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Performance of Lemongrass (*Cymbopogon citratus* L. (DC) Stapf) Agronomic and Chemical Traits in Different Agro-Ecologies of Ethiopia

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ABSTRACT

Lemongrass (*Cymbopogon citratus* L. (DC) Stapf) is a perennial aromatic and medicinal plant that belongs to the Graminae (Poaceae) family. It has long been introduced and maintained at Wondo Genet, Southern Ethiopia. Despite its long presence, various potential uses and the existence of diverse ecologies, the plant has not been evaluated for the performance of agronomic and chemical traits in different ecologies in Ethiopia. This study was thus designed to contribute to addressing the existing technology gaps and thereby bringing the crop to the level of cultivation in Ethiopia. Data on number of tillers/plant, number of leaves/tiller, number of leaves/plant, longest leaf length, plant height, fresh herbage yield/plant, fresh herbage yield/ha/yr, essential oil (EO) content and EO yield/ha/yr were collected from six locations arranged in a complete randomized block design with four replications. In addition, the overall mean values for citral, myrcene and geraniol contents were quantified and recorded. Growing location demonstrated a highly significant influence ($P < 0.01$) on the performance of all the parameters considered. With increasing year, the performance of lemongrass was significantly ($P < 0.01$) influenced in all the studied parameters except for number of leaves/tiller. The respective average fresh herbage yield/ha, EO content and EO yield/ha varied from 7.98-28.01 t, 0.34-0.53% and 42.29-108.16 kg for first year while, during the second year, average annual fresh leaf yield/ha, EO content and EO yield/ha varied from 32.31-75.89 t, 0.45-0.55% and 155.09-342.69 kg, respectively. Increasing age from the first to the second year resulted in an increase of 165.31, 6.66 and 189.91% for fresh leaf yield/ha, EO content and EO yield/ha, respectively. The overall mean performance of lemongrass in terms of citral content over the tested locations varied from 70.81-82.68%.

Keywords: citral content, essential oil, Ethiopia, herbage yield, lemongrass, vegetative characters

INTRODUCTION

Lemongrass (*Cymbopogon citratus* (DC) Stapf) is a perennial aromatic tropical C_4 grass that belongs to the family Poaceae (Kumari *et al*. 2009). The genus *Cymbopogon* comprises about 140 species (Kumari *et al*. 2007), of which lemongrass is one of the three aromatic grasses considered to be economically important for the production of essential oils (EOs) and aromatic herbs (Hassan *et al*. 2007; Eltahir and Abuereish 2010). The name lemongrass is derived from the typical lemon-like odor of the EO present in the shoot (Joy *et al*. 2006).

Lemongrass is native to South East Asian countries and is widely cultivated in Thailand, Vietnam, Cambodia, India, Indonesia (Chagonda and Makanda 2000), Africa, South America, Australia, Europe and North America (Joy *et al*. 2006). It grows best under sunny, warm and humid conditions; however, higher altitudes aggravate infestation of rusts on its economically important parts i.e. all over its expanding leaves (Wijesekera 1981). A rainfall of 2500-3000 mm evenly distributed throughout the year is preferred for good growth and yield of leaves (Virmani *et al*. 1977; Husain *et al*. 1988). It grows in a wide range of soils, but the best yields are obtained from well drained sandy to loam soils with a pH value ranging from 4.3 to 8.4 (Joy *et al*. 2001). Calcareous and water-logged conditions are unsuitable for its cultivation (Joy *et al*. 2006).

Lemongrass can be used as carminative (Kumari *et al*. 2009), insect repellant (Joy *et al*. 2006) and is widely used as a herbal tea (Beemnet *et al*. 2010). It has remedial properties and is used to treat bronchitis, sinusitis, cold, fever, malaria, hemorrhoids, toothache, as a baby oil, massage oil, body ointment, oil for rheumatism, beauty masks, herbal baths, soap and candle-making industries and herbal recipes (Hirt and Mpia 2001). It is a good source of EO following distillation of its herbage biomass of young expanding leaves (Pino and Rosado 2000). Its EO contains a high citral content with a typical strong lemon-like aroma (Carlini *et al*. 1986; Bham *et al*. 2005). Citral is used as a basic raw material for the synthesis of B-ionine, which is used for the synthesis of a number of useful aromatic compounds, vitamin A and E, carotenoids, pharmaceuticals and fragrances (Abello *et al*. 2007). Citral also possesses antioxidant activities which may be associated with some of the reputed beneficial effects on human health (Cheel *et al*. 2005).

Because of its diverse potential uses (Hirt and Mpia 2001; Bham *et al*. 2005; Kumari *et al*. 2009; Beemnet *et al*. 2010), there is increasing interest by farmers and investors in lemongrass cultivation in Ethiopia (EIAR 2009), which is possible due to the existence of diverse ecological conditions in the country (NMSA 1996; Kebebew 2003; Andargachew 2007). However, there exists scanty information about production, processing and utilization technologies in Ethiopia. This lack of information is the major hindrance to exploit the plant's potential. Therefore, in order to contribute to addressing the existing technology gaps and bringing the crop to the level of cultivation and utilization, this study was designed with the objective of evaluating the perfor-

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Table 1 Summary of site descriptions for six testing locations in Ethiopia.

Testing locations	Latitude	Longitude	Soil pH	Soil type	Rainfall (mm)	Altitude (m.a.s.l)	Annual average temperature (°C)	
							Minimum	Maximum
Wondo Genet	7°192'N	38°382'E	6.4	Sandy clay loam (Nitosol)	1000	1876	12.02	26.72
Awada	6°03'N	38°10'E	5.9	Clay loam (Nitosol)	1267.2	1750	11.0	28.4
Aawassa	7°05'N	39°29'E	7.2	Sandy loam (Andosol)	964	1652	12.94	27.34
Deberezeit	8°44'N	38°58'E	6.9	Black heavy clay (Vertisol)	851	1891	12.22	25.72
Melkassa	8°24'N	39°21'E	7.4	Sandy clay loam (Cambisol)	770	1547	13.02	27.33
Upper Awash	8°37'N	39°43'E	8.4	Sandy clay loam (Cambisol)	500	1133	11	36

mance of lemongrass for agronomic and chemical traits under different Ethiopian ecologies.

MATERIALS AND METHODS

A field experiment was conducted in two regions of the country, namely Oromia and Southern Nations and Nationality Peoples Regional State (SNNPRS), starting from the main rainy season of 2008 to the end of 2010. Descriptions of the sites of the testing locations are presented in **Table 1**.

Seedlings (slips) of lemongrass taken from a one-year-old mother plant obtained from Wondo Genet Agricultural Research Center were transplanted to experimental plots 7 m in length and 2.4 m wide with four replications. Slips were prepared by cutting tops of clumps 20-25 cm above the ground. The lower sheath was removed to expose young roots and the old roots were clipped off keeping the slip 25-30 cm long. Three slips were planted into each hole, about 5-8 cm deep. During planting, a 50-cm spacing was maintained between plants and 60 cm between rows.

During planting and after subsequent harvesting, 20 kg N/ha was applied in the form of urea. During experimentation, all field horticultural practices were performed, as required. First, harvesting was made 3 months after planting and subsequent harvestings were made 45 days after the preceding harvest. Harvesting was done by cutting the plant 10 cm above the ground level with the help of sickles as soon as the night dew had evaporated from the plants.

Data on number of tillers/plant, number of leaves/tiller, number of leaves/plant, longest leaf length, plant height, fresh herbage yield/plant and fresh herbage yield/ha were collected at the time of field harvest. EO content and EO yield, citral content, myrcene content and geraniol content were collected following laboratory analysis.

EO content was determined on a fresh weight basis from 250 g of herbage biomass harvested from the three middle rows of a plot. The laboratory analysis was performed at the Wondo Genet Agricultural Research Center. EO was determined by hydro-distillation as illustrated by Guenther (1972). Major components of the EO such as citral, myrcene and geraniol were identified and quantified by a Varian CP-3800 GC equipped with DB-5 column and FID detector according to the procedure of Liu *et al*. (2008).

To statically analyze the differences in agronomic and chemical characteristics caused by the growing locations and years, five samples were taken from the central rows of each plot and replicated four times. Statistical analysis of experimental data was performed by analysis of variance (ANOVA) using SAS PROC GLM (2002) at $P < 0.05$. Differences between means were assessed using the least significance difference (LSD) test at $P < 0.05$.

RESULTS AND DISCUSSION

Mean squares from the first and second year and combined analysis of variance for 9 traits of lemongrass tested over 6 locations of Ethiopia are summarized in **Tables 2**, **3** and **4**. Location exerted a highly significant influence ($P < 0.01$) on the number of tillers/plant, number of leaves/tiller, number of leaves/plant, longest leaf length, plant height, fresh herbage yield/plant, fresh herbage yield/ha, EO content and EO yield of lemongrass. This indicates that these traits were influenced by changes in the environment. The significance of location effect was expected because Awada, Wondo

Table 2 Mean squares from the first year analysis of variance for nine traits of lemongrass tested over six locations of Ethiopia.

Source of variation	Df	NTPPL	NLPT	NLPP	LLL	PH	FYPP	FYPH	EOC	EOY
Replication	3	3.05	0.02	516.12	0.8510	14.09	0.01	4489415.3	0.0009	163.05
Location	3	198.80**	5.61**	8428.00**	12.06**	267.52**	0.13**	179558541.1**	0.02**	2237.95**
Error	15	15.95	0.14	948.37	12.06	18.28	0.009	2558729.7	0.001	66.37
R^2		80.73	92.80	75.43	85.10	83.42	83.28	95.95	86.24	92.14
CV%		15.36	6.76	20.37	5.81	5.78	18.80	8.56	7.40	9.90

** = Significant at $P < 0.01$; NTPPL = Number of tillers/plant; NLPT = Number of leaves/tillers; NLPP = Number of leaves/plant; LLL = Longest leaf length, PH = Plant height; FYPP = Fresh herbage yield/plant; FYPH = Fresh herbage yield/ha; EOC = Essential oil content and EOY = Essential oil yield

Table 3 Mean squares from the second year analysis of variance for nine traits of lemongrass tested over six locations of Ethiopia.

Source of variation	Df	NTPPL	NLPT	NLPP	LLL	PH	FYPP	FYPH	EOC	EOY
Replication	3	2.87	0.07	125.79	5.58	7.17	0.01	10323419	0.0003	277.40
Location	3	106.79**	5.73**	13848.50**	347.11**	445.06**	0.67**	846412140**	0.0052**	16202.82**
Error	15	3.25	0.11	376.47	9.01	3.76	0.009	4948244	0.0002	169.66
R^2		91.73	94.49	92.49	92.83	97.54	95.84	98.28	90.96	96.98
CV%		5.34	5.84	9.92	4.87	2.29	7.24	4.48	2.77	5.46

** = Significant at $P < 0.01$; NTPPL = Number of tillers/plant; NLPT = Number of leaves/tillers; NLPP = Number of leaves/plant; LLL = Longest leaf length, PH = Plant height; FYPP = Fresh herbage yield/plant; FYPH = Fresh herbage yield/ha; EOC = Essential oil content and EOY = Essential oil yield

Table 4 Mean squares from the combined analysis of variance for nine traits of lemongrass tested over six locations of Ethiopia.

Source of variation	Df	NTPPL	NLPT	NLPP	LLL	PH	FYPP	FYPH	EOC	EOY
Replication	3	2.21	0.09	229.95	4.08	10.40	0.01	12567661	0.001	403.52
Location (L)	5	222.89**	7.16**	18922.92**	403.74**	388.27**	0.62**	786289386**	0.014**	14614.28**
Year (Y)	1	720.55**	0.10ns	23687.45**	40.48**	1336.33**	8.68**	11441952807**	0.009**	293009.23**
L*Y	5	82.70**	4.17**	3353.59**	148.43**	324.31**	0.19**	239681295**	0.011**	3826.48**
Error	33	9.07	0.11	639.65	9.96	11.00	0.01	3616367	0.0006	110.64
R^2		88.28	93.63	86.54	89.53	93.13	97.28	99.28	87.72	99.06
CV%		10.08	6.03	14.58	5.20	4.18	10.95	5.57	5.24	6.55

** = Significant at $P < 0.01$ and ns =Non significant at $P < 0.05$; NTPPL = Number of tillers/plant; NLPT = Number of leaves/tillers; NLPP = Number of leaves/plant; LLL = Longest leaf length, PH = Plant height; FYPP = Fresh herbage yield/plant; FYPH = Fresh herbage yield/ha; EOC = Essential oil content and EOY = Essential oil yield

Table 5 Mean first year performance of lemon grass for vegetative characters tested over six locations of Ethiopia.

Locations	Number of tillers/plant	Number of leaves/tillers	Number of leaves/plant	Longest leaf length (cm)	Plant height (cm)
Awada	20.29 b	4.79 cd	121.33 cd	52.25 c	63.25 d
Wondo Genet	30.95 a	4.58 d	159.00 bc	56.87 bc	72.50 bc
Upper Awash	34.54 a	6.83 b	173.29 b	56.35 bc	69.85 c
Melkassa	19.70 b	5.00 cd	129.96 bcd	60.23 b	76.60 b
Deberezeit	19.00 b	5.20 c	96.79 d	59.62 b	73.75 bc
Awassa	31.45 a	7.41 a	226.58 a	73.16 a	87.87 a
Mean	25.99	5.63	151.15	59.75	73.97
$LSD_{0.05}$	6.02	0.57	46.41	5.23	6.44
CV%	15.36	6.76	20.37	5.81	5.78

Means followed by the same letter with in the same column are statistically non significant at $P < 0.05$ according to least significant difference (LSD) test

Table 6 Mean second year performance of lemon grass for vegetative characters tested over six locations of Ethiopia.

Location	Number of tillers/plant	Number of leaves/tillers	Number of leaves/plant	Longest leaf length (cm)	Plant height (cm)
Awada	34.90 b	5.10 b	177.99 b	64.05 c	87.18 b
Wondo Genet	38.63 a	7.11 a	274.36 a	69.39 b	92.60 a
Upper Awash	35.01 b	4.85 b	169.70 b	52.50 e	87.06 b
Melkassa	35.97 ab	5.00 b	179.81 b	58.45 d	86.37 b
Deberezeit	23.67 c	4.91 b	116.24 c	50.89 e	63.55 c
Awassa	34.25 b	7.43 a	255.43 a	74.24 a	90.37 a
Mean	33.74	5.73	195.58	61.58	84.52
$LSD_{0.05}$	2.72	0.50	29.24	4.52	2.92
CV%	5.34	5.84	9.92	4.87	2.29

Means followed by the same letter with in the same column are statistically non significant at $P < 0.05$ according to least significant difference (LSD) test

Table 7 Overall combined mean performance of lemon grass for vegetative characters tested for two years over six locations of Ethiopia.

Location	Number of tillers/plant	Number of leaves/tillers	Number of leaves/plant	Longest leaf length (cm)	Plant height (cm)
Awada	27.59 b	4.94 c	149.66 b	58.15 cd	75.21 d
Wondo Genet	34.79 a	5.84 b	216.68 a	63.13 b	82.55 b
Upper Awash	34.77 a	5.84 b	171.49 b	54.42 e	78.45 cd
Melkassa	27.84 b	5.00 c	154.88 b	59.34 c	81.49 cb
Deberezeit	21.34 c	5.05 c	106.52 c	55.25 de	68.65 e
Awassa	32.85 a	7.42 a	241.00 a	73.70 a	89.12 a
Mean	29.86	5.68	173.37	60.66	79.24
$LSD_{0.05}$	3.06	0.35	25.72	3.21	3.37
CV%	10.08	6.03	14.58	5.20	4.18

Means followed by the same letter with in the same column are statistically non significant at $P < 0.05$ according to least significant difference (LSD) test

Genet, Upper Awash, Melkassa, Deberezeit and Awassa vary in their soil type, rainfall and temperature (**Table 1**).

The performance of lemongrass was highly and significantly influenced ($P < 0.01$) with increasing year in all the studied agronomic and chemical traits except for number of leaves/tiller. The interaction effects of location and years were highly significant ($P < 0.01$) for number of tillers/plant, number of leaves/tiller, number of leaves/plant, longest leaf length, plant height, fresh herbage yield/plant, fresh herbage yield/ha, EO content and EO yield of lemongrass thus indicated that the expression of these traits were strengthened by the effect location × year interaction. In agreement with the present study, Fehr (1991) reported that every factor that is a part of the environment of a plant has the potential to cause differential performance. Likewise, Frankel *et al*. (1994) and IRRI (1996) reported that fluctuating features of the location such as rainfall, relative humidity, temperature, etc. are some of the environmental factors that cause variation in the performance of plants.

Performance of vegetative characters as influenced by growing locations and years

Mean performance of lemongrass tested at Awada, Wondo Genet, Upper Awash, Melkassa, Deberezeit, Awassa and combined analysis data for 9 characters are summarized in **Tables 5, 6** and **7**.

The respective overall first year mean number of tillers/plant, number of leaves/tiller, number of leaves/plant, longest leaf length and plant height were 25.99, 5.63, 151.15, 59.75 cm and 73.97 cm, respectively. The values for number of tillers/plant, number of leaves/tiller, number of leaves/bunch, longest leaf length and plant height varied from 19.00 to 34.54, 4.58 to 7.41, 96.79 to 226.58, 52.25 to 73.16 cm and 63.25 to 87.87 cm and the highest values were recorded at Awassa. The highest values recorded at Awassa increased by 81.78, 61.79, 134.09, 40.01 and 38.92% for number of tillers/plant, number of leaves/tiller, number of leaves/plant, longest leaf length and plant height, respectively when compared with lowest values recorded in other testing locations.

In the second year, mean number of tillers/plant, number of leaves/tiller, number of leaves/plant, longest leaf length and plant height ranged from 23.67 to 38.63, 4.85 to 7.43, 169.70 to 274.36, 52.50 to 74.24 cm and 63.55 to 92.60 cm, respectively. When compared with the first year's results, a significant ($P < 0.01$) and highest values for all morphological characters were recorded in the second year except for number of leaves/tiller. The respective values recorded in the second year for number of tillers/plant, number of leaves/plant, longest leaf length and plant height increased by 29.81, 29.38, 3.06 and 14.26% compared with the first year values.

The overall combined first and second year mean values recorded for number of tillers/plant, number of leaves/tiller, number of leaves/plant, longest leaf length and plant height were 29.86, 5.68, 173.37, 60.66 cm and 79.24 cm, respectively. Their respective values ranged from 21.34 to 34.79, 4.94 to 7.42, 106.52 to 241.00, 54.42 to 73.70 cm and 68.65 to 89.12 cm. In agreement with the current study, comparable values were reported for number of leaves/tiller (6-15) and leaf length (40-80 cm) by Lal *et al*. (2006). On the other hand, relatively higher values for number of tillers/plant (45-65) and plant height (100-160 cm) for four elite clones of lemongrass was reported by Lal *et al*. (2006). Variation in the performance of vegetative traits in lemongrass may be due to the existence of variation in environmental factors. Allard (1960) and Poehlman and Sleper

Table 8 Mean performance of lemon grass for chemical characters tested over six locations of Ethiopia.

Locations	First year			Second year			Combined		
	FYPP	FYPH	EOY	FYPP	FYPH	EOY	FYPP	FYPH	EOY
Awada	0.78 a	28007 a	95.31 b	1.48 b	53091 b	263.80 b	1.13 b	40548.8 b	179.56 b
Wondo Genet	0.64 ab	22871 b	108.16 a	2.12 a	75894 a	342.69 a	1.38 a	49382.2 a	225.43 a
Upper Awash	0.48 c	17318 c	88.56 b	1.26 c	45259 c	249.14 b	0.876 c	31288.7 c	168.85 c
Melkassa	0.53 bc	19052 c	92.05 b	1.22 c	46176 c	217.02 c	0.878 c	32614.2 c	154.54 d
Deberezeit	0.22 d	7981 d	42.29 d	0.90 d	32312 d	155.09 d	0.56 d	20146.1 d	98.69 f
Awassa	0.48 c	16827 c	67.31 c	1.24 c	44597 c	203.49 c	0.86 c	30712.1 c	135.40 e
Mean	0.52	18676	82.28	1.37	49554.73	238.54	0.95	34115.36	160.41
$LSD_{0.05}$	0.14	2410.9	12.27	0.15	3352.6	19.63	0.11	1934.5	10.7
CV%	18.80	8.56	9.90	7.24	4.48	5.46	10.95	5.57	6.55

Means followed by the same letter with in the same column are statistically non significant at $P < 0.05$ according to least significant difference (LSD) test; FYPP = Fresh yield/plant (kg); FYPH = Fresh yield/ha (kg) and EOY = Essential oil yield/ha (kg)

Table 9 Association among yield and yield contributing characters of lemon grass grown in different parts of Ethiopia.

Agronomic and chemical parameters	NTPPL	NLPT	NLB	LLL	PH	FYPP	FYPH	EOC	EOY
Number of tillers/plant (NTPPL)	1.00								
Number of leaves/tillers (NLPT)	0.42**	1.00							
Number of leaves/plant (NLB)	0.76***	0.73***	1.00						
Longest leaf length (LLL) (cm)	0.36*	0.72***	0.74***	1.00					
Plant height (PH) (cm)	0.65***	0.47***	0.76***	0.71***	1.00				
Fresh yield/plant (FYP) (kg)	0.61***	0.16 ns	0.60***	0.27 ns	0.58***	1.00			
Fresh yield/ha (FYPH) (kg)	0.62***	0.16 ns	0.58***	0.25 ns	0.58***	0.99***	1.00		
Essential oil content (EOC) (%)	0.10 ns	-0.19 ns	-0.18 ns	-0.17 ns	0.13 ns	-0.01 ns	-0.008 ns	1.00	
Essential oil yield/ha (EOY) (kg)	0.65***	0.10 ns	0.54***	0.20 ns	0.61***	0.97***	0.98***	0.17 ns	1.00

***Significant at $P < 0.001$, ** Significant at $P < 0.01$, * Significant at $P < 0.05$; ns = non-significant at $P < 0.05$ probability level

(1995) also reported the occurrence of variation in performance in any plant due to hereditary differences in the plants, differences in the environments in which the plants are grown, or a combination of both.

Performance of leaf and EO yield as influenced by growing locations and years

Mean performance of lemongrass leaf in terms of EO yield for the first and second year and combined data tested over 6 locations are summarized in **Table 8**. A range of values for fresh herbage yield/plant (0.22-0.78 kg), fresh herbage yield/ha (7.98-28.01 t) and EO yield (42.29-108.16 kg) were recorded in first year over the 6 locations. In the second year, the values recorded for fresh herbage yield/plant, fresh herbage yield/ha and EO yield/ha were 0.90-2.12 kg, 32.31-75.89 t and 155.09-342.69 kg, respectively. The overall first year mean fresh herbage yield/plant, fresh herbage yield/ha and EO yield/ha were 0.52 kg, 18.68 t and 82.28 kg, respectively. The respective overall average value recorded for fresh herbage yield/plant, fresh herbage yield/ha and EO yield/ha during the second year were 1.37 kg, 49.56 t and 238.54 kg. The values recorded in the second year demonstrated an increased value of 163.46% for fresh herbage yield/plant, 165.31% for fresh herbage yield/ha and 189.91% for EO yield/ha. In agreement with the increasing trend of fresh herbage yield and EO yield with increasing year, Wijesekera (1981) and Joy *et al*. (2001) also reported an increase in herbage and EO yield from the 1st to the 4th year in lemongrass. The increase in fresh herbage yield/plant, fresh herbage yield/ha and EO yield/ha with an increase in growing years may be due to the production of more tillers/plant, number of leaves/tiller, number of leaves/plant, longest leaf length and plant height as they had a positive and strong association with fresh herbage yield/plant, fresh herbage yield/ha and EO yield/ha (**Table 9**). In agreement with the present study, Joy *et al*. (2006) reported a significant and positive association of morphological characters like plant height, number of leaves/plant and number tillers/plant with herbage and essential oil yield of lemongrass.

The overall combined first and second year mean values recorded for fresh herbage yield/plant, fresh herbage yield/ha and EO yield/ha were 0.95 kg, 34.12 t and 161.41 kg, respectively. The highest three values for fresh herbage yield and EO yield were recorded at Wondo Genet, Awada and Melkassa in decreasing order; while the lowest values were recorded at Debrezeit. Hence, these locations were considered to be the best locations for the cultivation of lemongrass both for herb and EO production. However, vertisols cannot be recommended for its cultivation because lowest yield was obtained in vertisols of the Deberezeit testing location.

The overall combined average annual value of fresh herbage yield/ha and EO yield/ha varied from 20.15 to 49.38 t and from 98.69 to 225.43 kg, respectively. The range of values obtained in the present study is in agreement within the range from different reports. Lal *et al*. (2006) reported a comparable range of fresh herbage biomass from 18.90 to 28.90 t/ha/yr and EO yield (122-248 kg/ha/yr) for four elite lemongrass clones. Tomar and Minhas (2004) reported a mean fresh leaf yield of 50.7 t/ha/yr under irrigated conditions. EO yields between 75 and 100 kg/ha/yr was also reported for lemongrass by Wijesekera (1981). In addition, PFMP (2004) reported that EO yield ranges from 50 to 80 kg/ha/yr for lemongrass. Nelkin and Schuch (2004) also reported a fresh herb yield of 28.9 t/ha/yr and EO yield of 261 kg/ha/y for a promising lemongrass clone SEG 49 in India. As the result obtained in the present study is comparable to different reports, it can be said that lemongrass is adaptable to the different parts of Ethiopia and hence can be cultivated in Ethiopia for the production of herbage biomass and EOs.

Performance of lemongrass at different ecologies of Ethiopia for EO content and composition

The mean performances of lemon grass for EO content and major EO components tested in 6 locations of Ethiopia are summarized in **Table 10**. During the first year, EO content varied from 0.34% (at Awada) to 0.53% (at Debrezeit) with an overall mean value of 0.45%. During the second year, the highest (0.55%) EO content was recorded at Upper Awash and the lowest (0.45%) at Awada and Wondo Genet. In comparison with the first year, an increase in EO content of 6.67% was obtained during the second year. The overall EO content over the first and second year varied from 0.42% for Awada to 0.53% for Upper Awash with an overall mean value of 0.47%. In agreement with the findings of the present study, a comparable range of EO content varying from 0.35-0.44% by Kumari *et al*. (2009) and from 0.2 to 0.4% by Wijesekera (1981) was found for lemongrass. On

Table 10 Mean performance of lemon grass for essential oil content and major essential oil compositions tested over six locations of Ethiopia.

Location	EO content (%)			EO compositions (%) for combined values		
	First year	Second year	Combined	Myrcene	Citral	Geraniol
Awada	0.34 d	0.49 b	0.42 c	4.05	74.95	1.005
Wondo Genet	0.47 b	0.45 d	0.46 b	18.195	80.845	0.965
Upper Awash	0.50 ab	0.55 a	0.53 a	6.775	70.81	2.43
Melkassa	0.48 ab	0.47 cd	0.48 b	17.27	82.68	0.66
Deberezeit	0.53 a	0.48 bc	0.51 a	2.46	75.90	1.65
Awassa	0.40 c	0.45 d	0.43 c	20.40	77.93	1.65
Mean	0.45	0.48	0.47	11.52	77.18	1.39
$LSD_{0.05}$	0.05	0.02	0.025	-	-	-
CV%	7.40	2.77	5.24	-	-	-

Means followed by the same letter with in the same column are statistically non-significant at $P < 0.05$ according to least significant difference (LSD) test

the other hand, higher values of EO content ranging between 0.57 and 0.93% were reported by Lal *et al*. (2006) for four elite clones of lemongrass. There are different factors that cause variations in EO content. According to Joy *et al*. (2001), the variation in EO content and composition in the grass depends upon the fertility of the soil, climatic conditions, age of the grass, time of cutting, the state of the grass when distilled, distillation method, etc.

Over all the test locations and years, a mean value of 11.52% myrcene, 77.18% citral and 1.39% geraniol was recorded from the EO of lemongrass grown in different environmental conditions of Ethiopia. In agreement with the present study, a comparable percentage of myrecene (12.75%) and geraniol (1.85%) was also reported by Joy *et al*. (2001) for lemongrass grown in India. Husain *et al*. (1988) also reported a range of geraniol from 0.5 to 0.6% and myrcene between 8.2 and 19.2% for West Indian lemongrass.

The citral content of the EO varied from 70.81-82.68%, the highest three values were recorded at Melkassa (82.68%), Wondo Genet (80.85%) and Awassa (77.93%) in decreasing order and the lowest value was recorded at Upper Awash (70.81%) (**Table 10**). A comparable mean citral content of 83.12% was reported for giant lemongrass of Congo-Brazzavilie (Loumouamou *et al*. 2010). Similarly, a citral content of 79% from Bénin (Molangui 1996) and 54.1% from Mali (Sidibe *et al*. 2001) were also reported from lemongrass. A citral content range between 72 and 75% was also reported by Kumari *et al*. (2009) for Indian lemongrass collections. Loubaki (2003) also reported a comparable citral content of 80% for lemongrass leaves grown in Congo Brazzaville. Husain *et al*. (1988) reported a relatively lower range of citral content between 60 and 75% for West Indian lemongrass. A relatively higher value of citral content (89%) was reported by Lal *et al.* (2001) for one promising lemongrass colone SEG 49 and a range between 82 and 88% was also reported by Ganjewala (2008) for West Indian lemongrass. A wide range of citral content (30-93.74%) in the EO of lemongrass was also reported by Negrelle *et al*. (2007). As the EO and compositions of the EO obtained from herbage biomass of lemongrass tested in different agro-ecologies of Ethiopia are comparable to different reports in the literature, it is possible to cultivate lemongrass in Ethiopia for the production of EO and herbage biomass.

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