

Physicochemical Properties of Soil and Plant Geometry in Oil Yield, Quality and Economics of Lemongrass in Rainfed Bundelkhand Region, India

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Keeping in mind the significance of sustainable production practices and greater resource use efficiency, a study was led to access five levels of Plant Geometry (PG)/spacing of lemongrass variety CKP-25 (*Cymbopogon khasianus* × *pendulous*) tested with three levels of Soil Types (ST) on the performance of essential oil (EO) yield, secondary metabolites (SM) and economic returns (ER) in rainfed Bundelkhand region. The results of the analysis of variance data were recorded for two consecutive years (2020–21 and 2021–22). On an average EO content was found to be highest (0.77%) in Mar Soil (MS). The interaction MS along with PG1 [62,500 plants/ha (40×40 cm)] observed the highest EO content (0.79%). The highest EO yield (228.23, 319.92 kg/ha) was obtained in MS along with PG3 [76,923 plants/ha (45×30 cm)] in 1st and 2nd years, respectively. The lemongrass variety, showed excellent performance in terms of achieving higher net income and benefit-cost (B:C) ratio, in respect of MS with PG3. The significantly highest Net Return (NR) (Rs. 1,70,995 and 3,02,984 /ha) and B:C ratio (2.66 and 4.74) were recorded in MS along with PG3 in the 1st and 2nd year, respectively. However, in terms of secondary metabolites, Neral (cis-citral) or citral B (40.13 ± 3.92%, 37.36 ± 4.63) and trans citral or citral A (47.97 ± 5.51%, 45.83 ± 5.54%) was noted to be highest in MS in both the year. On average, the total citral was found to be highest in MS (84.95 ± 5.36%, 83.19 ± 4.85%) in 1st and 2nd years, respectively.

Keywords: CKP 25, EO yield, Net return, Plant geometry, Soil types

Introduction

Lemongrass is a tropical, perennial grass, a member of the *Poaceae* family belonging to the genus *Cymbopogon*. The genus contains about 104 species.¹ The plant is widely cultivated in the tropics and sub-tropic regions including parts of America, Asia and Africa as well as mountains to arid regions.² Lemongrass has derived its name due to the presence of a typical lemon-like fragrance in its leaves and essential oil (EO). Its EO is primarily distinguished by the presence of components like limonene, citral, elemol, citronellal, 1,8 cineole, citronellol, linalool, geraniol, methylheptenone, b-carophyllene, geranyl formate and geranyl acetic acid derivation.^{3,4} As the crop is known to have several medicinal properties, it is used in the preparation of valuable medicinal products, fragrances in perfumes and cosmetics, such as soaps and creams.⁵ Likewise, the grass its EO also has a distinct lemon-like odor due to the high concentration (over 75%) of citral in the oil.⁶

Since, the past few years the demand for medicinal and aromatic plants has increased attributable to their

numerous uses in the perfumery, pharmaceutical, cosmetics and confectionery industries. However, several agronomic factors affect the various agronomic parameters inclusive of plant growth characteristics, biomass yield, EO content and EO yield. Among these parameters, plant density and crop geometry play a significant role and require special attention. Plant geometry is a primitive practice that describes how plants are arranged spatially and ascertains the structure of a given crop community, in association with this, these techniques can show a noticeable impact on the yield.⁷ The quality traits and yield perspective of lemongrass crop are insistent on their plantation *i.e.*, optimum plant spacing and appropriate usage of natural resources. Hence, for achieving a higher yield, determining the optimal number of plants per unit area is extremely critical.

Soil types in addition to plant geometry and density, have a significant impact on the composition, yield, and quality of EO. This makes it possible to determine the ST that are best suited for obtaining the maximum EO yield and the best quality possible. Soil properties are known to be the key influencing factors in the production of secondary metabolites and

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composition of EO produced by aromatic plant species.⁸ The quality and yield of EO may vary according to the ST and PG. To attain good quality of EO and to maximize its yield, the soil must be fertile as per the requirements of the crop. In the Bundelkhand region, the soil is majorly classified into two categories namely, red and black soil. In this particular region, four soil associations have been recognized which comprise Bundelkhand-coarse grained-reddish brown soils, Bundelkhand-coarse grained-grey to greyish brown soils, Bundelkhand-clay loam black soils and Bundelkhand-fine clayey black soils. These soils are locally referred to as rakar, parua, kabar and mar, respectively. Among the ST, most of the soils are less fertile. To date, not much work has been done in this context in the Bundelkhand region. Therefore, the major aim was to test lemongrass (*Cymbopogon flexuosus*) var. CKP 25 (*Cymbopogon khasianus x pendulous*) and determine the EO yield potential and its quality in diverse ST in the rainfed Bundelkhand region.

Material and Methods

Field Experimentations

The field experimentations were laid out at a farmer's field, Bundelkhand region, Jhansi (U.P.) in the year 2020–21 (1st year) and 2021–22 (2nd year). The research was led with three replications in Split Plot Design (SPD) with the main plot being Soil Types (ST) viz., PS = Parua Soil (Reddish grey-loam to sandy texture) which comes under order Ultisols, MS = Mar Soil (Black-fine grained in texture) under the order vertisols and KS = Kabar Soil comprised of Black-coarse grained texture soil that comes under vertisols order. The subplot treatments representing Plant Geometry (PG)/spacing viz., PG1 = 62,500 plants/ha (40 × 40 cm), PG2 = 66,666 plants/ha (60 × 25 cm), PG3 = 76,923 plants/ha (45 × 30 cm), PG4 = 1,11,111 plants/ha (30 × 30 cm) and PG5 = 1,61,290 plants/ha (25 × 25 cm). The quality traits of tested lemongrass variety CKP-25, drought tolerance and an interspecific hybrid of *C. khasianus* × *C. pendulus* were released in 1991 by CSIR-Indian Institute of Integrative Medicine, Jammu, known to have a rich source of citral content. The plantation was done through "SLIPS" (Rooted plant) which were obtained from one or two year old plants. One to two slips were planted at one spot as per the treatments. Crop plantation was done in the month of July–August. For nutrient management, 10 tons FYM (Farm yard manure) and 150 kg N, 75 kg P₂O₅ and 75 kg K₂O/ha

were applied. Full dose of P and K was applied as basal dose while, N was applied in split doses, half at the time of sowing as basal and remaining after first weeding. The first harvesting was done at 120 days after transplanting after that harvesting was done at 75–90 days intervals in both years, therefore three harvests were done in the first year and four harvests were taken in the second year. The harvesting was done 8 inches above the ground surface. Life saving irrigation was given at the time of transplanting for the accepted establishments of plants. During the experiment, plant growth and herbage yield were recorded at harvest maturity and calculated yield per hectare in two consecutive years (2020–21 and 2021–22). The economics found out in terms of Net Return (NR) and Benefit Cost (B:C) ratio which was calculated by the formula $NR = GR - CC$ and expressed in Rs./ha, where GR = Gross Return and CC = Cost of Cultivation) while the B:C ratio was calculated by the ratio of GR to CC.

Climate and Soil Physio-chemical Properties

The experimental site was situated at 25.436298° N latitude and 78.567352° E longitude with an elevation of 285 above mean sea level. The weather parameters including average maximum temperature, minimum temperature, relative humidity and rainfall recorded in the year 2020–21 varied between 25.00–47.50°C, 16.50–38.50°C, 25.50–78.54% and 2.25–105.90 mm, respectively, while in the year 2021–22, it ranged between 17.15–37.70°C, 19.20–38.70°C, 30.85–82.50% and 4.25–150.95 mm. Weather parameters of the experimental site for the year 2020–21 and 2021–22 are presented in Table 1.

The experiment was conducted on three different types of soil: Parua Soil (PS), which is reddish grey in colour and has a loam to sandy texture, Mar Soil (MS), which is black in colour and has a fine-grained texture, and Kabar Soil (KS), which is black in colour and has a coarse-grained texture. Samples were taken from the experimental field to a depth of 15 cm, then air-dried and passed through a 2 mm sieve. The prepared soil samples were utilized to carry out the physiochemical characteristics examination of these soils. The details of the physiochemical properties of the evaluated soil samples are given in Table 2.

Essential Oil Extraction

The Clevenger apparatus was employed to isolate the EO, through the process of hydrosteam distillation.¹⁷ Steam and hot water are the principal sources used in this procedure to extract the essential

Table 1 — Weather parameters/ meteorological data of the experimental site for the year 2020–21 and 2021–22

Month	Meteorological data for the year “2020–21”				Meteorological data for the year “2021–22”			
	Maximum Temperature (°C)	Minimum Temperature (°C)	Rainfall (mm)	Relative Humidity (%)	Maximum Temperature (°C)	Minimum Temperature (°C)	Rainfall (mm)	Relative Humidity (%)
January	25.00	16.50	15.45	57.59	17.15	19.20	12.80	62.50
February	30.00	20.50	7.85	42.96	21.75	23.25	10.15	47.95
March	39.00	27.50	8.70	31.50	27.15	28.90	11.60	36.60
April	44.50	34.00	4.95	25.58	32.95	35.40	4.25	28.85
May	47.50	36.50	5.35	25.90	37.70	38.70	8.30	30.85
June	47.00	38.50	16.95	40.94	36.90	38.35	55.85	46.05
July	43.50	35.00	79.30	68.78	34.10	33.25	167.30	75.95
August	38.50	32.00	44.25	78.54	31.60	31.50	150.95	82.50
September	37.50	31.00	105.90	71.56	31.10	31.30	111.20	76.65
October	36.00	29.00	2.25	48.58	29.10	31.15	9.50	55.55
November	32.50	25.00	5.80	48.06	23.75	26.35	8.80	55.60
December	30.00	23.50	10.65	53.32	20.95	23.00	4.50	61.75
Average	37.58	29.08	25.62	49.44	28.68	30.03	46.27	55.07

Note: “a” represents meteorological data for the year “2020–21” and “b” represents meteorological data for the year “2021–22”

Table 2 — Soil physio-chemical properties of experimental fields

Particulars	Soil Types (ST)			Methods
	Parwa Soil (PS)	Mar Soil (MS)	Kabar Soil (KS)	
	a. Mechanical properties of soil			
Sand (%)	64.00 ± 4.23	10.55 ± 1.12	17.00 ± 1.06	Bouyocous Hydrometer method ⁹
Silt (%)	20.65 ± 3.55	29.45 ± 1.17	30.00 ± 1.95	
Clay (%)	15.35 ± 1.16	60.00 ± 2.39	53.00 ± 2.45	
Textural class	Reddish grey-loam to sandy texture	Black-fine grained in texture	Black-coarse grained texture	
	b. Chemical properties of soil			
pH (1:2 soil:water suspensions)	8.09 ± 1.23	7.85 ± 1.54	8.21 ± 1.31	Glass electrode method ¹⁰
EC (ds m-1) (1:2 soil:water suspensions)	0.16 ± 0.25	0.10 ± 0.22	0.12 ± 0.08	Solu-bridge method
Organic Carbon (%)	0.27 ± 0.45	0.38 ± 0.24	0.25 ± 0.31	Walkley and Black ¹⁰
Available N (kg/ha) ¹	175.00 ± 5.67	205.30 ± 5.67	162.83 ± 6.78	Alkaline permanganate method ¹¹
Available P (kg/ha)	9.05 ± 2.35	10.54 ± 3.32	7.86.38 ± 3.22	Colorimetric procedure ¹²
Available K (kg/ha)	185.32 ± 3.45	215.00 ± 4.68	150.56 ± 4.21	Neutral normal ammonium acetate and estimated by Flame Photometer ¹³
Available S (kg/ha)	155.43 ± 4.32	112.45 ± 1.67	75.32 ± 2.54	Determined by 0.15% solution of calcium chloride turbidimetric method ¹⁴
Available Zn (mg/kg soil)	1.15 ± 0.02	1.95 ± 0.03	1.02 ± 0.01	Determined by 0.005 M DTPA, 0.01 M CaCl ₂ and 0.1 M triethanol amine (TEA) and determined on atomic absorption spectrophotometer ¹⁵
Available B (mg/kg soil)	0.66 ± 0.02	0.79 ± 0.02	0.43 ± 0.01	
Available Fe (mg/kg soil)	13.11 ± 0.23	16.25 ± 1.75	14.23 ± 0.16	Determined by Hot water extraction method using Azomethian-H ¹⁶
Available Mn (mg/kg soil)	55.23 ± 1.05	69.54 ± 2.35	58.12 ± 1.01	
Available Cu (mg/kg soil)	203.00 ± 1.45	249.00 ± 3.29	113.00 ± 0.67	

Note: Soil Types (ST) {PS = Parwa Soil (Reddish grey-loam to sandy texture), MS = Mar Soil (Black-fine grained in texture) and KS = Kabar Soil (Black-coarse grained texture)}; The results are presented in mean ± standard deviation

components from the plant matrix. The entire distillation procedure could take three hours.

Quality Analysis of Essential Oil

Gas chromatography and Mass Spectrophotometry (GC-MS) studies were performed using a Shimadzu

gas chromatograph, model 17-A, which was outfitted with a Flame Ionisation Detector (FID) and a functional version 4.3 of the class VP chromatography data system (Schimadzu). Helium gas was utilized as the carrier gas at a rate of 1 ml per minute in an SPB-1 & SPB-5

capillary column (15 m, 0.110 mm, 0.15 μ l) for analysis. Injection in split mode (1:200) injected volume 2 μ L (4% essential oil/ CH_2Cl_2 v/v), with temperatures of 220 and 270 $^\circ\text{C}$ for the injector and detector, respectively. The linear velocity in column was 19 cm/sec. The column temperature was initially set at 50 $^\circ\text{C}$ for 4 minutes, then increased to 150 $^\circ\text{C}$ at a rate of 7 $^\circ\text{C}$ for 4 minutes, and finally increased to 260 $^\circ\text{C}$ at a rate of 7 $^\circ\text{C}$ for 4 minutes using split ratio (30:70) mode. The oven temperature was maintained at 60 $^\circ\text{C}$ for one minute, then was programmed as previously described. Thin peak areas in the GC-FID profile were used to calculate compound proportions. Rapid mode GC-MS was performed on a Shimadzu GC-MS model GC-2030 series using the same column and operating conditions as for analytical GC-FID operation with Software GC-MS solution version 1.02 (Shimadzu). The ion source temperature was 220 $^\circ\text{C}$, electron multiplies 900 v, and ionisation voltage was 70 ev. In the m/z range of 40–500, mass spectra data were collected in scan mode. At a steady temperature of 260 $^\circ\text{C}$, a split model (1:96) was injected into a diluted oil sample solution (10:100 v/v ethyl acetate). The use of the NIST libraries was made for compound identification.

Data Analysis

To examine the data from the experimental site, a factorial split-plot design was used. In three replications, multiple compression was carried out using the LSD (least significant difference) method.

The averages were used to analyse the data by utilizing two-way ANOVA and Microsoft Excel 2019. At 5% and 1% level of significance, the data from various observations were statistically analyzed.¹⁸

Result and Discussion

Agronomic Traits

The data in Fig. 1, depicts the agronomic features of lemongrass including plant height, effective clumps/ha and number of effective tillers/clump. Analysis of variance of pooled data for five PG and three ST for the four agronomic traits is depicted in Table 3. From the data, it was clear that, in the second cropping year, the plant height was maximum in contrast to the first cropping year. The interaction effect was recorded to have a maximum plant height of 125.00 cm in PG5 \times MS which was at par with PG3 \times MS and PG4 \times MS that recorded plant height of 118.00 cm and 123.67 cm, respectively. The mean data of the ST represented the maximum plant height of 119.07 cm in MS which was statistically different from the other two soil types *i.e.* PS and KS soil. Among, the mean of PG/spacing, PG5 recorded maximum plant height followed by PG4, PG3, PG2 and PG1 and recorded 3.87%, 10.16%, 12.72% and 16.99% more plant height, respectively. A slight variation was observed in plant height during the second cropping season. Similarly, like the previous year the interaction effect in the second year recorded a maximum plant height of 145.00 cm in PG5 \times MS

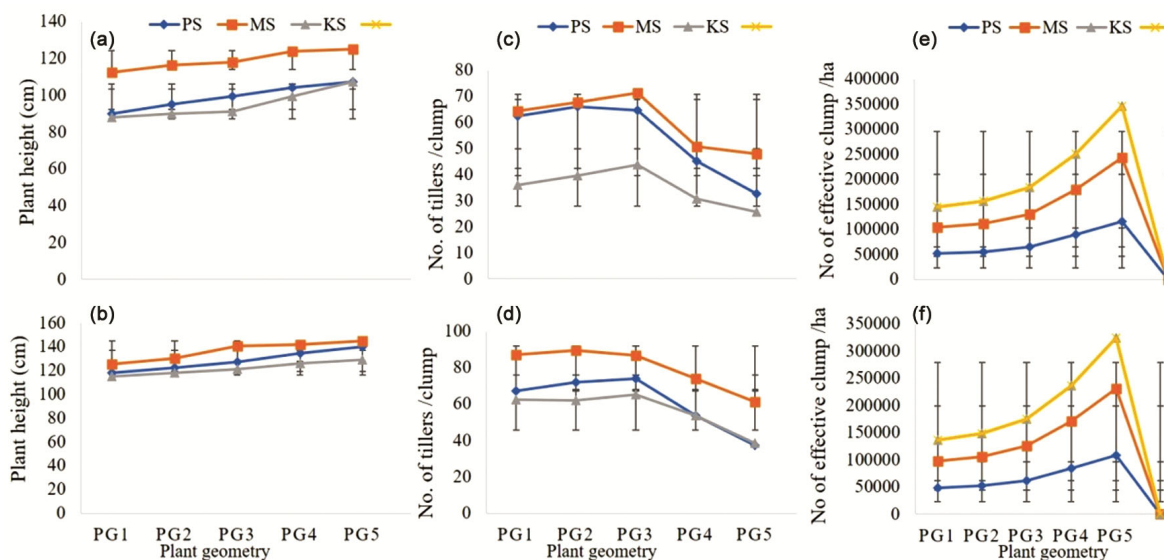


Fig. 1 — Agronomic features of lemongrass (*Cymbopogon flexuosus*) var. *Cymbopogon khasianus x pendulous* (CKP-25) at different soil types and plant geometry/spacing: (a) Plant height (cm) in 2020–21, (b) plant height (cm) in 2021–22, (c) No. of tillers/clump in 2020–21, (d) No. of tillers/clump in 2021–22, (e) No. of effective clump/ha in 2020–21, (f) No. of effective clump/ha in 2021–22

Table 3 — Analysis of variance of pooled data of three soil types and five plant geometry/spacing for the four agronomic traits

Source of Variation	df	Mean Sum of Square of traits							
		Plant height (cm)		No. of tillers/clump		Mortality percentage		No. of effective clump/ha	
		a	b	a	b	a	b	a	b
Replications	2	109.62	151.67	0.82	19.76	1.76	16.79	3734364.048	18422672.91
Soil Types (ST)	2	2465.36*	832.87*	2596.69*	2314.96*	1209.09*	36.79*	1046827154*	1190712629.11*
Error(a)	4	31.29	43.83	2.56	8.09	12.09	0.21	10391738.25	9311187.67
Plant Geometry (PG)	4	394.56*	521.53*	1012.83*	1428.03*	94.03*	2.93*	6903545547*	6040689642.85*
ST x PG	8	13.69*	16.53	57.30*	25.90	9.78*	0.78	37135401.86*	41796396.64*
Error (b)	24	24.59	8.92	10.06	12.14	2.20	2.17	2611014.019	3512166.67
Total	44								

Note: df = degree of freedom, *Significant at $p < 0.05$ levels of probability, “a” represents data for the year 2020–21 and “b” represents data for the year 2021–22

which was at par with PG4 × MS and PG3 × MS that noted plant height of 142.00 and 140.33 cm, respectively. Among, the different ST, MS was found superior in plant height (136.47 cm) over the other ST *i.e.* PS and KS by 6.51% and 12.23%, respectively. Among the different PG/spacing, maximum plant height was recorded in PG5 with 137.78 cm followed by PG4 (134.00 cm), PG3 (129.44 cm), PG2 (123.33 cm) and PG1 (15.67 cm) which were 2.82%, 6.44%, 11.72% and 15.67% more, respectively. The reason for maximum plant height under narrow geometry might be attributed to the denser plantation that leads to more competition for sunlight which could be a reason for upward growth of stem that helped them to increase the plant height. A research conducted on Kalmegh (*Andrographis paniculata* Nees) revealed that different planting geometries tested significantly affect the plant height at 90 DAT (at harvest stage) of the crop, in both years.¹⁹ Another study reported that different plant geometry significantly influenced the plant height in fenugreek, where maximum plant height was attained in closer spacing (20 cm × 15 cm).²⁰ Similar, findings were reported in ajwain²¹ and fenugreek.²²

The analysis of data showed a significant effect of ST, PG and their interaction on the number of effective clumps/ha at $p < 0.05$ levels of probability. It was observed that all the treatments showed significantly different effects on the effective clumps/ha in both years. Among ST, MS gave the best results over PS and KS with 78216.16 and 74883.42 clumps/ha during the first and second year, respectively. Among, the mean PG, PG5 recorded the maximum number of effective clump/ha (115232.74 clump/ha), followed by PG4 (83209.79 clump/ha), PG3 (61367.46 clump/ha), PG2 (52073.55 clump/ha) and PG1 (48263.89 clump/ha). Like the first year, in

the second year also PG5 recorded the maximum effective number of clumps/ha (108080.43), which was 58.13% more than the treatment with the minimum number of effective clumps/ha (PG1). Among the interactions, PG5 × MS was observed to have the maximum number of effective clumps/ha (127419.10 and 121472.88) in the first and second year, respectively which was 67.79% and 68.68% more than the treatments with minimum effective clumps/ha *i.e.* PG1 × KS.

The variance analysis of the data of two years revealed that both the parameters *i.e.* ST and PG have a significant impact on the number of tillers/clump. The data of the number of effective tillers/clump presented in Fig. 1, revealed that maximum number of tillers/clump were recorded in the second year as compared to the first cropping season. In the first year, PG3 × MS interaction recorded maximum number of tillers which was 71.33 tillers/clump and was at par with PG2 × PS and PG2 × MS having 66.00 and 67.67 tillers/clump, respectively. It was 64.01% more than the lowest (PG5 × S3) with 25.67 tillers/clump. On an average, among ST and PG, maximum number of tillers/clump were recorded in MS (60.40 tillers/clump) and PG2. In case of PG/spacing, the average value revealed that PG3 had the maximum tillers which was at par with PG2. The lowest tillers (35.44 tillers/clump) were recorded in PG5. In the second cropping year, the mean value of ST showed a similar result as that of the first year with maximum number of tillers recorded in MS (79.73 tillers/clump) followed by PS (60.80 tillers/clump) and KS (56.33 tillers/clump). However, among the PG/spacing, PG3 (75.22 tillers/clump) was observed to have maximum number of tillers/clump which was 39.14% more than the treatment with minimum tillers/clump (PG5). Treatment PG2 × MS (89.67 tillers/clump) recorded the highest tillers/clump which was at par with PG1 ×

MS (87.00 tillers/clump) and PG3 × MS (86.67 tillers/clump). PG2 × MS recorded 58.37% more tillers than P5 × S1 recorded minimum tillers/clump. Our results confirmed with the study²³, which revealed that among the different spacing tested, spacing 45 × 45 cm was best among other treatments concerning all growth such as foliage stalk length, number of primary branches per foliage stalk, number of cladodes per foliage stalk, length of primary branches in foliage stalk, and plant spread. A similar result was reported in tuberose double²⁴ and gypsophylla.²⁵ Plants grown on sandy clay soil supported the maximum growth among all the tested soil types.²⁶

Mortality Percentage

The analysis data in Fig. 2, depicts the mortality percentage and showed a significant variance at $p < 0.05$ levels of probability to ST and PG. The mortality percentage was immensely reduced in the second year. Based on the mean of PG/spacing treatment, PG3 recorded the minimum mortality percentage in both years, which was 29.20% and 21.17% less than the treatment recorded the highest mortality percentage in PG1 and PG5 in both years. Similarly, the mean of ST, MS showed the best result having less mortality percentage of 17.47% and 4.27% in the first and second year, respectively. In both years, all the ST were found significantly different from one another. Among the interactions, the minimum mortality percentage was

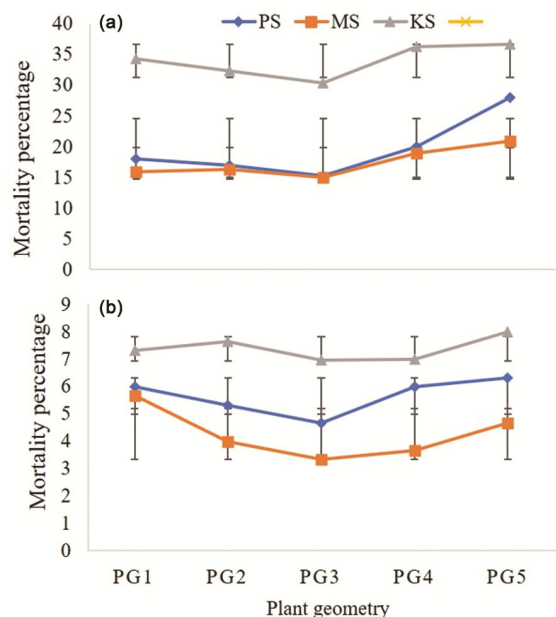


Fig. 2 — Mortality percentage of lemongrass (*Cymbopogon flexuosus*) at different soil types and plant geometry/spacing: (a) Mortality % in 2020–21, (b) Mortality % in 2021–22

recorded in PG3 × MS (15.00%) which was 59.09% less than PG5 × S3 that recorded the highest mortality rate (36.67%) in the first year and was at par with PG2 × PS (17.00%), PG1 × MS (16.00%) and PG2 × MS (16.33%). However, in the second cropping season, PG3 × MS recorded the minimum mortality percentage. The lowest mortality percentage was recorded in MS soil, which was due to the higher moisture-retaining capacity of the soil. Alike result was also reported.²⁷

Essential Oil Content Percentage

The results of the EO content percentage recorded in both years are presented in Fig. 3. The data of both the years imparted that not much difference in the percentage of EO content was noticed. The results revealed that the average mean of EO content in all the ST and PG/spacing and their interactions were found to be statistically at par with each other in both years. In the first year, the mean values of PG/spacing recorded the maximum percentage of EO content in PG1 (0.77%) while, among the different, MS type proved to be the best in comparison with the other two soil type and recorded highest (0.77%) EO content than PS and KS. Among the interactions, PG1 × MS recorded the highest EO content (0.79%). Minimum EO content was recorded in PG2 × KS (0.67%). Alike, in the second year, a similar trend was observed as in the first year. The EO content in lemongrass was found to be higher and was also reported in Bundelkhand soil.²⁷

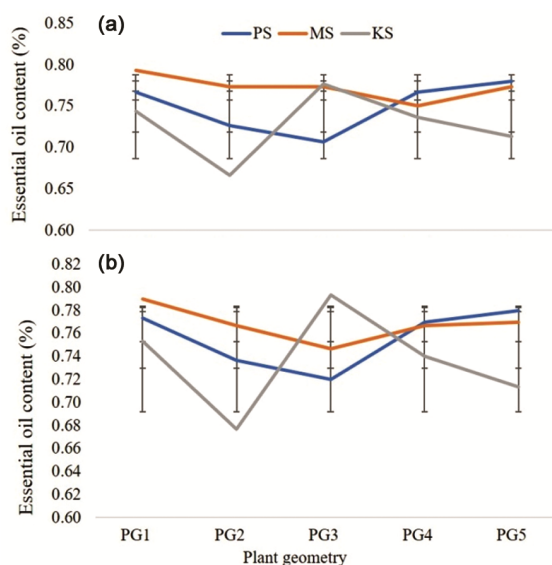


Fig. 3 — Essential oil content percentage in fresh herb of lemongrass at different soil types and plant geometry/spacing: (a) Essential oil content (%) in 2020–21, (b) Essential oil content (%) in 2021–22

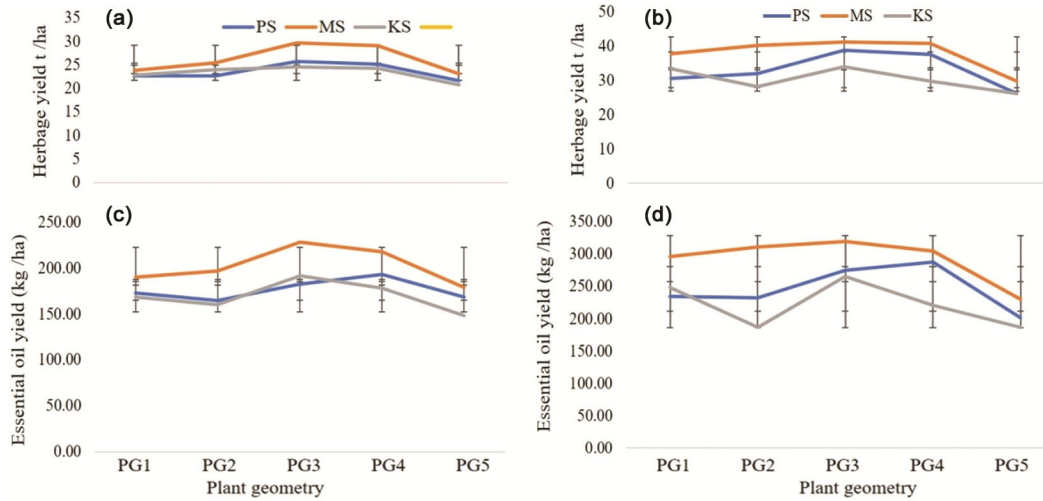


Fig. 4 — Fresh biomass yield (t/ha) and essential oil yield (kg/ha) of lemongrass at different soil types and plant geometry/spacing: (a) Herbage yield (t/ha) in 2020–21, (b) Herbage yield (t/ha) in 2021–2022, (c) Essential oil yield (kg/ha) in 2020–21, (d) Essential oil yield (kg/ha) in 2021–22

Table 4 — Analysis of variance of pooled data of three Soil Types (ST) and five Plant Geometry (PG)/spacing for the five economic traits

Source of Variation	df	Mean Sum of Square of traits									
		Fresh herb yield (t/ha)		EO content (%)		EO yield (kg/ha)		Net return (Rs./ha)		B:C ratio	
		a	b	a	b	a	b	a	b	a	b
Replications	2	0.91	8.71	0.01	0.01	836.50	66.34	1204566489.60	95527593.60	0.12	0.01
Soil types (ST)	2	38.49	224.44	0.01	0.00	4544.73	19440.68*	6544416969.60	27994586150.40*	0.63	4.28*
Error(a)	4	26.81	32.74	0.01	0.01	2218.56	2634.18	3194731401.60	3793215446.40	0.30	0.58
Plant geometry (PG)	4	37.57*	145.98*	0.00	0.00	2077.12*	8476.09*	3092635337.50*	12205566291.20*	0.34*	1.86*
ST x PG	8	3.12	18.87*	0.00	0.00	186.06	1381.26	267928237.60	1989019702.40	0.02	0.30
Error (b)	24	2.32	3.47	0.01	0.01	450.56	892.53	648799613.60	1285239072.80	0.06	0.20
Total	44										

Note: df = degree of freedom, *Significant at $p < 0.05$ levels of probability, “a” represents data during 2020–21 and “b” represents data during 2021–22

Fresh Biomass and Essential Oil yield

The data in Fig. 4, shows fresh biomass and essential oil yield and Table 4 shows analysis of variance of pooled data of three soil types and five PG/spacing for the five economic traits. A vast variation was observed in the Fresh Biomass (FB) yield t/ha in both the cropping years. In the second year, the FB yield was highest in comparison to the first year. The interaction effect revealed that PG3 × MS recorded the highest FB yield (29.57 t/ha) as compared to all other interactions and was at par with PG3 × PS and PG4 × MS which recorded FB yield of 25.77 and 29.00 t/ha respectively. The interaction with the highest FB yield recorded 29.90% more regarding the interaction PG5 × KS that recorded the lowest FB yield (20.73 t/ha). The mean values of PG/spacing in the first year recorded maximum FB yield under PG3 (26.64 t/ha) and it was 1.99, 9.79,

13.55 and 18.17% more than PG4, PG2, PG3 and PG5, respectively. Similarly, the mean values of ST showed that MS recorded the highest FB yield (26.17 t/ha) followed by PS (23.55 t/ha) and KS (23.26 t/ha). MS (S2) recorded 10.01 and 11.12% more FB yield than the PS and KS, respectively. The data of the second year followed a similar pattern in the observation of FB yield. Among, the interactions, PG3 × MS showed the best results with maximum FB yield (41.17 t/ha) in contrast with the rest of the interactions. It recorded a 36.60% higher FB yield contrasted with the interaction recorded minimum FB yield (26.10 t/ha) *i.e.* PG5 × KS. However, the mean values of soil types showed that MS recorded the highest FB yield (37.93 t/ha) which was 12.92 and 20.12% more than PS and KS, respectively.

The analysis of data revealed that ST, PG and their interaction were found significant in both years. The

yield of EO obtained was comparatively higher in the second year than in the first year. In both years, the mean of ST showed similar results, the maximum EO yield obtained from plants cultivated in ST, MS (202.15 kg/ha and 292.56 kg/ha) followed by PS and KS in the first and second year, respectively. It was 15.82% and 24.24% higher than PS and KS. The mean of PG revealed that PG3 was found superior over all other treatments and was at par with PG4. The average highest EO yield (200.63 kg/ha and 286.75 kg/ha) was observed in PG3 in the first and second year, respectively and was at par with PG4 (196.08 kg/ha) and PG1 (260.04 kg/ha) in the year 2020–21 and 2021–22, respectively. The minimum EO yield was found in PG5 (165.10 and 206.57 kg/ha) in the first and second years, respectively. The interaction of PG3 \times MS was found to be best in both the years that obtained 228.23 kg/ha and 319.92 kg/ha EO yield in the first and second year, respectively. Similarly, a study on *Mentha arvensis* recorded highest EO yield when plants were grown on sandy clay soil type with 0.78 ml of oil per 100 g fresh herb.²⁶ Likewise, the highest EO yield of 209 to 406.57 kg/ha was recorded in Bundelkhand region.²⁷ Our study is in consideration with the results found in the study conducted on *Lippia citriodora* that concluded that soil type had a substantial effect on the amount of its EO ($P \leq 0.001$) and revealed that the maximum EO percentage recorded in silt clay loam textured soil and the minimum percentage in sandy soil texture.²⁸ Another study reported that lemongrass produce maximum herb production in 60 \times 30 cm spacing and it was statistically at par with 45 \times 30 cm, 45 \times 45 cm, 60 \times 30 cm, 60 \times 45 cm spacing. They also reported that the highest oil yield of 216.40 liter ha⁻¹ year⁻¹ in a similar treatment with 60 \times 30 cm spacing, which was statistically at par with treatment with a spacing of 45 \times 30 cm (193.80 kg/ha).²⁹ The reason for the maximum herb yield under closer spacing was due to the presence of a higher plant population in that particular PG which further accredited to the higher EO yield under 60 \times 30 cm spacing. The physiological traits of the plants, extraction methods (using fresh or dry leaves) used for the production of EO, plant stages, nutrients given and the types of soil, all these factors contributed to the similarities or variances between EO yields.^{30,31} Plant geometry of 50 \times 50 cm recorded the maximum yield of oil in Patchouli as the provided spacing promoted more vegetative growth which led to herbage production and, consequently, increased the EO yield.³²

Chemical Compositions of Essential Oil

The results of GC-MS analysis for the identification of the chemical composition of EO of lemongrass exhibited a considerable variation in all three ST. A total of ten to twelve components namely 6-Methyl-5-hetpen-2-one or sulcatone, beta-Myrcene, D-Limonene, eucalyptol, linalool, citronellal, isoneral, citronellol, trans-citral or citral A, Neral (cis-citral) or citral B and geranyl acetate etc were identified in both years from each ST and are depicted in Table 5. Out of these components, Neral (cis-citral) or citral B and trans citral or citral A which are an important component of EO of lemongrass were present in higher percentages in all the soil types in both years. Among the ST, MS noted the highest Neral percentage ($40.13 \pm 3.92\%$) than the KS ($36.98 \pm 3.92\%$) and PS ($34.77 \pm 3.67\%$) in the first year, while in the second year also MS ($37.36 \pm 4.63\%$) recorded highest percentage than the KS ($37.24 \pm 3.92\%$) and PS ($36.87 \pm 4.32\%$). Likewise, citral or trans-citral or citral A was found highest ($47.97 \pm 5.51\%$) in MS than PS ($46.52 \pm 5.25\%$) and KS ($40.08 \pm 3.88\%$) in the first year, while in the second year, it was recorded highest in MS ($45.83 \pm 5.54\%$) than PS ($45.51 \pm 5.12\%$) and KS ($43.92 \pm 4.65\%$). However, the total citral [Neral (cis-citral) or citral B + trans-citral or citral A) content in the EO of lemongrass is depicted in Fig. 5, As compared to the second year the percentage of the components present was found slightly higher in the first year. The total citral was found highest in MS ($84.95 \pm 5.36\%$ and $83.19 \pm 4.85\%$) followed by PS ($81.29 \pm 3.86\%$ and $82.38 \pm 4.12\%$) and KS ($80.21 \pm 3.56\%$ and $81.16 \pm 3.74\%$) in first and second year, respectively. This might be due to the favorable climate that led to higher production of secondary metabolites and also MS has the ability to retain moisture for a longer time and has good soil fertility that maximizes the production of secondary metabolites. The highest citral content in lemongrass (82.47%) was also reported in the Bundelkhand region.²⁷ Similarly, the phytochemical analysis GC-MS report of EO of *Monarda citrodora* plants showed a higher content of monoterpene.^{33–36}

Economic Returns

Data presented in Fig. 6, depicts that both ST and PG have persuaded the economics of lemongrass crops in both years. Among PG, PG3 recorded the highest average NR (Rs. 137873.67 and Rs. 263180.00/ha) in the years 2020–21 and 2021–22, respectively. It was

Table 5 — Chemical compositions (CC)/quality of lemongrass essential oil in different soil types

S.No	Name of component	data during 2020–21				data during 2021–22			
		Retention time (RT)	RI ^[a]	RI ^[b]	CC (%)	Retention time (RT)	RI ^[a]	RI ^[b]	CC (%)
Parwa Soil (PS)									
1	6-methyl-5-Hepten-2-one	5.310	938	965	0.43 ± 0.05	ND	ND	ND	ND
2	.beta.-Myrcene	5.390	958	980	0.43 ± 0.05	8.079	991	993	1.36 ± 0.27
3	D-Limonene	6.215	1018	1025	2.85 ± 0.38	8.689	1017	1025	4.52 ± 1.65
4	Linalool	7.554	1082	1085	0.49 ± 0.06	9.674	1059	1085	0.55 ± 0.18
5	Citronellal	8.547	1125	1132	0.47 ± 0.05	10.358	1080	1132	0.59 ± 0.21
6	Isoneral	8.750	1126	1165	0.79 ± 0.08	10.695	1123	1165	4.22 ± 1.09
7	Neral (cis-citral) or citral B	10.069	1174	1214	34.77 ± 3.67	11.409	1172	1214	36.87 ± 4.32
8	Geraniol	ND	ND	ND	ND	11.527	1185	1221	1.38 ± 0.58
9	trans-citral or citral A	10.530	1196	1227	46.52 ± 5.25	11.727	1225	1227	45.51 ± 5.12
10	Cyclohexasiloxane, dodecamethyl-	11.331	1240	1341	0.93 ± 0.09	ND	ND	ND	ND
11	Cyclooctasiloxane, hexadecamethyl-	18.622	1654	1688	3.99 ± 0.37	ND	ND	ND	ND
12	Cyclononasiloxane, octadecamethyl-	21.145	1860	1865	3.40 ± 0.25	ND	ND	ND	ND
13	Geranyl acetate	ND	ND	ND	ND	12.826	1288	1359	3.85 ± 0.96
Mar Soil (MS)									
1	5-Hepten-2-one, 6-methyl-	ND	ND	ND	ND	8.030	938	965	0.30 ± 0.08
2	6-methyl-5-Hepten-2-one	6.773	938	965	0.35 ± 0.09	ND	ND	ND	ND
3	.beta.-Myrcene	6.852	958	980	1.41 ± 0.51	8.077	968	980	1.35 ± 0.48
4	D-Limonene	7.708	1018	1025	4.56 ± 1.01	8.690	1018	1025	3.94 ± 0.88
5	Eucalyptol	7.776	1031	1033	0.36 ± 0.02	8.735	1042	1050	0.51 ± 0.07
6	Citronellal	10.015	1125	1132	0.11 ± 0.01	10.357	1079	1132	0.56 ± 0.09
7	Isoneral	10.475	1156	1165	2.11 ± 0.18	10.482	1115	1165	3.67 ± 0.58
8	7-Octen-1-ol, 3,7-dimethyl-, (S)-	ND	ND	ND	ND	11.226	1171	1211	0.57 ± 0.08
9	Neral (cis-citral) or citral B	11.442	1174	1214	40.13 ± 3.92	11.411	1174	1214	37.36 ± 4.63
10	Geraniol	ND	ND	ND	ND	11.524	1195	1221	2.37 ± 0.34
11	trans-citral or citral A	11.897	1204	1227	47.97 ± 5.51	11.728	1226	1227	45.83 ± 5.54
12	2-Undecanone	12.268	1251	1293	0.17 ± 0.03	ND	ND	ND	ND
13	Geranyl acetate	13.752	1352	1359	5.03 ± 1.02	12.827	1328	1359	3.53 ± 0.66
Kabar Soil (KS)									
1	6-Methyl-5-hetpen-2-one or sulcatone	7.311	938	965	0.82 ± 0.07	ND	ND	ND	ND
2	.beta.-Myrcene	7.421	958	980	0.99 ± 0.09	8.077	965	989	1.58 ± 0.23
3	D-Limonene	8.296	1018	1025	5.16 ± 1.14	8.690	1017	1032	4.66 ± 1.05
4	Eucalyptol	8.374	1039	1042	0.57 ± 0.05	ND	ND	ND	ND
5	Linalool	10.041	1082	1085	0.71 ± 0.07	9.674	1082	1103	0.53 ± 0.06
6	Citronellal	11.460	1125	1132	0.80 ± 0.07	10.358	1107	1132	0.63 ± 0.08
7	Isoneral	11.690	1158	1165	4.53 ± 1.01	10.694	1136	1165	3.85 ± 0.99
8	7-Octen-1-ol, 3,7-dimethyl-, (S)-	ND	ND	ND	ND	11.228	1174	1211	0.73 ± 0.08
9	Citronellol	13.186	1163	1210	0.70 ± 0.04	ND	ND	ND	ND
10	Neral (cis-citral) or citral B	13.459	1174	1214	36.98 ± 3.92	11.409	1172	1244	37.24 ± 3.92
11	Geraniol	ND	ND	ND	ND	11.526	1228	1260	1.48 ± 0.17
12	trans-citral or citral A	14.046	1223	1227	40.08 ± 3.88	11.725	1225	1276	43.92 ± 4.65
13	Geranyl acetate	15.959	1352	1382	4.86 ± 1.01	12.827	1352	1382	3.38 ± 0.48

Note: Soil Types (ST) {PS = Parwa Soil (Reddish grey-loam to sandy texture), MS = Mar Soil (Black-fine grained in texture) and KS = Kabar Soil (Black-coarse grained texture)}, RI^[a] = Retention index calculated, RI^[b] = Retention index from {NIST, 2023 (version 3.4.5)}³⁷⁻⁴⁴, ND = Not detected; Result presented in mean ± standard deviation

34.64% higher than that noted the lowest NR *i.e.* PG5. Among the ST, MS recorded the highest NR in both years (Rs 140716.00/ha and Rs 270152.00/ha). The

interaction effect of the treatments revealed that in both the cropping seasons, PG3 × MS recorded the maximum NR (Rs 1,70,995.00/ha and Rs 3,02,984.00/ha) which

was 59.22% and 52.75% more than that of lowest NR, PG5 × KS (Rs 69,728.00 /ha and Rs 1,43,812.00 /ha) in the year 2020–21 and 2021–22, respectively. A similar result of the mean (±) maximum NR (Rs. 146580.02/ha) in lemongrass var. CKP-25 was reported in the Bundelkhand region.²⁹

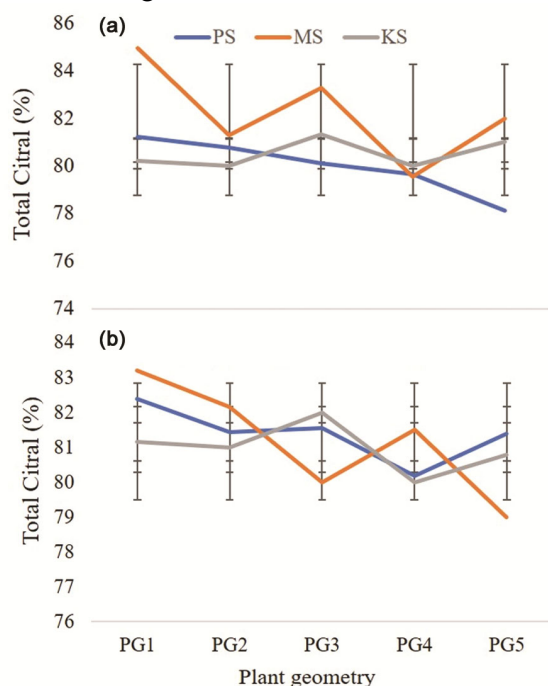


Fig. 5 — Total citral [Neral (cis-citral) or citral B + trans-citral or citral A] content of lemongrass at different soil types and plant geometry/spacing: (a) represents Total citral (%) in 2020–21, (b) represents Total citral (%) in 2021–22

B:C ratio refers to the estimation of the relative cost and benefit which is expressed in qualitative terms. Based on mean values, it was perceived that among the PG/spacing, PG3 observed a higher B:C ratio than PG5 which was 27.86% higher. Among the soil types, MS recorded the maximum B:C ratio (2.39 and 4.34) which was 12.97% and 19.50% higher than that of PS and KS, respectively. The interaction effect revealed that PG3 × MS recorded the highest B:C ratio 2.66 and 4.74 in the first and second year, respectively. It was found to be statistically at par with interactions PG1 × MS (2.38), PG2 × MS (2.41), PG4 × MS (2.66) and PG3 × MS (2.23). Among the mean values of ST, MS observed the maximum B:C ratio of 4.34 which was 19.73% and 31.94% higher than that of PS and KS, respectively. As far as the economics is concerned similar results were shown by various researchers, they reported that among the different ST in the Bundelkhand region, MS showed the best results as compared to Kabar, Parua and Rakar and would be recommended to the farmers for the maximum yield.^{27,45}

Conclusions

Bundelkhand region is largely characterized by less fertile soils, undulating topography, extreme weather conditions, and recurrent droughts, making the agriculture more difficult leading to low crop productivity. People need smart agriculture approaches and diversification in agriculture for sustainability. The conclusions of the conducted study, lemongrass variety

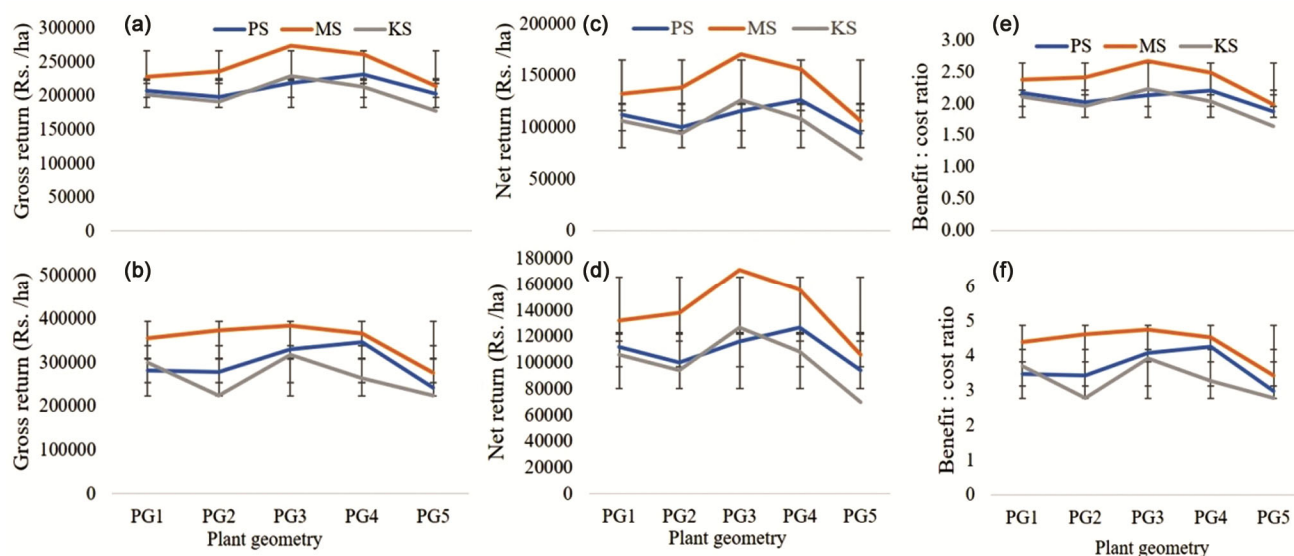


Fig. 6 — Economic returns of lemongrass at different soil types and plant geometry/spacing: (a) represents Gross return (Rs./ha) in 2020–21, (b) represents Gross return (Rs./ha) in 2021–22, (c) represents Net return (Rs./ha) in 2020–21, (d) represents Net return (Rs./ha) in 2021–22, (e) represent Benefit: Cost ratio 2020–21, (f) represent Benefit: Cost ratio 2021–22

CKP 25 tested in the existing soil types of Bundelkhand region is suitable in all soil like PS, MS and KS, in which, best result obtained in Mar soil (MS). Although, the results of sophisticated plant geometry/spacing *i.e.* PG3 (76,923 plants/ha and 45 × 30 cm) delivers good bright sunshine, water and nutrients and gave the best results for agronomic traits, yield, quality and economic returns. Thus, these findings can be further suggested to the farmers in the Bundelkhand region, it will be helpful for them in choosing the right plant geometry as well as soil types in future. Hopefully, these results could help as a reference for further studies on relevant aspects.

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