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# Response of Lemongrass (*Cympopogon citratus* (DC) Stapf) to Deficit Irrigation and Furrow Irrigation Water Application Methods at Wondo Genet, 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 three years (2015/16 to 2017/18) based on the objective to determine the level of deficit irrigation levels and furrow irrigation water application techniques on yield and water productivity of lemongrass (*Cympopogon citratus* (DC) Stapf). Three types of furrow irrigation techniques (alternate, fixed and conventional furrow) combined with different irrigation levels (100, 75 and 50% $ET_C$) with three replications were used in randomized complete block design. Different furrow irrigation application methods and irrigation levels highly significantly ($p<0.01$) affected fresh biomass, dry biomass and water use efficiency of lemongrass during 2015/16 and 2017/18. Moreover, essential oil yield of lemongrass was significantly ($p<0.05$) affected due to different furrow irrigation application methods and irrigation levels both during 2015/16 and 2017/18. However, no significant ($p \geq 0.05$) variation was observed in number of tillers per hill and essential oil content of lemongrass due to different furrow irrigation methods and deficit levels during 2015/16 and 2017/18. Higher fresh biomass (9610, 7348 and 4458 kg/ha) and dry biomass (2507, 2136 and 1408 kg/ha) were obtained at 100% ETC under conventional furrow method during the three successive years. Similarly, maximum essential oil yield of 62.5 and 40.1 kg/ha was obtained at conventional furrow irrigation method with 75 and 100% ETC during 2015/16 and 2017/18, respectively. On the other hand, minimum fresh biomass (7123, 4689 and 2296 kg/ha) and dry biomass (1903, 1308, 704 kg/ha) during the three successive year, and essential oil yield of 44.9 and 20.0 kg/ha were obtained at fixed furrow with 50% ETC during 2015/16 and 2017/2018, respectively. In addition to these, higher water productivity of 0.080, 0.075 and 0.052 kg/$m^3$ was obtained due to alternate furrow irrigation with 50% $ET_C$ during three successive years. On the other hand, the minimum water productivity of 0.024, 0.026 and 0.021 kg/$m^3$ was obtained at conventional furrow technique with 100% $ET_C$ during 2015/16, 2016/17 and 2017/18, respectively. Therefore, for maximizing essential oil yield under no water limiting scenario, lemongrass could be irrigated with conventional furrow irrigation methods with 100% $ET_C$. However, under limited water resource condition, the main objective will be to maximize the water use efficiency without significantly reducing the oil yield. Therefore, in this case lemongrass could be irrigated with alternate furrow technique with 100% $ET_C$ at Wondo Genet and similar agro-ecology and soil type.

**Keywords:** Alternate furrow; Conventional furrow; Fixed furrow; Lemon grass; Water use efficiency

## Introduction

Lemongrass (*Cymbopogon citratus* (DC) Stapf) is one of the essential oil-bearing perennial grasses belong to Poaceae or Gramineae family which mainly used for aromatic and medicinal purposes. Among the aromatic purpose it is widely used in different foods, soft drink, alcohols and sanitation materials like soups. Moreover, 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, anti-purgative and sudorrific to reduce fever with anti-oxidant activity [1-4]. Lemongrass could be grown as a perennial crop under either irrigated or non-irrigated condition in different part of the world especially in India in which most of the oil produced is being exported to West Europe, U.S.A. and Japan [5].

Irrigated agriculture supply more than 40% of food and agricultural commodities within 17% of agricultural land with consumption of more than 70% of the water withdrawal from all sources; despite water is limited resource and the temporal and spatial variation exacerbating the problems [6]. Moreover, among different water consuming sectors, irrigation is the most inefficient sector [7]. On the other hand, water scarcity is increasing from time to time in the globe and now days almost one-fifth of the world's population live in areas of scarcity and almost one quarter of the world's population face economic water shortage [8].

However, application of irrigation water is essential as crop growth and yield majorly affected due to drought in different crops especially in low rainfall areas [9]. Similarly, despite high tolerance to a wide range of soils and climatic conditions, better performance of lemongrass growth and yield could be obtained on well-drained sandy loam soil with high fertility and exposed to sunlight with good irrigation [10]. Lemongrass is cultivated under rain fed condition in high rainfall area and as irrigated crop under semi-arid tropical conditions [11,12].

Since water stress is among the major factors that affect the yield of different crops, it is essential to maximize the yield obtained per amount of irrigation water used in water limiting areas. The issue is more vital as agricultural land and irrigation water are rapidly diminishing due to rapid industrialization and urban development [13].

Under limited water resource area, efficient utilization of the

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scarce water resource in irrigated agriculture is crucial. Previous research reports revealed that, water productivity of different crops improved through deficit irrigation practices. Among these, furrow irrigation water application techniques like alternate furrow irrigation for different irrigated crops was reported [14-16]. Meskelu et al. [17] reported that, maximum water use efficiency based on essential oil yield was obtained due to deficit irrigation under alternate furrow irrigation method on spearmint plant. Moreover, Nasri et al. [18] reported that, alternate furrow irrigation save water in arid area where higher irrigation water applied for maize production.

Different studies have been reported the influence of deficit irrigation on water productivity improvement in different crops, majorly food crops. However, little information is available on aromatic crops especially lemongrass on deficit irrigation in the study area. Hence, this research was conducted based on an objective to improve water productivity and to evaluate lemongrass herbage and essential oil yield under limiting water resource scenario with deficit irrigation under alternate, fixed and conventional furrow irrigation water application methods.

## 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 three dry seasons (from mid November to mid January) during 2015/16, 2016/17 and 2017/18 based on an objective to determine the effect of deficit irrigation on yield and water productivity of lemongrass (*Cymbopogon citratus* 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 1.1 g/cm$^3$ and total volumetric available water in the root zone was 130 mm/m. The climate of the area is characterized as semi-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 maximum temperature varies from 23.3 to 28.4°C; while mean minimum temperature varies from 9.3 to 12.5°C (Table 1).

### Experimental design and procedure

The field experiment was carried out using the design procedure set by Gomez and Gomez [19] for randomized complete block design with three replications. Each experimental unit had 3.00 m length and 3.00 m width with spacing of 1.50 m between each units and 3.00 m between blocks. Nine treatments, three level of deficit irrigation and three furrow irrigation water application techniques were used in combination. Furrow irrigation water application techniques used include alternate furrow (selective watering of every other furrow alternating during consecutive irrigation; considering furrow number from the beginning, irrigation was done for only odd number furrows during first irrigation then for only the even number furrows in the next irrigation time), Fixed furrow (selective watering of every other furrow without alternating during consecutive irrigation; considering furrow number from the beginning, irrigation was done for only odd number furrows during all irrigation time) and conventional furrow (irrigating every furrows; all furrows were irrigated during all irrigation time which is a control treatment). These treatments were randomly assigned in each experimental units (plots) as follows:

i. 100% ETc in alternate furrow,

ii. 75% ETc in alternate furrow,

iii. 50% ETc in alternate furrow,

iv. 100% ETc in fixed furrow,

v. 75% ETc in fixed furrow,

vi. 50% ETc in fixed furrow,

vii. 100% ETc in conventional furrow (control),

viii. 75% ETc in conventional furrow and

ix. 50% ETc in conventional furrow irrigation application system.

After the experimental land prepared well for better performance of the crop, lemongrass (*Cymbopogon citratus* (DC) Stapf) bulbous stems were collected from one year old mature plant from well-grown clumps. The tops of clumps were cut off 25 cm from the root and the lower brown sheath was removed to expose young roots. Three tiller splits were planted at an interval of 60 cm both between plant (hill) and row of plant in the ridge of furrow prepared in 60 cm spacing. Regular agricultural management like weeding and hoeing in the study area were followed during the experimental period for all plots uniformly.

Irrigation water was applied based on the treatment variation, after it is calculated using CROPWAT 8.0 software using necessary input data. The calculated gross irrigation depth was applied using 2-inch Parshall flume. Soil sample before and after irrigation was taken to monitor the moisture dynamics in the control treatment until the moisture content depleted by 60% from field capacity. The rest treatments obtained irrigation water with in the same date as control

| Month | $T_{min}$ (°C) | $T_{max}$ (°C) | 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 |
| Source: Wondo Genet College of Forestry Metrology Station | | | | | | |

**Table 1:** Long-term (1980 to 2015) monthly climatic data of the experimental area.

treatment and the irrigation depth was given based on the percentage of treatment.

### Data collection and analysis

Lemongrass yield and yield components were collected from central five plant hills in the plot excluding border rows. Field data on number of tiller per hill was collected from these sample hills by counting the number of tillers within the sample hills and the mean was calculated. For other yield and yield component data, the selected five samples were harvested 30 cm above the ground at the edge of the leaf manually using sickle. The harvesting was done 120 days after planting for the first harvest and 60 days after first cut for the proceeding harvest. 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 at 105°C for 3 hours. 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.

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

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 level of deficit irrigation with different furrow irrigation water application techniques significantly affected all recorded yield and yield components except number of tillers per hill and essential oil content. Significantly highest fresh and dry biomass yield of lemongrass was recorded in the conventional furrow irrigation technique with 100% $ET_C$ while the highest water use efficiency was associated with alternate furrow irrigation technique when the deficit level is 50% $ET_C$.

### Number of tillers per hill

Number of tillers per hill was not significantly ($p\geq0.05$) affected due to different level of deficit irrigation and furrow irrigation water application technique during all season except 2016/17. Although there was no statistical difference among different treatments, average number of tillers per hill recorded varied from 25.5 to 32.0 and 22.8 to 33.9 during 2015/16 and 2017/18, respectively. This might be due to the fact that the number of tiller per hill established during the common establishment at initial growth stage. This is in line with the findings of Henok et al. [20] who reported that different level of soil moisture depletion level did not influenced number of tiller per hill in lemongrass. Similarly, there are also some reports who found no difference in number of tiller per hill in some of the harvesting cycle due to different irrigation levels. For example, Singh et al. [21] reported that the number of tiller of lemongrass at the 1st, 4th and 5th harvest did not respond significantly to increasing levels of irrigation.

### Fresh biomass and dry biomass

Different levels of deficit irrigation under different furrow irrigation water application techniques significantly ($p<0.01$) influenced fresh biomass production of lemongrass during 2015/16 and 2017/18. Similarly, fresh biomass production of lemongrass was significantly ($p<0.05$) affected due to different deficit levels during 2016/17. Moreover, dry biomass production of lemongrass was highly significantly ($p<0.01$) influenced due to different levels of deficit irrigation under different furrow irrigation water application techniques during all the three study years. The study revealed that higher both fresh and dry biomass production associated with application of higher irrigation water depth.

Maximum fresh biomass (9610, 7348 and 4458 kg/ha) and dry biomass (2507, 2136 and 1408 kg/ha) were recorded at 100% $ET_C$ under conventional furrow irrigation techniques during three consecutive years. Moreover, the maximum fresh biomass obtained at 100% $ET_C$ under conventional furrow was statistically similar with 75% $ET_C$, under conventional furrow during all the study years. On the other hand, the minimum fresh biomass (7123, 4689 and 2296 kg/ha) and dry biomass (1903, 1308 and 704 kg/ha) were obtained at 50% $ET_C$ under fixed furrow irrigation and these were not statistically different with that of 50 and 75% $ET_C$ under alternate furrow and fixed furrow irrigation (Tables 2-4). Reduction of irrigation water from 100% $ET_C$ to 50% $ET_C$ under conventional and fixed furrow leads to a reduction of fresh biomass by 26, 36 and 48% during 2015/16, 2016/17 and 2017/18, respectively. Likewise, 24, 39 and 50% reduction in dry biomass was observed due to increasing deficit level from 100% $ET_C$ in conventional furrow to 50% $ET_C$ in fixed furrow during 2015/16, 2016/17 and 2017/18, respectively.

Higher lemongrass fresh and dry biomass was obtained at higher

| Treatment | NTPH | FBM (kg/ha)** | DBM (kg/ha)** | EOC (%) | EOY (kg/ha)* | WP (kg/m$^3$)** |
|---|---|---|---|---|---|---|
| 100% AF | 25.6 | 8287$^{bc}$ | 2374$^{a}$ | 0.71 | 58.7$^{ab}$ | 0.047$^{b}$ |
| 75% AF | 28.1 | 7613$^{cd}$ | 2062$^{bc}$ | 0.60 | 45.7$^{c}$ | 0.048$^{b}$ |
| 50% AF | 27.6 | 7600$^{cd}$ | 2274$^{ab}$ | 0.66 | 50.1$^{bc}$ | 0.080$^{a}$ |
| 100% FF | 25.5 | 8591$^{b}$ | 2357$^{ab}$ | 0.71 | 60.7$^{ab}$ | 0.048$^{b}$ |
| 75% FF | 25.5 | 7403$^{d}$ | 2075$^{bc}$ | 0.72 | 53.4$^{abc}$ | 0.056$^{b}$ |
| 50% FF | 27.7 | 7123$^{d}$ | 1903$^{c}$ | 0.63 | 44.9$^{c}$ | 0.071$^{a}$ |
| 100% CF | 29.2 | 9610$^{a}$ | 2507$^{a}$ | 0.63 | 60.5$^{ab}$ | 0.024$^{d}$ |
| 75% CF | 29.2 | 9423$^{a}$ | 2509$^{a}$ | 0.66 | 62.5$^{a}$ | 0.033$^{cd}$ |
| 50% CF | 32.0 | 9449$^{a}$ | 2507$^{a}$ | 0.59 | 55.6$^{abc}$ | 0.044$^{bc}$ |
| CV (%) | 11.7 | 5.6 | 7.5 | 10.5 | 12.0 | 15.5 |
| $LSD_{0.05}$ | ns | 807 | 295 | ns | 11.4 | 0.014 |

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 $p<0.05$; *significant at $p<0.05$; **significant at $p<0.01$; NTPH: number of tillers per hill; FBM: fresh biomass; DBM: dry biomass; EOC: essential oil content; EOY: essential oil yield; WP: water productivity; CV: coefficient of variation; $LSD_{0.05}$: Fisher's least significant difference at 5% probability level.

**Table 2:** Lemongrass response to deficit irrigation at Wondo Genet 2015/16 (one harvest).

| Treatments | NTPH* | FBM (kg/ha)* | DBM (kg/ha)** | EOC (%) | EOY (kg/ha) | WP (kg/m³)** |
|---|---|---|---|---|---|---|
| 100% AF | 41.7$^{c}$ | 5756$^{bc}$ | 1688$^{bc}$ | 0.88 | 50.9 | 0.040$^{ef}$ |
| 75% AF | 43.1$^{bc}$ | 5529$^{bc}$ | 1585$^{bcd}$ | 0.96 | 53.3 | 0.055$^{cd}$ |
| 50% AF | 40.5$^{c}$ | 5015$^{bc}$ | 1416$^{cd}$ | 0.96 | 48.1 | 0.075$^{a}$ |
| 100% FF | 43.0$^{bc}$ | 5799$^{bc}$ | 1630$^{bc}$ | 0.92 | 53.3 | 0.042$^{de}$ |
| 75% FF | 41.7$^{c}$ | 5719$^{bc}$ | 1551$^{bcd}$ | 0.97 | 55.4 | 0.058$^{bc}$ |
| 50% FF | 48.7$^{a}$ | 4689$^{c}$ | 1308$^{d}$ | 0.95 | 44.5 | 0.070$^{ab}$ |
| 100% CF | 43.6$^{bc}$ | 7348$^{a}$ | 2136$^{a}$ | 0.92 | 67.2 | 0.026$^{f}$ |
| 75% CF | 47.0$^{ab}$ | 6243$^{ab}$ | 1758$^{b}$ | 0.90 | 56.5 | 0.029$^{ef}$ |
| 50% CF | 43.6$^{bc}$ | 5959$^{b}$ | 1674$^{bc}$ | 0.90 | 53.5 | 0.042$^{de}$ |
| CV (%) | 6.0 | 12.4 | 11.0 | 6.10 | 15.0 | 16.6 |
| $LSD_{0.05}$ | 4.5 | 1243 | 312 | ns | ns | 0.014 |

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; *significant at p<0.05; **significant at p<0.01; NTPH: number of tillers per hill; FBM: fresh biomass; DBM: dry biomass; EOC: essential oil content; EOY: essential oil yield; WP: water productivity; CV: coefficient of variation; $LSD_{0.05}$: Fisher's least significant difference at 5% probability level.

**Table 3:** Lemongrass response to deficit irrigation at Wondo Genet 2016/17 (one harvest).

| Treatments | NTPH | FBM (kg/ha)** | DBM (kg/ha)** | EOC (%) | EOY (kg/ha)* | WUE (kg/m³)** |
|---|---|---|---|---|---|---|
| 100% AF | 33.7 | 3724$^{abc}$ | 1147$^{abc}$ | 0.94 | 34.9$^{abc}$ | 0.036$^{bc}$ |
| 75% AF | 33.9 | 3194$^{bcd}$ | 1020$^{c}$ | 0.92 | 29.8$^{abcd}$ | 0.041$^{ab}$ |
| 50% AF | 26.4 | 2949$^{cd}$ | 874$^{cd}$ | 0.85 | 25.1$^{cd}$ | 0.052$^{a}$ |
| 100% FF | 22.8 | 3147$^{bcd}$ | 983$^{cd}$ | 0.88 | 27.9$^{cd}$ | 0.029$^{bcd}$ |
| 75% FF | 26.5 | 3102$^{bcd}$ | 997$^{cd}$ | 0.91 | 28.6$^{bcd}$ | 0.040$^{abc}$ |
| 50% FF | 26.2 | 2296$^{d}$ | 704$^{d}$ | 0.88 | 20.0$^{d}$ | 0.042$^{ab}$ |
| 100% CF | 33.8 | 4458$^{a}$ | 1408$^{a}$ | 0.90 | 40.1$^{a}$ | 0.021$^{d}$ |
| 75% CF | 33.9 | 4021$^{ab}$ | 1336$^{ab}$ | 0.97 | 39.1$^{ab}$ | 0.027$^{cd}$ |
| 50% CF | 28.9 | 3232$^{bcd}$ | 1044$^{bc}$ | 0.94 | 30.3$^{abcd}$ | 0.031$^{bcd}$ |
| CV (%) | 25.1 | 16.3 | 16.7 | 8.0 | 20.5 | 21.7 |
| $LSD_{0.05}$ | ns | 942.4 | 306.2 | ns | 10.9 | 0.013 |

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; *significant at p<0.05; **significant at p<0.01; NTPH: number of tillers per hill; FBM: fresh biomass; DBM: dry biomass; EOC: essential oil content; EOY: essential oil yield; WP: water productivity; CV: coefficient of variation; $LSD_{0.05}$: Fisher's least significant difference at 5% probability level.

**Table 4:** Lemongrass response to deficit irrigation at Wondo Genet 2017/18 (one harvest).

irrigation levels in conventional furrow irrigation method. Similar result was reported by Singh et al. [21] that higher herbal yield was obtained under optimum irrigation level in lemongrass. The current finding is also in line with the former findings of Skaria et al. [11] who reported better performance of lemongrass growth and yield obtained with good irrigation. The reduction in fresh and dry biomass as deficit level increase might be due to the drought stress that reduces photosynthesis capacity through reduction of chlorophyll content and damage of the reaction center of photosystem [22]. This highly affects biomass production of a plant as more than 90% of biomass is from photosynthesis in which water is the main constituent [23]. Different studies revealed that moisture stress in crop affects biomass production. Henok et al. [20] reported moisture stress due to higher depletion level in lemongrass leads to a reduction in both fresh and dry biomass production. Similar findings were reported by Meskelu et al. [17] and Okwany et al. [24] on spearmint, Sharmin et al. [25] on Japanese mint and Bahreininejad et al. [26] on *Thymus daenensis*. Moreover, the study showed that both fresh and dry biomass production were decreased as lemongrass gets older. This is in agreement with the findings of Kothari et al. [27] who reported *Ocimum tenuiflorem* biomass decreased as it gates older.

## Essential oil content and Essential oil yield

Essential oil content of lemon grass was not significantly (p≥0.05) affected due to different levels of deficit irrigation under different furrow irrigation water application techniques. However, the value ranged from 0.59 to 0.72, 0.88 to 0.97 and 0.85 to 0.97 during 2015/16, 2016/17 and 2017/18, respectively. On the other hand, different levels of deficit irrigation under different furrow irrigation water application techniques significantly (p<0.05) influenced essential oil yield of lemongrass during 2015/16 and 2017/18. However, during 2016/17 essential oil yield was not significantly (p≥0.05) affected due to different levels of deficit irrigation and furrow irrigation water application technique.

Maximum essential oil yield of 62.5 and 40.1 kg/ha was obtained at 75 and 100% $ET_C$ both under conventional furrow irrigation method during 2015/16 and 2017/18, respectively. However, the maximum essential oil yield obtained at 75 and 100% $ET_C$ under conventional furrow irrigation water application technique was statistically similar with 50% $ET_C$ under conventional furrow irrigation and 100% $ET_C$ under alternate and fixed furrow methods (Tables 2-4). On the other hand, minimum essential oil yield of 44.9 and 20.0 kg/ha was obtained at 50% $ET_C$ under fixed furrow method during 2015/16 and 2017/18, respectively. Generally, the study revealed that higher essential oil yield associated with application of higher irrigation water depth. This might be due to higher biomass production under higher irrigation water application depth despite no statistical variation in essential oil content among different treatments. Reduction of irrigation water from 75 and 100% $ET_C$ under conventional furrow method to 50% $ET_C$ under fixed furrow leads to a reduction of essential oil yield by 28 and 50% during 2015/16 and 2017/18, respectively. Moreover, the study showed that essential oil yield production was decreased as lemongrass gets older from 2015/16 to 2017/18 dry season.

Better essential oil yield was recorded at higher irrigation levels in conventional furrow irrigation method. This is might be due to higher biomass production when good irrigation applied for lemongrass which is in agreement with Skaria et al. [10]. Moreover, Singh et al. [21] reported that optimum irrigation level leads to higher essential oil production for lemongrass. The reduction in essential oil yield as deficit level increase might be due to the reduction of biomass despite similar essential oil content, as drought stress reduces it since moisture stress affects photosynthesis [22].

Different studies revealed that moisture stress due to different water saving practices like deficit irrigation in crop affects essential oil production. For example, Henok et al. [20] reported moisture stress due to higher depletion level in lemongrass leads to a reduction of essential oil production. Similar findings were also reported by Elias et al. [17] and Okwany et al. [24] on spearmint, Sharmin et al. [25] on Japanese mint and Bahreininejad et al. [26] on *Thymus daenensis*. On the other hand, Singh et al. [28] reported that quality of the essential oil is not affected by soil moisture regimes.

### Water productivity

Water productivity of lemongrass was highly significantly ($p<0.01$) influenced by different levels of deficit irrigation under different furrow irrigation water application techniques during all the three experimental years. Maximum water productivity of 0.080, 0.075 and 0.052 kg/m$^3$ was obtained at 50% $ET_C$ with alternate furrow irrigation water application technique during all the three years. However, the maximum water productivity obtained at 50% $ET_C$ under alternate furrow irrigation method was statistically similar with 50% $ET_C$ with fixed furrow method during 2015/16 and 2016/17, with 75% $ET_C$ both under alternate and fixed furrow during 2017/18, respectively (Tables 2-4).

On the other hand, lowest water productivity (0.024, 0.026 and 0.021 kg/m$^3$) was recorded at 100% $ET_C$ under conventional furrow method during all the experimental years. However, the minimum water productivity obtained at 100% $ET_C$ with conventional furrow method is statistically similar with 75% $ET_C$ with conventional furrow during all the three years. Moreover, it was not statistically different with 100% $ET_C$ under alternate furrow during 2016/17, and with 50% $ET_C$ under conventional furrow and 100% $ET_C$ under fixed furrow during 2017/18. Increasing the amount of irrigation water depth from 50% $ET_C$ under alternate furrow method to 100% $ET_C$ with conventional furrow method reduce water productivity by 70, 65 and 60% during 2015/16, 2016/17 and 2017/18, respectively.

The study revealed that higher water productivity achieved when lower irrigation depth applied and lower water productivity associated with higher irrigation water application for lemongrass. Similar finding was reported by Elias et al. [17] that maximum water use efficiency based on essential oil yield was achieved due to deficit irrigation level under alternate furrow irrigation method on spearmint plant.

On the other hand, Singh et al. [21] reported that higher water use efficiency obtained at optimum irrigation level. The current finding is in conflict with this report which might be due to lower difference in essential oil yield production than difference in irrigation amount between the optimum irrigation and lower irrigation level treatments. The current finding is in line with Henok et al. [20] who reported higher water productivity achieved at 60% depletion level than the frequently irrigated treatments in lemongrass in the same study area. This might be due to higher tolerance level of lemongrass for drought and yielding comparable essential oil yield despite lower irrigation water applied. Different former reports in different crops also revealed that certain degree of water stress improve water productivity [29-33] (Tables 2-4).

## Conclusions

The current study revealed that application of 100% $ET_C$ irrigation water with conventional furrow method improved fresh and dry biomass of lemongrass than the deficit treatments. Similarly, essential oil yield production of lemongrass was also higher under higher irrigation depth treatments of convention furrow with 100% $ET_C$ due to higher biomass and similar oil content. On the other hand, water use efficiency was associated with lower irrigation depth treatment due to comparable oil yield under lower irrigation depth. Accordingly, application of 50% $ET_C$ irrigation depth under alternate furrow method leads to the higher water productivity with significant yield reduction. On the other hand, application of 100% $ET_C$ irrigation depth under alternate furrow method improve water productivity without significant reduction in essential oil yield. Therefore, for maximizing essential oil yield under no water limiting scenario, lemongrass could be irrigated with conventional furrow irrigation methods with 100% $ET_C$. However, under limited water resource condition, the main objective will be to maximize the water use efficiency without significantly reducing the oil yield in which 100% $ET_C$ under alternate furrow method satisfied. The mean essential oil yield of 100% $ET_C$ alternate and conventional furrow was 46.8 and 50.3 kg/ha, respectively. Thus, with the amount to irrigation water used to irrigate a hectare of land with conventional furrow irrigation, additional 0.92 ha of land could be irrigated with alternate furrow irrigation method with 100% $ET_C$. Therefore, in this case lemongrass could be irrigated with alternate furrow technique with 100% $ET_C$ at Wondo Genet and similar agro-ecology and soil type.

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