect the photosynthesis process as water is the main component. Since photosynthesis is the building block of biomass production in crops, its reduction leads to lower the biomass production of crops [18]. Similar findings were also reported in different crops due to supplemental irrigation leads to improve higher crop yield [1]. For example, Kukal*et al*. [19] reported that application of full supplemental irrigation leads to improve yield by 14 to 74% for different crop as compared with the rain-fed production system. On the other hand, different research also revealed that reduction of moisture leads to reduce lemongrass biomass production [17]. Similarly, application of supplemental irrigation at different growth stages improve crop yield and yield components. For example, application of supplemental irrigation at different growth stages of wheat affects yield and yield component of wheat and it increased both photosynthetic rate and transpiration rate in which the net effect is higher [20]. Others also recommend that timely and adequate amount of supplemental irrigation could improve yield and yield components of different crops which leads to even improve water productivity [1].

Dry biomass

Significant ($p<0.05$) difference was observed in dry biomass production of lemongrass due to application of supplemental irrigationat different irrigation levels and on different crop growth stages during both the study years (Tables 2 and 3). Maximum annual dry biomass production of 9.15 and 13.8 t/ha were recorded at 100% ET_c (full supplemental irrigation) treatment both during 2013/14 and 2014/15, respectively (Tables 4 and 5). However, the maximum dry biomass production obtained at 100% ET_c was statistically similar with all other treatments except the rain-fed treatment during the first experimental season and it was statistically similar with that of 75 and 50% ET_c supplemental irrigation during the second year. On the other hand, minimum annual dry biomass production of 5.74 and 11.4 t/ha were recorded at rain-fed (no supplemental irrigation) treatment both during 2013/14 and 2014/15, respectively (Tables 4 and 5). The minimum dry biomass production obtained at rain-fed treatment was statistically inferior to all other treatments during the first year and it was statistically

Table 2: Analysis of variance of yield and yield components during 2013/14.

Source of variation	Degree of freedom	MS					
		NTPH	FBM	DBM	EOC	EOY	WUE
Replication	2	31.59*	37.64^{ns}	0.84^{ns}	0.0014^{ns}	553.3^{ns}	0.0014^{ns}
Treatment	7	5.38^{ns}	63.39**	3.54*	0.0034**	1739.0*	0.046**
Error	14	6.40	11.03	1.00	0.001	459.2	0.002

MS: mean squares, NTPH: number of tillers per hill, FBM: aboveground fresh biomass, DBM: aboveground dry biomass, EOC: essential oil content, EOY: essential oil content, WUE: water use efficiency. **: highly significant at p<0.01 level of probability, *: significant at p<0.05 level of probability and ^{ns}: non-significant at p<0.05 level of probability.

Table 3. Analysis of variance of yield and yield components during 2014/15.

Source of variation	Degree of freedom	MS					
		NTPH	FBM	DBM	EOC	EOY	WUE
Replication	2	30.99^{ns}	11.375^{ns}	0.348^{ns}	0.0004^{ns}	572.43^{ns}	0.0019^{ns}
Treatment	7	9.406^{ns}	23.171**	1.860**	0.0025*	166.86^{ns}	0.4359**
Error	14	8.825	3.292	0.394	0.0006	398.47	0.0021

MS: mean squares, NTPH: number of tillers per hill, FBM: aboveground fresh biomass, DBM: aboveground dry biomass, EOC: essential oil content, EOY: essential oil content, WUE: water use efficiency. **: highly significant at p<0.01 level of probability, *: significant at p<0.05 level of probability and ^{ns}: non-significant at p<0.05 level of probability.

Table 4. Effect of supplemental irrigation on yield and water use efficiency of lemongrass at Wondo Genet 2013/14.

Treatments	NTPH	FBM (t/ha)**	DBM (t/ha)*	EOC (t/ha)**	EOY (t/ha)*	WUE (kg/mm)**
Rain-fed (no SI)	27.3	29.7^{d}	5.74^{b}	0.54^{a}	152.2^{c}	0.59^{a}
100% ETc SI	29.7	43.4^{a}	9.15^{a}	0.44^{c}	187.8^{abc}	0.19^{f}
75% ETc SI	30.0	42.6^{a}	8.80^{a}	0.51^{ab}	219.7^{a}	0.24^{ef}
50% ETc SI	28.5	39.9^{ab}	8.58^{a}	0.52^{ab}	198.6^{ab}	0.27^{de}
25% ETc SI	26.8	36.4^{bc}	8.18^{a}	0.49^{b}	168.4^{bc}	0.32^{cd}
One SI at mid stage	28.4	33.8^{cd}	8.10^{a}	0.53^{ab}	172.3^{bc}	0.38^{bc}
One SI at maturity stage	30.6	36.4^{bc}	8.41^{a}	0.51^{ab}	184.1^{abc}	0.32^{bcd}
Two SI (at mid & maturity stage)	29.5	39.8^{ab}	9.07^{a}	0.55^{a}	219.8^{a}	0.39^{b}
CV (%)	8.77	8.81	12.17	4.77	11.41	11.52
$LSD_{0.05}$	ns	5.8	1.76	0.04	37.5	0.07

NB: - ET_C: evapotranspiration of the crop, SI: supplementary irrigation, NTPH: number of tillers per hill, FBM: aboveground fresh biomass, DBM: aboveground dry biomass, EOC: essential oil content, EOY: essential oil content, WUE: water use efficiency. Means followed by different letters in a column differ significantly and those followed by same letter are not significantly different at p<0.05 level of significance. ^{ns}: non-significant at p<0.05. NTPH, EOC and WUE is average of each harvest. FBM, DBM and EOY is total yield obtained during the year (five harvesting cycle).

Table 5. Effect of supplemental irrigation on yield and water use efficiency of lemongrass at Wondo Genet 2014/15

Treatments	NTPH	FBM (t/ha)**	DBM (t/ha)**	EOC (t/ha)*	EOY (t/ha)	WUE (kg/mm)**
Rain-fed (no SI)	50.3	51.1^{e}	11.4^{d}	0.64^{a}	325.1	1.47^{a}
100% ETc SI	51.4	60.1^{a}	13.8^{a}	0.55^{d}	328.1	0.28^{d}
75% ETc SI	51.3	57.8^{ab}	13.6^{ab}	0.58^{cd}	334.4	0.31^{d}
50% ETc SI	52.1	56.9^{bc}	13.4^{abc}	0.59^{bc}	336.1	0.40^{c}
25% ETc SI	48.4	54.1^{cde}	12.5^{cd}	0.61^{abc}	329.2	0.57^{b}
One SI at mid stage	50.1	53.7^{de}	12.3^{cd}	0.60^{abc}	322.5	0.51^{b}
One SI at maturity stage	53.1	55.4^{bcd}	12.5^{bc}	0.61^{abc}	338.6	0.58^{b}
Two SI (at mid & maturity stage)	47.9	54.8^{bcd}	12.7^{bc}	0.63^{ab}	344.8	0.41^{c}
CV (%)	5.87	3.27	4.91	4.13	6.01	8.03
$LSD_{0.05}$	ns	3.2	1.1	0.04	Ns	0.08

NB: - ET_C: evapotranspiration of the crop, SI: supplementary irrigation, NTPH: number of tillers per hill, FBM: aboveground fresh biomass, DBM: aboveground dry biomass, EOC: essential oil content, EOY: essential oil content, WUE: water use efficiency. Means followed by different letters in a column differ significantly and those followed by same letter are not significantly different at p<0.05 level of significance. ^{ns}: non-significant at p<0.05. NTPH, EOC and WUE is average of each harvest. FBM, DBM and EOY is total yield obtained during the year (five harvesting cycle).

similar with that of 25% ET_C and supplementary irrigation only during the mid-season stage treatments during the second year. The study revealed that application of full supplemental irrigation on lemongrass at the study area leads to improvement of dry biomass by 59.4 and 21.1% as compared with the rain-fed system during 2013/14 and 2014/15, respectively.

The decrease in dry biomass production in rain-fed and lower supplemental irrigation water treatments might be due shortage of adequate moisture supply to the crop from the soil. As water supply to crops is the main component of photosynthesis process, its reduction has a direct negative impact with the dry matter production of crops as photosynthesis is a process to make dry matter in crop production [18]. Similar findings were also reported in different crops due to supplemental irrigation leads to improve higher crop yield production [1]. On the other hand, different research also revealed that reduction of moisture leads to reduce lemongrass biomass production [17]. Different research findings also revealed that application of supplemental irrigation at different growth stages improve crop yield and yield components. For example application of supplemental irrigation at different growth stages of wheat affects yield and yield component of wheat. Moreover, it increased both photosynthetic rate and transpiration rate in which the net effect is higher [20]. Others also recommend that timely and adequate amount of supplemental irrigation could improve yield and yield components of different crops which leads to even improve water productivity [1].

Essential oil content

Significant ($p<0.05$) difference between treatments was observed in essential oil content of lemongrass due to application of supplemental irrigationat different irrigation levels and on different crop growth stages during both the study years (Table 2 and 3). The study revealed that higher essential oil was associated with application of lower supplementary irrigation and rain-fed treatments. Maximum essential oil content (0.55%) was recorded at application of supplemental irrigation at two stages (mid and maturity stages) which was followed by rain-fed treatment (0.54%) during the first year and at rain-fed (0.64%) which is followed by application of supplemental irrigation at two stages (0.63%) during the second experimental year, respectively (Table 4 and 5). Contrary to this, application of higher supplemental irrigation leads to minimum essential oil content in which 100% ET_c leads to the lowest (0.44 and 0.55%) oil content during both year and it was statistically inferior to all other treatments during the first experimental year and statistically similar with that of 75% ET_c during the second year.

The improved essential oil content due to lower supplemental irrigation and rain-fed treatments might be due to the stress in lower supplemental irrigation leads to improve secondary metabolites like essential oil content as compared with the higher irrigation water applied treatments. According to the findings of Singh *et al*. [21] essential oil content of lemongrass was not affected by different levels of soil moisture regime or nitrogen application. Moreover, it was reported that lemongrass is a tolerant crop for moisture stress by the same author. On the other hand, a different research report was also reported that different deficit levels did not affect essential oil content in lemongrass [17]. However, this might be due to the fact that all treatments obtained irrigation and the deficit was imposed only during one harvesting cycle of lemongrass which is for two month.

Essential oil yield

Application of different supplemental irrigation level and at different growth stage had a significant ($p<0.05$) influence on essential oil yield production of lemongrass during 2013. However, no significant ($p>0.05$) variation was observed among different treatments during 2014 (Table 2 and 3). Maximum annual essential oil production of 219.8 and 219.7 kg/ha were recorded at 75% ET_c and supplemental irrigation during two growth stages (mid and maturity stages) treatments during the first year, respectively (Table 4 and 5). However, the maximum essential oil production obtained was statistically similar with 50% ET_c supplemental irrigation and supplemental irrigation only during maturity stage treatments. On the other hand, minimum annual essential oil production of 152.2 kg/ha was recorded at rain-fed (no supplemental irrigation) treatment during the first year (Table 4 and 5). The minimum essential oil yield production obtained at rain-fed treatment was statistically similar with that of 100 and 25% ET_c, supplemental irrigation only during mid-stage and supplemental irrigation only during maturity stage treatments in the first year. The study revealed that application of higher supplemental irrigation on lemongrass at the study area leads to improvement of essential oil yield during the first year and this might be due to the higher improvement of biomass production during 2013/14 and the improvement in essential oil content of supplemental irrigation in two crop growth stages which leads to improvement of 44.4% as compared with the rain-fed treatment.

Different research also revealed that reduction of moisture leads to reduce lemongrass biomass production which further leads to a reduction of total essential oil production despite improvements could be observed in essential oil content under stressed condition [17]. Former research findings in different crops are also in line with the current finding that application of supplemental irrigation at different growth stages improve crop yield and yield components. For example, Wang *et al*. [20] reported that application of supplemental irrigation at different growth stages affects yield and yield component of wheat. Others also reported that higher biomass obtained due to well watered lemongrass leads to an improvement in essential oil production of lemongrass [16,17].

Contrary to this improvement in essential oil yield production during the first year, significant variation was not observed during the second year. However, the average annual essential oil production varied from 322.5 to 344.8 kg/ha during 2014 cropping season (Table 5). Even though significant improvement in biomass production was observed due to the higher levels of supplemental irrigation treatments, essential oil content improvement for stressed treatments leads to a balance on the total essential oil production among all treatments as this perennial lemongrass get older. The results of biomass production variation during the first year was not strong enough to leads to a variation of oil production as compared with the effect of essential oil content on essential oil yield during the second year.

Water use efficiency

Application of different supplemental irrigation levels and at different growth stages had a highly significant ($p<0.01$) influence on water use efficiency based on essential oil yield production of lemongrass during both 2013/14 and 2014/15 season (Table 2 and 3). The study showed that higher water use efficiency associated with lower supplemental irrigation treatments. The maximum water use efficiency of 0.59 and 1.47 kg/mm were recorded at rain-fed treatment during both years (Table 4 and 5). Moreover, the maximum water use efficiency obtained at the rain-fed (no supplemental) treatment was statistically superior to all other treatment during both the experimental years. On the other hand, minimum water use efficiency of 0.19 and 0.28 kg/mm were recorded at 100% ET_c (full supplemental irrigation) treatment (Table 4 and 5). However, the minimum water use efficiency obtained due to 100% ETC was statistically similar with that of 75% ET_c during both years. The study revealed that application of full supplemental irrigation on lemongrass at the study area leads to a reduction of water use efficiency by 67.8 and 81.0% as compared with the rain-fed system during the first and the second years, respectively.

The decrease in water use efficiency for higher supplemental irrigation treatments might be due lemongrass is not as much responsive for additional amount of irrigation beyond the rainfall and its tolerance for drought stress. Moreover, as the study clearly showed, essential oil content was reduced when ample amount of moisture available in the soil than rain-fed and lower supplemental irrigation water applied treatments. This might be due to drought stress leads to improvement in secondary metabolites like essential oil which leads to improve water use efficiency by producing comparable oil yield with lower moisture in the soil (Yang *et al*., 2018).

Similar findings were also reported on lemongrass that higher irrigation levels leads to a reduction in water use efficiency due to consuming huge amount of water but nearly similar essential oil yield as compared with the lower irrigated treatments with deficit irrigation [17]. The improvement in water use efficiency in no supplementary treatment and lower supplementary treatments is majorly due to the high tolerance level of lemongrass for moisture stress [21]. However, different former research in different crops revealed that timely and adequate amount of supplemental irrigation could improve water productivity [1,3]. This might be due to most of the crops were food crops in which the yield is different as compared with lemongrass economic yield which is essential oil.

Conclusion

This study clearly revealed that application of higher supplementary irrigation leads to improve both biomass and essential oil yield of lemongrass as compared with the rainfed and lower amount of supplemental irrigation. However, as lemongrass get older during the second year higher essential oil content in the rainfed and lower supplementary irrigation level leads to balance the total essential oil yield production with the higher supplemental irrigation treatments. On the other hand, water use efficiency was found to be negatively associated with the amount of supplementary irrigation as it produced comparable essential oil yield with lower irrigation water amount in the rainfed and lower supplementary irrigation treatments. Therefore, for maximizing biomass yield production and essential oil yield during the first year full supplementary irrigation or application of two supplementary irrigation one during mid-season stage and the other during maturity stage could leads to improve both biomass and oil yield. However, in area where limited amount of irrigation water available and the main concern is production of essential oil and not biomass production, two supplementary irrigation at mid-season and maturity stage could be applied during the first year and using rainfed during the second year to maximized the water use efficiency in water scarce area at the study area and similar agro-ecology and soil type.

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