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Effect of irrigation regimes and nitrogen levels on herbage and oil yield, oil quality, nutrient uptake and economics of lemongrass (*Cymbopogon flexuosus*) in a sandy loam soil of Orissa

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ABSTRACT

Field experiment was conducted during (2005–07) in a sandy loam soil at Bhubaneswar,Orissa to study the effect of 2 different irrigation regimes (irrigation at 1.0 and 0.5 IW/CPE) and 4 nitrogen rates (0, 30, 60 and 90 kg N/ha/year) on the herbage yield, oil yield, nitrogen uptake and oil quality of 'OD-19' lemongrass [*Cymbopogon flexuosus* (Steud.) J.F.Wats.]. Herbage and oil yield under the irrigation level I_1 (irrigation at 1.0 IW/CPE) was more than that under I_2 (irrigation at 0.5 IW/CPE) by 13, 19, 12 and 13% in the second, third, fifth and sixth harvests, respectively. The increased rate of N application up to 90 kg N/ha/year has resulted in an increase in nitrogen uptake by 38.8, 60.4 and 80.4% in $N_{30,}$ N_{60} and N_{90}, respectively over the N_0. However, 'citral a' and 'citral b' showed no variation in relation to irrigation regimes and nitrogen rates. The benefit : cost ratio was found to be superior with treatment receiving irrigation at 0.5 IW/CPE and N rate @ 90 kg/ha/year in both the years with 1.68 in 2005–06 and 2.99 in 2006–07.

Key words: Citral, *Cymbopogon flexuosus*, Irrigation, Lemongrass, Nitrogen, Oil quality, Oil yield

Lemongrass oil obtained from the multi-harvest perennial C_4 aromatic grass [*Cymbopogon flexuosus* (Steud.) J.F. Wats.] is a rich source of citral. The global demand of lemongrass oil is about 4 500 million tonnes/annum; however the production is only 600 tonnes/annum (Barbosa *et al.* 2008). The demand for citral in India is about 750 million tonnes/annum for different industries related to fragrance and flavour applications. This requirement is partially supplied from lemongrass oil and the rest through synthetic citral produced by chemical industries. Monoterpene citral as a major constituent (75%) of the essential oil is used as flavouring agent and as a natural precursor of vitamin A (Luthra *et al.* 2007, Negrelle and Gomes 2007). India is the largest producer of lemongrass oil (300–350 tonnes/annum) and at present this crop is cultivated in an area of about 3 000 ha mainly in Kerala, Karnataka, Uttar Pradesh and Assam (Rashi and Singh 2007). Researchers also reported that lemongrass can be cultivated as one of the most suitable crops for effective management of shoal forests (Chandrasekhara *et al.* 2006). In north and western part of the country this crop is cultivated as an irrigated crop, while in southern and eastern part it is grown mostly as rainfed.

Considerable literature is available regarding the performance of crop under semi-arid and sub-humid climate. Effective irrigation scheduling during dry season and nutrient management in wet season are the two most important components that influence the total herbage production and oil yield of any multi-cut perennial aromatic grass. Previous reports revealed that lemongrass responds well to nitrogen fertilizer application and optimum use of irrigation water markedly increases the yield of several oil-yielding aromatic crops. Moreover, the studies conducted so far are primarily aimed at suitability of varieties, season and soil characteristics in relation to lemongrass cultivation (Singh *et al.* 2005). As a C_4 plant, its nitrogen requirement is expected to be higher compared to C_3 crops and differential irrigation would influence the N-uptake of the crop. There is a lacking of systematic study on irrigation × N interaction on N-uptake and economic returns of lemongrass under sub-humid tropical situation of eastern India. This information would help the growers to select the levels of key inputs, viz irrigation and nitrogen according to the availability of resources and their economic condition for this agro-climatic region and vis-à-vis to have an idea of probable economic returns after the harvest of the crop. Hence, this study attempts to investigate the herbage production potential,

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nitrogen uptake and economics of lemongrass under varying levels of irrigation and nitrogen application rates in a sandy loam soil of Orissa.

MATERIALS AND METHODS

The experiment was conducted with lemongrass 'OD 19' at the experimental farm of the Directorate of Water Management at Mendhasal block, Orissa (20°30' N and 87°48' E) during 2005–07. The soil was sandy loam with a *p*H of 6.3, water-holding capacity of 0.26 cm^3/cm^3 at 0.3 MPa and 0.09 cm^3/cm^3 at 1.5 MPa. The soil was low in organic carbon (0.38%) and available N (228 kg/ha), medium in available P and K (18 and 195 kg/ha, respectively). Farmyard manure (containing 0.63% N, 0.28% P_2O_5 and 0.51% K_2O) @ 5 tonnes/ha together with phosphorus @ 40 kg P_2O_5/ha through single superphosphate and potassium @ 40 kg K_2O/ha through muriate of potash were applied during the final land preparation (15 days prior to planting) as a basal dose in all plots in the first year. Farmyard manure (containing 0.61% N, 0.29% P_2O and 0.54% K_2O) together with single superphosphate and muriate of potash was also applied in the same rate after the summer harvest in the second year. Nitrogen through urea was applied @ 0 (N_0), 30 (N_{30}), 60 (N_{60}) and 90 (N_{90}) kg N/ha/year in 3 equal splits, viz 1/3 at 20 days after planting in the first year and 1/3 after each harvest, respectively during the entire experimental period.

Rooted slips of lemongrass were planted on 5 May 2005 with a spacing of 45 cm × 30 cm. Two irrigation treatments, viz I_1 (irrigation at 1.0 IW/CPE) and I_2 (irrigation at 0.5 IW/CPE) and 4 rates of N viz were tested in a split-plot design with 3 replications. The irrigation treatments were randomized in the main plots and the nitrogen rates in sub-plots. Irrigations were applied when the cumulative pan evaporation reached 50 and 100 mm to represent 1.0 and 0.5 IW/CPE, respectively. The depth of irrigation was 5 cm. The irrigation timings were decided based on the soil water balance method (Mishra and Ahmed 1987) using daily pan evaporation values, rainfall amount and soil moisture data. Need-based weeding was done to keep the field weed free.

A total of 6 harvests were taken on 24 October 2005, 8 February 2006, 14 June 2006, 16 October 2006, 11 February 2007 and 12 June 2007 during the study. Monitoring of the soil moisture content (thermo-gravimetrically) was done twice every week at an interval of 3 days. At each harvest fresh and dry biomass of the crop were recorded. Plant samples from each treatment combinations were distilled in a Clevenger type glass apparatus for the estimation of essential oil content. The available nitrogen in the soil was estimated by the alkaline $KMnO_4$ method. The plant samples were dried at 70°C for 48 hrs in an oven, processed and representative sub-samples were subsequently analyzed for nitrogen content by Kjeldahl method (AOAC 1970). 'Citral a' and 'Citral b' of the oil were assayed by gas chromatograph fitted with a flame ionization detector and using nitrogen as a carrier gas with a flow rate of 30 ml/min. The column was initially kept at 110°C and subsequently raised to 150°C @ 1.5°C/min. The injector and detectors were kept at 200°C. The peaks of major constituents namely 'citral a' and 'citral b' were identified by their retention times using standards under similar conditions. The analysis of variance (ANOVA) technique was carried out on the data for each parameter as applicable to split-plot design (Gomez and Gomez 1984). The response functions of herbage yield to N rates were derived following the least square technique; goodness of fit was tested through F-test. The economics was worked out based on the current prices of both the inputs and outputs during the study period.

RESULTS AND DISCUSSION

Herbage and oil yield

The herbage yield of lemongrass was markedly influenced by irrigation treatments; significantly greater herbage yield of lemon grass was recorded in treatment I_1 compared to I_2 irrespective of nitrogen rates in every harvests except first and fourth. (Table 1). Actually for the first and fourth harvests the rainfall received during the crop growth period masked the effect of irrigation treatments. The mean herbage yield increased in I_1 by 13, 19, 12 and 13% compared to I_2 in the second, third, fifth and sixth harvests, respectively. Similarly, oil yield under I_1 was higher than that under I_2 by 13, 19, 12 and 13% in second, third, fifth and sixth harvests, respectively.

The effect of varying nitrogen rates has manifested its effect on herbage production. The increase in nitrogen dose from 0 to 90 kg/ha/year resulted in significantly higher herbage yield of lemon grass in all the harvests. The positive effect of applied N on herbage yield of lemongrass might have contributed to higher chlorophyll a/b ratio and higher photosynthetic efficiency.

The interaction effect of irrigation and N was also found significant in all the harvests except the first and fourth. The treatment I_1 N_{90} resulted in highest herbage yields of 13.51, 14.87, 14.22 and 19.04 tonnes/ha during second, third, fifth and sixth harvests, respectively. Mean data from all the 6 harvests revealed that nitrogen application rates has resulted in 33, 54 and 76% increase in N_{30}, N_{60} and N_{90}, respectively over the N_0. Although the herbage production is higher in the summer harvest in the first year but in the second year, ie rainy (*kharif*) season harvest recorded the highest production because of better dissolution of the applied nutrients due to rainfall received during that period (1 185 mm). It was might be due to some biochemical and microbiological changes in the soil which in presence of the adequate available moisture aided in decomposition of plant litters and uprooted weeds and enhanced the uptake and utilization of the nutrients (Fatima *et al.* 2002).

The oil yield increased with higher IW/CPE ratio because

Table 1 Mean herbage yield of lemongrass as influenced by different moisture regimes and nitrogen rates

Treatment	Herbage yield (tonnes/ha)				
	N_0	N_{30}	N_{60}	N_{90}	Mean
First harvest (24 October 2005)					
I_1	6.77	8.31	9.68	11.74	9.12
I_2	6.41	7.94	9.18	11.30	8.71
Mean	6.55	8.16	9.43	11.52	
$LSD_{0.05}$	I: ns	N: 0.27	I × N: ns		
Second harvest (8 February 2006)					
I_1	7.28	10.15	12.34	13.51	10.82
I_2	6.95	8.87	10.56	11.96	9.58
Mean	7.12	9.50	11.45	12.74	
$LSD_{0.05}$	I: 0.13	N: 0.42	I × N: 0.59		
Third harvest (14June 2006)					
I_1	9.32	11.21	13.06	14.87	12.10
I_2	7.45	9.85	11.10	12.28	10.17
Mean	8.38	10.53	12.08	13.58	
$LSD_{0.05}$	I: 0.25	N: 0.37	I × N: 0.52		
Fourth harvest (16 October 2006)					
I_1	11.49	16.27	18.41	20.50	16.66
I_2	10.24	15.33	17.64	19.75	15.74
Mean	10.87	15.80	18.02	20.13	
$LSD_{0.05}$	I: ns	N: 0.80	I × N: ns		
Fifth harvest (11 February 2007)					
I_1	8.54	10.62	11.80	14.21	11.29
I_2	7.73	9.98	10.38	12.17	10.06
Mean	8.13	10.30	11.09	13.19	
$LSD_{0.05}$	I: 0.18	N: 0.43	I × N: 0.60		
Sixth harvest (12 June 2007)					
I_1	10.46	14.39	17.53	19.04	15.35
I_2	9.20	12.55	15.07	17.35	13.54
Mean	9.83	13.47	16.30	18.19	
$LSD_{0.05}$	I: 0.60	N: 0.34	I × N: 0.48		

I, Irrigation; N, nitrogen; ns, non-significant

Table 2 Mean oil yield of lemongrass as influenced by different moisture regimes and nitrogen rates

Treatment	Oil yield (kg/ha)				
	N_0	N_{30}	N_{60}	N_{90}	Mean
First harvest (24 October 2005)					
I_1	21.77	27.18	32.09	37.34	29.59
I_2	20.68	25.72	30.16	36.49	28.26
Mean	21.22	26.45	31.12	36.92	
$LSD_{0.05}$	I: ns	N: 0.85	I × N: ns		
Second harvest (8 February 2006)					
I_1	25.18	34.95	42.84	46.75	37.43
I_2	23.86	30.67	36.38	41.52	33.11
Mean	24.52	32.81	39.60	44.14	
$LSD_{0.05}$	I: 1.25	N: 1.05	I × N: 1.4		
Third harvest (14 June 2006)					
I_1	40.54	47.22	56.73	63.65	52.04
I_2	31.82	42.68	47.41	53.56	43.87
Mean	36.18	45.95	52.07	58.61	
$LSD_{0.05}$	I: 1.37	N: 1.29	I × N: 1.82		
Fourth harvest (16 October 2006)					
I_1	39.75	55.43	63.38	70.35	57.23
I_2	35.40	52.29	60.12	67.20	53.75
Mean	37.58	53.86	61.75	68.78	
$LSD_{0.05}$	I: ns	N: 1.80	I × N: : ns		
Fifth harvest (11 February 2007)					
I_1	28.81	36.37	40.72	48.10	38.50
I_2	25.90	34.02	35.46	42.13	34.38
Mean	27.36	35.20	38.09	45.12	
$LSD_{0.05}$	I: 1.66	N: 0.77	I × N: 1.09		
Sixth harvest (12 June 2007)					
I_1	38.65	53.44	65.62	69.53	56.81
I_2	34.15	46.51	56.15	65.02	50.45
Mean	36.40	49.97	60.89	67.27	
$LSD_{0.05}$	I: 1.60	N: 0.96	I × N: 1.37		

I, Irrigation; N, nitrogen; ns, non-significant

of the increased biomass production under higher soil moisture regime. The oil yield was significantly greater in treatment I_1 when compared to I_2, irrespective of nitrogen treatments (Table 2). This enhancement in oil yield was significant in all harvests except the first and fourth. The increase in N rate up to 90 kg/ha/year resulted in significantly higher oil yield of lemongrass in all harvests. The interaction effect of irrigation and N on oil yield of lemongrass was also found to be statistically significant at all the harvest except the first and fourth. It was found that the response of lemongrass with increasing rate of N was greater at higher water regimes and lower levels of irrigation could achieve comparable yields with increasing rate of N application. The treatment I_1N_{90} resulted in highest oil yield, ie 46.75, 63.65, 48.10 and 69.53 kg/ha in second, third, fifth and sixth harvests, respectively. It was observed that with the increase in N rates the oil yield has also increased by 33.2, 54.7 and

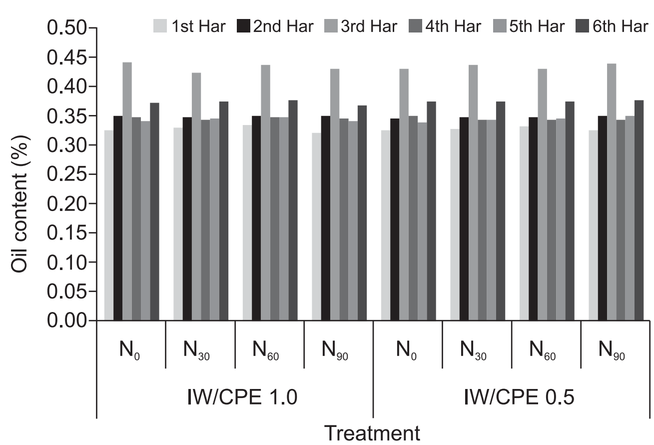

Fig 5 Partial factor productivity of nitrogen in 'LRA 5166' cotton as influenced by date of sowing and nitrogen levels (pooled over 2002–03 to 2004–05)

75.1 in N_{30}, N_{60}, $N_{90,}$ respectively over the N_0; but the concentration of oil was not significantly influenced by irrigation and N. However, seasonal variation was observed in the oil recovery in different harvests (Fig 1). In a long-term trial with lemongrass Singh *et al*. (2005) also found a seasonal variation in oil recovery at different harvest time.

Nitrogen uptake

The N uptake of lemongrass was positively influenced by different irrigation regimes. Significantly greater N uptake was estimated in I_1 compared to I_2, irrespective of N treatments (Table 3). This increase in nitrogen uptake was significant in all harvests except the first and fourth. The increase in nitrogen rate from 0 to 90 kg/ha/year resulted in significantly higher N uptake in all the harvests. The favourable effect of increased N rates on nitrogen uptake of aromatic plants was also observed by Novak *et al*. (2003) and Azizi *et al.* (2009).

The interaction effect of irrigation and N rates on nitrogen uptake of lemongrass was also found to be significant at all the harvest periods except the first and fourth. The treatment I_1N_{90} showed highest N uptake, ie 20.10, 24.60, 21.76 and 25.95 kg/ha in the second, third, fifth and sixth harvests, respectively. The data reveal that higher rate of N application up to 90 kg N/ha/year has resulted an increase in nitrogen uptake by 38.8, 60.4 and 80.4% in $N_{30,}$ N_{60} and N_{90}, respectively over the N_0. The N-uptake by the crop in all 3 harvests in the second year was more than the first year due to better crop establishment and root proliferation. Previous researchers also found a greater uptake of N associated with higher growth and root development in oil-yielding aromatic grasses. Though the N content in the plant was lower in *kharif* harvest (June–October) in comparison to summer and winter harvests in the second year, but the higher herbage yield has resulted in higher total N uptake by the crop.

Table 3 Nitrogen uptake of lemongrass as influenced by different moisture regimes and nitrogen rates

Treatment	Nitrogen uptake (kg/ha)				
	N_0	N_{30}	N_{60}	N_{90}	Mean
First harvest (*24 October 2005*)					
I_1	8.52	11.75	13.47	15.31	12.27
I_2	8.18	11.34	13.10	14.82	11.86
Mean	8.35	11.55	13.29	15.11	
$LSD_{0.05}$	I: ns	N: 0.41	I ×N: ns		
Second harvest (*8 February 2006*)					
I_1	10.66	14.54	17.63	20.10	15.74
I_2	9.81	13.36	15.25	17.16	13.90
Mean	10.24	13.95	16.44	18.63	
$LSD_{0.05}$	I: 0.53	N: 0.28	I × N: 0.39		
Third harvest (*14 June 2006*)					
I_1	15.18	18.64	21.51	24.60	19.98
I_2	12.11	15.30	17.84	20.23	16.37
Mean	13.65	16.97	19.67	22.42	
$LSD_{0.05}$	I: 0.20	N: 0.45	I ×N: 0.63		
Fourth harvest (*16 October 2006*)					
I_1	14.75	21.66	24.32	27.38	22.03
I_2	13.28	19.95	23.10	25.77	20.54
Mean	14.02	20.81	23.71	26.58	
$LSD_{0.05}$	I: ns	N 0.50	I ×N: ns		
Fifth harvest (*11 February 2007*)					
I_1	12.32	17.25	19.12	21.76	17.61
I_2	10.86	14.62	16.95	19.24	15.42
Mean	11.59	15.93	18.03	20.49	
$LSD_{0.05}$	I: 0.60	N: 0.33	I ×N: 0.46		
Sixth harvest (*12 June 2007*)					
I_1	13.65	19.38	22.57	25.95	20.39
I_2	11.84	17.10	20.41	22.32	17.92
Mean	12.75	18.24	21.49	24.14	
$LSD_{0.05}$	I: 0.49	N: 0.39	I ×N: 0.56		

I, Irrigation; N, nitrogen; ns, non-significant

Response functions

The response functions of herbage yield to N rates were developed under both irrigation levels, ie I_1 and I_2 for both the years (Fig 2). It was observed that the quadratic regressions for I_1 and I_2 were tested significant at 1 and 5% level, respectively during 2005–06, while in 2006–07 regressions under I_1 was significant and under I_2 was not significant at 5% level. As the quadratic coefficient for every response curves were very low, the economic optimum rate, within the boundary of 0 to 90 kg N/ha were not obtained. Additional herbage yield may have been possible beyond 90 kg N/ha. However, the response functions under I_1 clearly showed a greater intercept, greater linear coefficient than those under I_2 in both the years. This quantitative relationship revealed that the optimal irrigation gave greater yield that sub-optimal irrigation with same N rates; and the rate of increase in herbage yield with increasing N rate (ie linear coefficient) was greater in I_1 than I_2. This trend was similar in both the years. Zemenchik and Albrecht (2002) found similar quadratic response curves of orchardgrass (*Dactylis glomerata* L.) forage dry matter to fertilizer N rates.

Oil quality

Analysis of the principal constituents of the essential oil, viz 'citral a' and 'citral b' in all the 6 harvests revealed that 'citral a', 'citral b' and total citral (citral a + citral b) content were not influenced by the nitrogen rates and irrigation levels. Similar result was also reported by Negrelle and Gomes (2007). However, there was a seasonal variation in the content which was manifested in different harvests. The 'citral a' content was higher in the second and the fourth harvests, while 'citral b' content was higher in the second and fifth harvests (Fig 3). The total citral (a+b) content was also higher in second and fifth harvests which occurred during the winter season. Due to the low night temperature during the first fortnight of February when second and fifth harvests were taken, the crop might have better translocation and

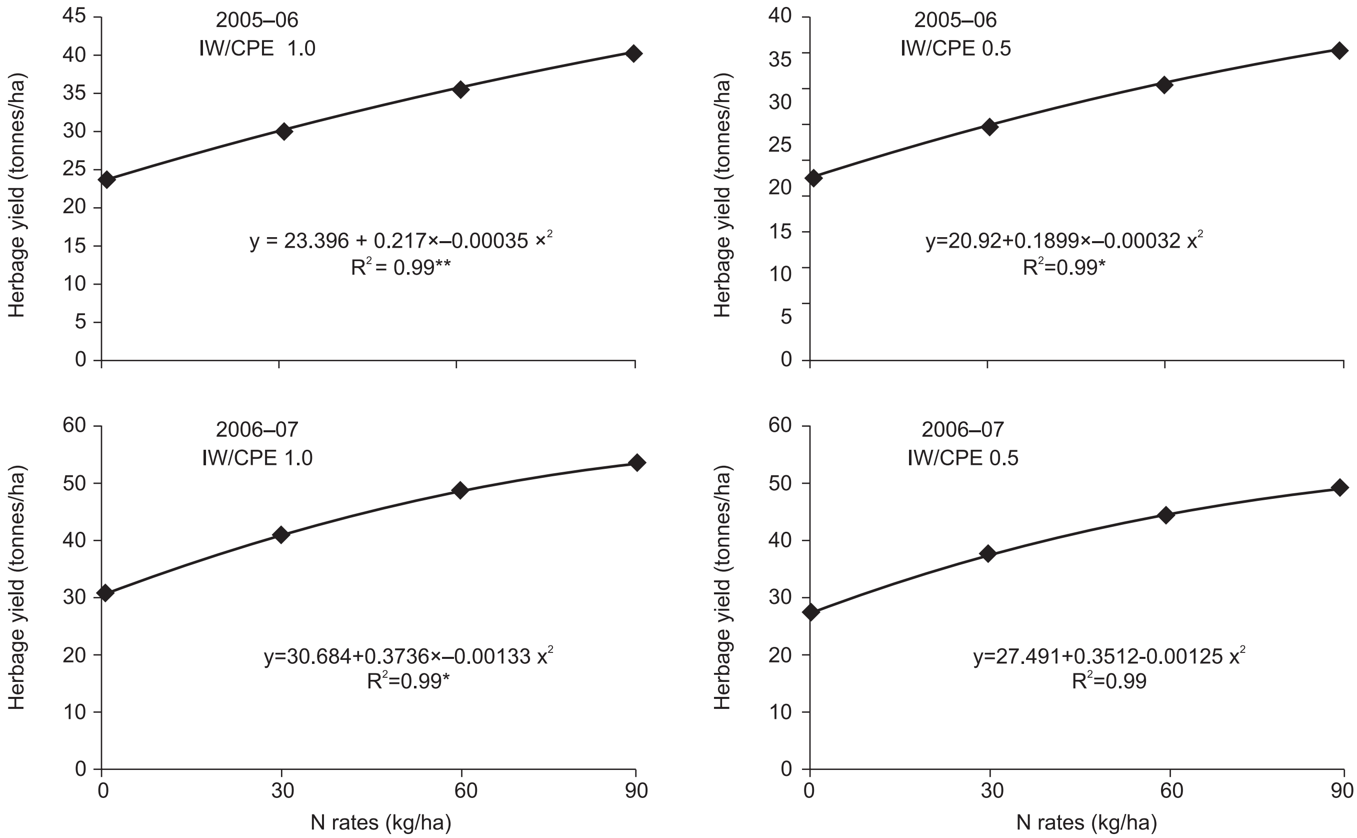

Fig 2 Response functions of herbage yield of lemongrass to N rates at IW/CPE 1.0 and 0.5 in 2005-06 and 2006-07, **indicates significance at 1%, and *at 5% level.

assimilation of secondary metabolites when compared to the summer and *kharif* harvests (Fatima *et al*. 2002).

Economics of the system

The economics of the system as a whole including the cost of inputs and output (essential oil) at the current market price were computed on yearly basis (Table 4). The highest gross returns of Rs 50 476/ha/year and Rs 65 671/ha/year during 2005–06 and 2006–07, respectively was obtained from the treatment combination I_1N_{90}. Consequently the net returns were also highest for the same treatment combination (Rs 20 076 and Rs 42 271/ha/year during 2005–06 and 2006–07, respectively). The net returns were found to be higher in the second year compared to the first year irrespective irrigation and N treatments due to higher gross returns and lesser cost of cultivation. Actually, in the first year the net economic return was low due to the substantial cost of planting material (Rs 7 500/ha). Moreover, in the first year, due to slow initial slow crop growth rate the herbage yield was lower consequently net return was also lower.

Table 4 Economics of lemongrass cultivation under different nitrogen levels and irrigation water regimes

Treatment	First year (2005–06)				Second year (2006–07)			
	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B: C ratio	Cost of cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B : C ratio
I_1N_0	29 500	30 622	1 122	1.04	22 500	37 525	15 025	1.66
I_1N_{30}	29 800	38 271	8 471	1.28	22 800	50 836	28 036	2.23
I_1N_{60}	30 100	46 085	15 985	1.53	23 100	59 402	36 302	2.57
I_1N_{90}	30 400	50 476	20 076	1.66	23 400	65 671	42 271	2.80
I_2N_0	26 500	27 130	630	1.02	19 500	33 397	13 897	1.71
I_2N_{30}	26 800	34 674	7 874	1.29	19 800	46 485	26 685	2.34
I_2N_{60}	27 100	39 881	12 781	1.47	20 100	53 108	33 008	2.64
I_2N_{90}	27 400	46 050	18 650	1.68	20 400	61 023	40 623	2.99

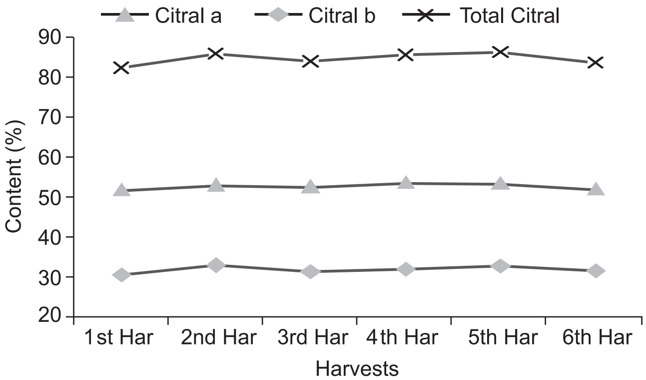

Fig 3 The variation in citral a, citral b and total citral in different harvests (LSD for citral a = 0.52; citral b = 0.63; total citral = 0.68)

Subsequently, due to generation of more tillers after each harvests and development and proliferation of the shallow root system of the crop higher mean yield of oil were obtained from all the treatments in comparison with the first year. The higher net returns from lemongrass cultivation in second year compared to first year were also reported by Rashi and Singh (2007). The benefit : cost ratio was found to be superior with treatment receiving irrigation at 0.5 IW:CPE ratio and N rate @ 90 kg/ha/year in both the years with 1.68 in 2005–06 and 2.99 in 2006–07.

Thus, it is concluded that irrigation at 1.0 IW:CPE ratio and application of 90 kg N/ha/year would be judicious practice for realizing a greater herbage yield of lemongrass, its oil yield, N-uptake, greater economic returns and higher benefit:cost ratio from lemongrass cultivation for this agro-climatic region of the country.

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