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Growth, nodulation, yield, nitrogen uptake, and economics of lentil as influenced by sowing time, tillage, and management practices

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Crop management practices and variety are two very important parameters that decides the crop performance. A field experiment was carried out during the two consecutive *rabi* seasons of 2018–19 and 2019–20 to determine the impact of sowing timing, tillage operation, and variety on the growth, development, yield characteristics, and nitrogen uptake in lentil crops. The experiment was conducted in a split-split plot design with 3 replications comprising two different sowing conditions (S_1: early sowing after harvesting of short duration *kharif* rice, S_2: delayed sowing after harvesting of long duration *kharif* rice) in main plots, three different tillage operations (T_1: Relay cropping, T_2: Zero tillage, T_3: Conventional tillage) in subplots and two different varieties (V_1: short duration: L4717, V_2: long period: *Moitri*) in subplots. The findings demonstrated a substantial interaction between sowing time, tillage, and variety on various growth and yield parameters of lentil crops. The early sowing of lentil crops (early November) yielded 4.8% more (1,105 kg ha^{-1}) than late November sowing and adapting to the short-duration variety L4717 over the long-duration cultivar *Moitri* resulted in a yield increase of 5.9% (1,086 kg ha^{-1}). Apart from providing a higher yield, it also provided an opportunity to take another crop like leafy vegetables. Among the three tillage practices adopted, conventional tillage produced the lowest yield (1,017 kg ha^{-1}) in both experimental years. In contrast, a yield increase of 6.9% and 26.9% in relay cropping and zero tillage systems was observed, respectively. Early-sown lentils with no-tillage and a short-duration variety reached a certain phenophase faster than other combinations (life cycle: 96.2 and 98.7 days for lentils in both years). For both the sowing times, the growth parameters and the number of nodules $plant^{-1}$ were highly correlated with nitrogen uptake at different stages of the life cycle. High net returns (Rs. 51,220 and 59,257) leading to higher benefit-cost ratios were observed under the treatment combination of early sowing + zero tillage + short duration variety. Therefore, the study found that short-duration lentil cultivars in combination with early sowing in the zero-tillage system are the best agronomic approach for the sustainability of lentil production after the monsoon rice harvest.

KEYWORDS

lentil, nitrogen uptake, nodule, sowing time, tillage, variety, LAI

1. Introduction

Several grain legumes have been found to be crucial for meeting food requirements and for food security as they are primary plant protein sources. Besides being a rich source of proteins and essential amino acids, pulses can serve as a 'mini nitrogen factory', reducing the requirement for chemical fertilizers and maintaining environmental balance. Legumes have become recognized for their extensive contribution to crop diversity and sustainable agriculture. In light of urgent challenges such as climate change, population explosion, and agricultural land degradation, legumes have a bigger and more important role to play. Chickpeas, lentils, and faba beans are three food legumes whose production has decreased over the past decade. Though there are many high-yield varieties and advanced production technologies that should result in higher and more stable yields, production trends regarding food legumes have mostly been static or have declined in developing countries. In developing countries like India, food legumes are as equally important as food grains and oilseeds (Choudhary, 2009).

In India, chickpea, pigeon pea, mungbean, urdbean, lentil, and field pea are the important legume crops grown (Saxena et al., 2000; Ali and Gupta, 2012), which form an integral part of the different cropping systems for sustainable agriculture. Lentil (*Lens culinaris*) is amongst the oldest domesticated crops cultivated in the world. The world's total lentil cultivated area is estimated at ∼6.10 million ha, with annual production and yield of 6.33 million tons (MT) and 1,038 kg ha^{-1}, respectively (FAOSTAT, 2019). Lentil is India's second most important *rabi* pulse crop (Singh et al., 2014) with a rich source of protein and essential amino acids (Tripathi, 2016). Lentil cultivation in India is characterized by low yields with high variability and is grown mainly by marginal farmers. There are studies that have indicated that replacing age-old lentil varieties and adjusting sowing time in the crop sequence may help improve yield and expand the area in potential regions (Sen et al., 2016).

Adjusting sowing time may be an important factor in lentil production as it is an essential factor that plays a pivotal role in crop growth, phenological development, nodulation, pod development, and productivity (Pradhan et al., 2018). The plant environment such as temperature, photo-period, and moisture availability (in dryland/rainfed conditions), significantly differs from the sowing date. Therefore, shifting the *kharif* crop sowing dates to accommodate the next cool-season crop (*rabi*) in the cropping system can ensure more system productivity (Maji et al., 2019). In the lower Gangetic plains of India, late transplanting of monsoon rice with long-duration varieties along with erratic rainfall in October or November delays the sowing of post-rice CSFLs, making them susceptible to terminal heat/drought stresses and eventually lowering productivity. In the future, the change in rainfall is going to be drastic. According to Yadav et al. (2017) and Chandran et al. (2022) the mean percent change in projected rainfall compared to baseline during the lentil growing period was −7%, −8.5%, +1.7%, and −6.8%, respectively under mid_rcp4.5, mid_rcp8.5, end_rcp4.5 and end_rcp8.5 scenarios.

Along with the proper time of sowing, a high-yielding short-duration variety is equally important. Days to maturity of a crop have a significant role in finding a fit, especially after the rice harvest. During the last three decades, lentil breeders have made tireless efforts to increase the productivity of lentil crops across different global locations by developing short-duration varieties with high and stable yield advantages for diverse agro-climatic conditions. An early maturing variety may escape from drought or flooding and allow the cultivation of multiple crops in a year. At Indo Gangetic plains of India, lentil varieties like Ranjan, Subrata, and *Moitri* (duration: 125–130 days) are popular across agro-climatic zones. But, many location-specific and widely adaptable high-yielding short-duration varieties of pulses have already been developed (Erenstein and Laxmi, 2008), which also need to be popularized across different lentil growing locations to provide tolerance against biotic and abiotic stresses.

Tillage is a well-known agricultural practice that has a larger impact on creating better soil conditions for ensuring satisfactory crop growth and development (Singh et al., 2022). Conservation or zero tillage, which leads to less disturbance of soil and permits residue retention, has gained momentum across the globe (Nuttonson, 1955). No-till or zero tillage is a critical component of conservation agriculture to produce crops cheaply with a profound effect on natural resources. In many parts of the world, conservation agriculture has become increasingly popular because soil degradation and the sustainability of agriculture have become increasingly apparent. Proper tillage management can be a better solution for the soil degradation processes documented in parts of Indo-Gangetic plains.

Keeping a view of the literature above, an experiment was designed to study the effects of different sowing times, tillage, and varieties on growth, nodulation pattern, yield parameters, phenophase attainment, total N uptake and economics in lentils grown after monsoon rice. We believe this study will also be important for a future in which we expect a change in the climate. The changes in rainfall and maximum and minimum temperatures can be effectively managed with this agronomic management.

2. Materials and methods

2.1. Details of experimental site

The present experiment was carried out during two successive *rabi* seasons (October to March) of 2018–19 and 2019–20 at the District Seed Farm (22°56′ N latitude, 88°32′ E longitude, and an altitude of 9.75 m above mean sea level), AB Block, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal, India. The soil was well-drained Gangetic alluvial (order: Inceptisol), which belongs to the class of sandy loam with medium fertility, almost neutral in reaction (pH 7.0), low in organic carbon (0.52 and 0.57%), available nitrogen (132.59 and 138.19 kg ha^{-1}), phosphorus (24.86 and 29.66 kg ha^{-1}), and potassium (157.82 and 159.16 kg ha^{-1}) for both the years.

2.2. Weather conditions

The day-to-day meteorological data during the period of the experiment was collected from AICRP on Agro Meteorology, Directorate of Research, Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal. The maximum and minimum temperatures during the cropping period ranged between 24.5 and 32.4°C and 10.1–22.5°C in 2018–19 and 23.4–32°C and 11.2–23.3°C in 2019–20. The daily temperature during the experiment period of both years started to decline in November and reached a minimum in January. The relative humidity in these cropping seasons was perceived between 96.0–42.5% and 97.5–40.1% during 2018–19 and 2019–20, respectively. The crop was grown exclusively under rainfed conditions. The total amount of rainfall received during the experiment period was 133.7 mm in 2018–19 and 189.6 mm in 2019–20.

2.3. Experimental design and treatment details

The investigation was laid out in a split-split plot design with three replications comprising 12 treatment combinations (Supplementary Figure S1). In the study, the main plots included two sowing conditions (S_1: Early sowing, i.e., 1st week of November after harvesting of short duration *kharif* rice, i.e., Sahabhagi and S_2: Delayed sowing, i.e., last week of November) after the harvesting of long period *Kharif* rice, i.e., Swarna, 3 tillage practices in the subplots (T_1: Relay cropping, T_2: Zero tillage, T_3: Conventional tillage), and two varieties of lentil (V_1: short duration L4717, V_2: long duration Moitri) that were laid on sub-sub plots. The L4717 variety used in the experiment is an early maturing (105 days), powdery mildew and Fusarium wilt disease-resistant lentil variety released by the Indian Agriculture Research Institute, New Delhi, India, with a yield potential of 12–13 q ha^{-1}. On the other hand, *Moitri* is a long-duration (120 days), rust disease-resistant popular lentil variety released by the Pulses and Oilseed Research Station, Berhampore, West Bengal, India, with a yield potential of 10–12 q ha^{-1}. There was a difference of at least 20 days between the early and late sowing period. There was a visible difference noted in the moisture content of the soil between the early November sowing (initial moisture content was 25.24% at 0–15 cm and 27.07% at 15–30 cm) and the last week of November sowing (initial moisture content was 24.12% at 0–15 cm and 25.58% at 15–30 cm) of the lentil crops.

2.4. Crop management

Lentil (60 kg ha^{-1}) seeds were broadcasted on the standing rice crop for both dates of sowing in relay cropping. On both dates of sowing, residues of previously grown rice crops were left in the field. A zero till drill was used to implement zero tillage in the plots. One deep plowing with a disc plow followed by 2 harrowing and 1 planking was provided for conventional tillage treatment. After the final land preparation, the seeds were sown at a distance of 25 cm row to row by opening furrows and placing seeds in a depth of 3–4 cm in both zero-tilled and conventionally-tilled plots in both the sowing dates.

A recommended fertilizer dose of 20:40:40 kg N-P_2O_5-K_2O ha^{-1} for lentils was applied as basal dose. The whole quantity of nitrogen, phosphorous, and potassium was applied at the time of sowing of the crop. No external irrigation was provided to the crops and the crop survived by utilizing the residual soil moisture. Two-hand weeding at 25 DAS (days after sowing) and 50 DAS for the lentil crops was done to minimize crop weed competition. The crop was harvested manually when the leaves became yellow, and ∼85–90% of green pods turned to golden straw color. After threshing, cleaning, and drying, the grains of each plot were weighed separately, and the yield was determined in terms of kg ha^{-1}.

2.5. Methodology used

For growth analysis, five randomly selected lentil plant samples from the experimental plots were collected at respective stages of observation, and plant height (45, 75 DAS and at harvest), dry aerial biomass accumulation (45, 75 DAS, and at harvest), the number of nodules $plant^{-1}$ (45, 60, and 75 DAS), and leaf area index, i.e., LAI (45, 60, and 75 DAS), were determined by following the standard procedure. The yield components and grain yield of the lentil crops were determined at maturity. The different phenophases (viz., days to flower initiation, flowering to pod initiation and pod initiation to maturity, sowing to maturity) of lentil crops planted at other dates were noted using the regular field inspection method. The degree days were obtained as the difference between the mean daily temperature and the base temperature of the crop (AOAC, 1995).

$$\mathrm{GDD} = \sum_{i=1}^{n}\left[\left(\frac{T_{max}+T_{min}}{2}\right)-T_b\right]$$

where Tmax. and Tmin. were the maximum and minimum air temperatures of a day, Tb was the base temperature (50 C for pulses) and n was the number of days to attain a phenophase. The degree days for different phenophases of lentil varieties were calculated, which were summed up from the sowing to the maturity of the crop.

The micro-Kjeldahl method was used to determine the total nitrogen (N) in the lentil plant samples as per the procedure suggested by Gomez and Gomez (1984). The uptake of N by the plant on a dry weight basis (seed and stover) was calculated by the following formula:

$$\text{Uptake in Kg ha}^{-1} = \frac{\text{Nutrient \% } (\text{seed or stover}) \text{ XYield (seed orstover)}}{100}$$

For the economics of lentil cultivation, the cost of each treatment was calculated based on the then-prevailing market price of the inputs. The cost of cultivation was worked out with the following formula:

$$\begin{aligned}\text{Cost of Cultivation (Rs ha}^{-1}) &= \text{Variable Cost (Rs. ha}^{-1}) \\ &+ \text{Fixed Cost (Rs. ha}^{-1})\end{aligned}$$

The gross return was obtained by converting the harvest into monetary terms at the prevailing market rate during the study period. The net return was calculated by deducting the cost of production from the gross return and expressed as:

$$\begin{aligned}\text{Net Return (Rs. ha}^{-1}) &= \text{Cost of Cultivation (Rs. ha}^{-1}) \\ &- \text{Gross Return(Rs. ha}^{-1})\end{aligned}$$

The benefit-cost ratio was calculated with the help of the following formula:

$$\text{B : C ratio} = \frac{\text{Gross return (Rs ha}^{-1})}{\text{Cost of Cultivation (Rs ha}^{-\ 1})}$$

The data obtained on the various parameters under study were analyzed statistically using the variance analysis method (ANOVA) for a split–split plot design. The significance of the treatments was tested at a 5% least significant difference and was computed by the "F" test (Wickham, 2016).

2.6. Correlation

The Pearson correlation coefficients with significance levels presented in a scatterplot and correlogram were done with the help of ggplot2 (Schloerke et al., 2021) and GGally (Edalat and Naderi, 2016) package in R v4.1.2.

3. Results and discussion

As lentil is an indeterminate crop, growth parameters such as plant height and dry aerial biomass accumulation tend to increase with the advancement of the crop growth and reach a peak at harvest irrespective of different treatments.

3.1. Impact on growth and nodulation

The significantly highest plant height in the lentil crops was found in the early sown treatment (first week of November) as compared to the delayed sowing (last week of November) in all the different growth stages, as shown in Supplemenatry Table S1 and Figure 1.

These results are in line with the findings of Sen et al. (2016) and Venugopalan et al. (2022) where he has reported a reduction in plant height when the lentil was sown late (last week of November). This might be due to its congenial weather condition during the first sowing date of the lentil crops which provided a favorable environment for the growth and development of the crop. Among the various tillage conditions, maximum plant height was noted in the zero tillage plots in both years (Figure 1). Zero tillage perhaps provided an advantage to crop over weeds, resulting in better resource utilization and greater suppression ability of weeds than the other treatments that indirectly led to better growth of the crop. Among the various varieties studied, lentil variety L4717 resulted in the significantly tallest plant at various growth stages. The genetic makeup of the short-duration varieties may have resulted in taller plants compared to the longer-duration varieties. An earlier experiment showed that the simultaneous improvement of yield and earliness was possible because of high heritability for important traits, including crop growth rate, efficient partitioning of photosynthetic assimilates, and reproductive duration (Jogloy et al., 2010; Edalat and Naderi, 2016). However, the interaction effect of sowing condition, tillage, and variety did not significantly affect the plant height of the lentil crop.

A significant influence of sowing time was noted on the dry aerial biomass accumulation of lentils at 75 DAS during 2018–19 in the experiment. The early sowing of lentils at various stages resulted in superior dry aerial biomass accumulation (Supplementary Table S2 and Figure 2), which may be due to proper weather conditions.

The experiment results found similarity with the results of Tyagi (2014) and Visha Kumari et al. (2021). Maximum aerial biomass was noted in the treatment plots with zero tillage during both years. Improved soil moisture and nutrient availability at the crop root zone, sufficient aeration facility, and greater transpiration surface area could all contribute to better results in lentil plots with zero tillage. During both years of experimentation, the short-duration variety L4717 produced maximum dry aerial biomass accumulation (Supplemenatry Table S2 and Figure 2) compared to the long-duration variety *Moitri*. In the case of plant height and dry aerial biomass accumulation of the lentil crops, the 2nd year of the study recorded superior values due to receiving of excess amount of rainfall (almost 56 mm) and there were also improved soil physical properties in response to winter pulse cultivation in the previous year which contributed to better vegetative growth of the lentil crops.

Early sowing resulted in a significantly higher number of nodules plant^{-1} throughout the growth stages (13.0 and 14.3 at 45 DAS, 23.2 and 27.2 at 75 DAS, and 11.7 and 14.5 at 75 DAS) compared to delayed sowing of lentil (12.4 and 13.6 at 45 DAS, 22.5 and 26.5 at 75 DAS, and 11.2 and 13.8 at 75 DAS) for both the years of experimentation (Table 3 and Figures 3–5). The results of the experiment are

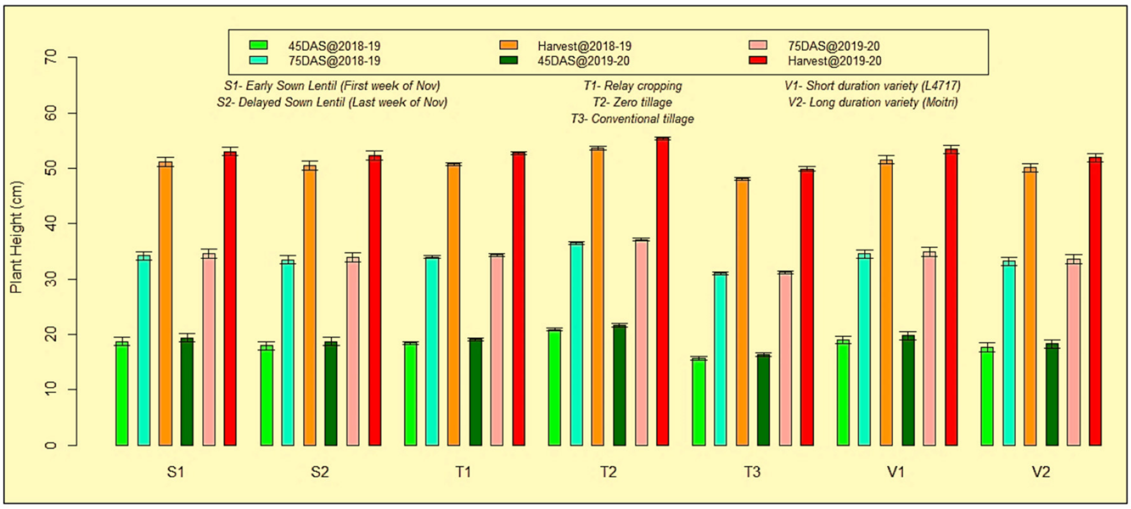

FIGURE 1
The effect of sowing time, tillage, and variety on the plant height of the lentil crops sown after the harvesting of monsoon rice. S_1, Early sowing (1st week of November) after the harvesting of short-duration *Kharif* rice; S_2, Delayed sowing (last week of November) after the harvesting of long-duration *Kharif* rice. T_1, Relay cropping; T_2, Zero tillage; T_3, Conventional tillage; V_1, Lentil short duration: L4717; V_2, Lentil long duration: Moitri. Significant at $p \leq 0.05$. NS- Non-significant at $p \geq 0.05$.

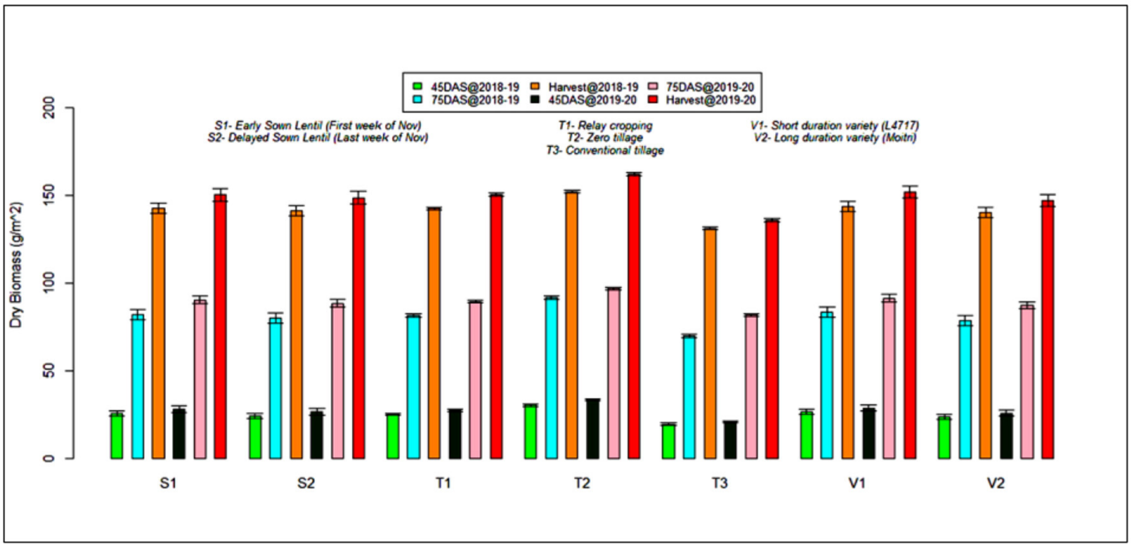

FIGURE 2
Effect of sowing time, tillage, and variety on dry aerial biomass accumulation of lentil crops sown after monsoon rice harvesting. S_1, Early sowing (1st week of November) after harvesting of short-duration *Kharif* rice; S_2, Delayed sowing (last week of November) after harvesting of long-duration *Kharif* rice. T_1, Relay cropping; T_2, Zero tillage; T_3, Conventional tillage; V_1, Lentil short duration: L4717; V_2, Lentil long duration: Moitri. Significant at $P \leq 0.05$. NS- Non-significant at $P > 0.05$.

close to the results of the experiment (Sah et al., 2019) in chickpeas.

A significant influence of earlier sowing date on the nodules plant^{-1} of lentils was also observed by Visha Kumari et al. (2019). Among the different crop establishment methods, the maximum number of nodules plant^{-1} was recorded in the zero tillage plots followed by the relay cropping plots during both the years of the experiment (Table 3 and Figures 3–5). This may be attributed to better seedbed preparation, which might have facilitated better root growth in the no-till plots. These findings could be supported by the previous observations of Quddus et al. (2020) in various growth parameters of winter chickpeas with various tillage operations. Among the different lentil varieties studied, the maximum number of nodules plant^{-1} was found in the short-duration variety L4717 at all the growth stages (Supplemenatry Table S3 and Figures 3–5) in both years. The difference in growth attributes may be due to the varietal characteristics and their crop duration.

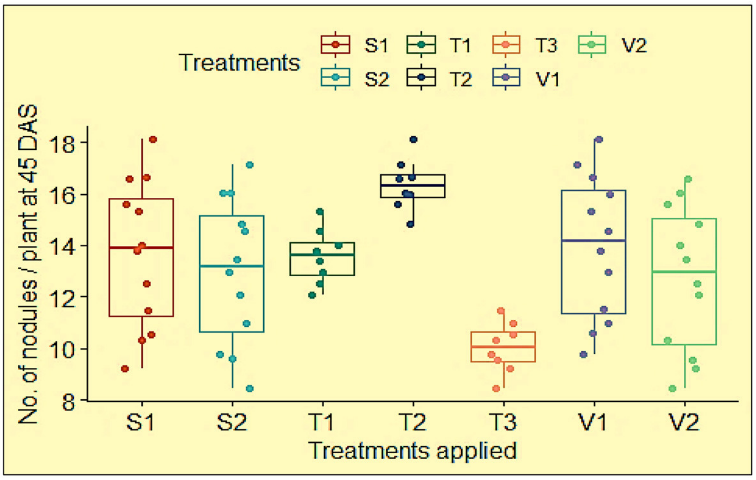

FIGURE 3
Effect of sowing time, tillage, and variety on a number of nodules plant^{-1} at 45 DAS of lentil crops sown after monsoon rice harvesting (S_1, Early Nov sown Lentil; S_2, Late Nov sown Lentil; T_1, relay cropping; T_2, zero tillage; T_3, conventional tillage; V_1, L4717; V_2, Moitri).

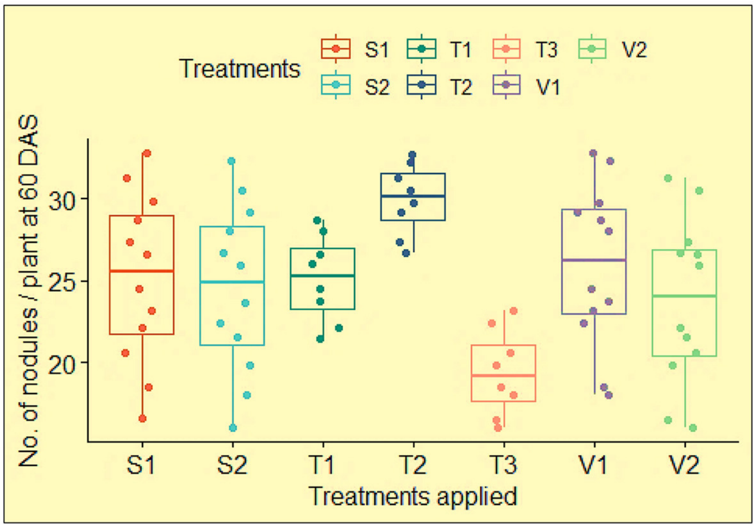

FIGURE 4
Effect of sowing time, tillage, and variety on the number of nodules plant^{-1} at 60 DAS of lentil crops sown after monsoon rice harvesting (S_1, Early Nov sown Lentil; S_2, Late Nov sown Lentil; T_1, relay cropping; T_2, zero tillage; T_3, conventional tillage; V_1, L4717; V_2, Moitri).

The trend remained the same for LAI too. Sowing in the first week of November resulted in a significantly higher LAI throughout the growth stages compared to sowing in the last week of November for both the years of investigation (Supplementary Table S4 and Figure 6). For the various tillage treatments, LAI could be arranged as zero tillage > relay cropping > conventional tillage (Supplementary Table S4 and Figure 6). There are few studies which show that no-tillage and minimum tillage performed better in terms of LAI in lentil crops in new alluvial soil (Bandyopadhyay et al., 2018). These results can be explained by the fact that the soil's physical properties such as organic carbon content, aeration facility, and fertility status might be more favorable in zero tillage than in other tillage-based systems. During both years of the experiment, lentil variety L4717 attained the highest LAI at all observed stages as compared to the long-duration lentil variety Moitri due to faster genetic expressions under favorable conditions.

3.2. Impact on grain yield

Among the different yield traits observed, the early sown lentil crops showed the highest number of plants m^{-2} (28.7 and 27.6), while the late sown lentil crops showed fewer plants (25.7 and 25.3). At the lower Gangetic plains of India, the first fortnight of November is considered optimum (Sen et al., 2016; Visha Kumari et al., 2019) and our results are in line with the earlier studies. As

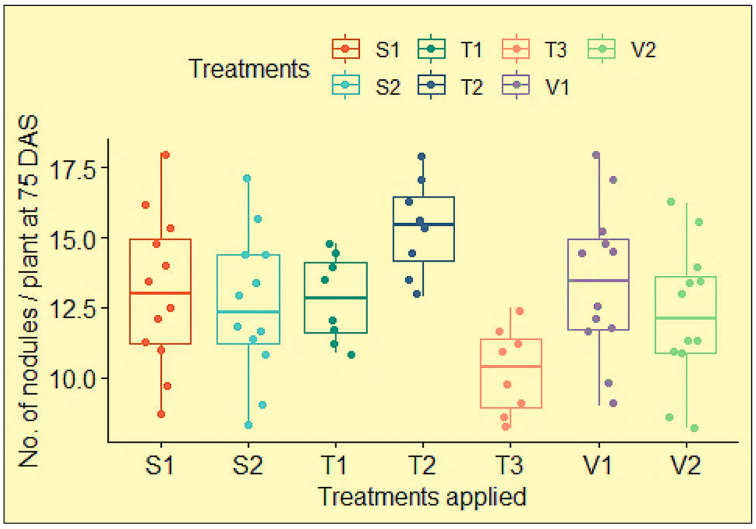

FIGURE 5
Effect of sowing time, tillage, and variety on the number of nodules plant^{-1} at 75 DAS of lentil crops sown after monsoon rice harvesting (S_1, Early Nov sown Lentil; S_2, Late Nov sown Lentil; T_1, relay cropping; T_2, zero tillage; T_3, conventional tillage; V_1, L4717; V_2, Moitri).

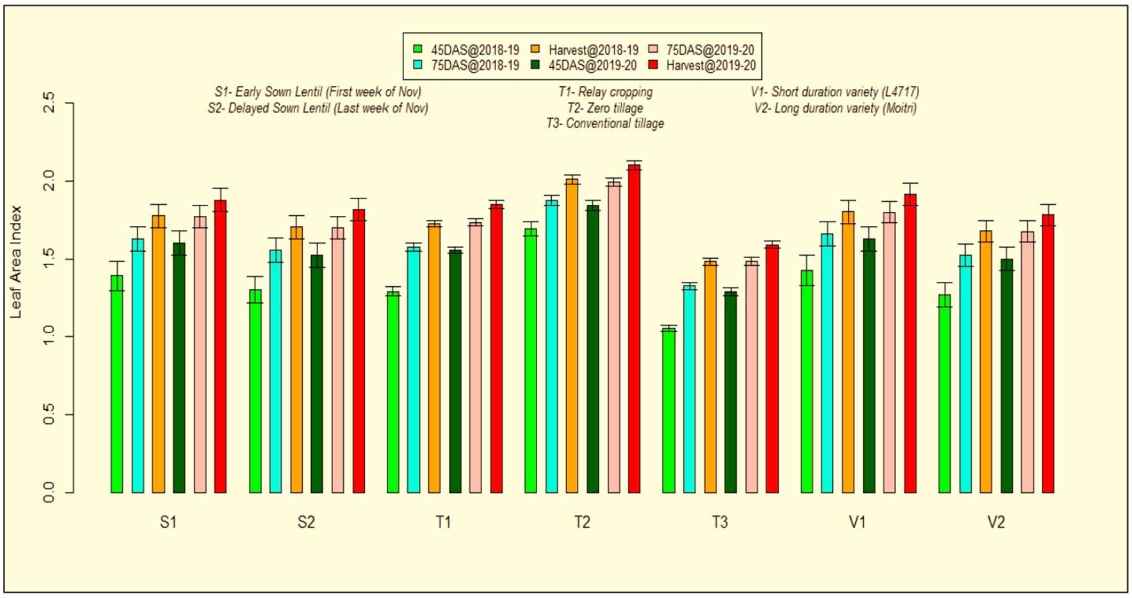

FIGURE 6
Effect of sowing time, tillage, and variety on leaf area index (LAI) of lentil crops sown after monsoon rice harvesting.

per the results, tillage treatments can be significantly arranged as zero tillage (35.3 and 35.8) > relay cropping (25.8 and 24.9) > conventional tillage (20.4 and 18.6) regarding this parameter during both consecutive years of study (Table 1).

The short-duration variety L4717 produced the significantly highest number of plant stand m^{-2} in both years, followed by the long-duration variety *Moitri* (Table 1). The interaction effect of sowing condition, tillage, and variety, however, did not significantly affect the plant population of the lentil crops. Among the different treatments, a significant difference in the number of pods plant^{-1} in the lentil crops was observed during the study (Table 1). Early sowing of lentils resulted in more pods (89.2 and 105.4) due to favorable temperatures during the crop growth period and higher growth attributes, which may be responsible for a better source-sink relationship. Zero tillage-treated plots recorded a higher number of pods plant^{-1} (105.7 and 107.3), followed by relay cropping (87.4 and 97.2) and conventional tillage (70.9 and 82.4) in both years. Due to the compound effects of reduced soil erosion, suppressed nutrient removal by weeds, better soil physical health, improved water regimes, and restoration of soil moisture, there were more

TABLE 1 Effect of sowing time, tillage, and variety on yield parameters of lentil crops sown after monsoon rice harvesting.

ANOVA		Plants m^{-2}		Pods $plant^{-1}$		Test weight (g)	
		2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
Sowing condition (S)	S_1	28.7 ± 1.2a	27.6 ± 2.1a	89.2 ± 12a	105.4 ± 12a	18.75 ± 0.2a	18.93 ± 0.2a
	S_2	25.7 ± 1.4b	25.3 ± 1.3b	86.8 ± 15b	85.9 ± 12b	18.57 ± 0.5a	18.70 ± 0.4b
Tillage (T)	T_1	25.8 ± 1.4b	24.9 ± 2.2b	87.4 ± 18b	97.2 ± 15b	18.70 ± 0.8b	18.64 ± 0.2b
	T_2	35.3 ± 2.1a	35.8 ± 2.0a	105.7 ± 17a	107.3 ± 17a	19.30 ± 0.1a	19.95 ± 0.5a
	T_3	20.4 ± 1.2c	18.6 ± 1.4c	70.9 ± 21c	82.4 ± 0.8c	18.00 ± 0.4c	17.85 ± 0.4c
Variety (V)	V_1	29.7 ± 1.1a	28.6 ± 1.2a	93.1 ± 24a	98.4 ± 14a	18.90 ± 0.1a	19.05 ± 0.5a
	V_2	24.7 ± 1.0b	24.3 ± 1.5b	82.9 ± 25b	92.8 ± 15b	18.45 ± 0.5b	18.60 ± 0.8b

S_1, Early sowing (1st week of November) after the harvesting of short duration Kharif rice; S_2, Delayed sowing (last week of November) after the harvesting of long duration Kharif rice, T_1, Relay cropping; T_2, Zero tillage; T_3, Conventional tillage; V_1, Lentil short duration: L4717; V_2, Lentil long duration: Moitri. Significant at $P \leq 0.05$. NS, Non-significant at $p \geq 0.05$. Values are means ± SEM ($n = 3$). Different letters indicate significant differences between means.

TABLE 2 Effect of sowing time, tillage, and variety on seed yield and total *N* uptake of lentil crops sown after monsoon rice harvesting.

ANOVA		Seed yield (kg ha^{-1})		Total *N* uptake (kg ha^{-1})	
		2018–19	2019–20	2018–19	2019–20
Sowing condition (S)	S_1	1,131 ± 85a	1,185 ± 115a	80.28 ± 87a	87.24 ± 42a
	S_2	1,108 ± 105b	1,102 ± 148b	71.25 ± 25b	76.07 ± 18b
Tillage (T)	T_1	1,081 ± 124b	1,092 ± 135b	73.38 ± 15b	77.80 ± 45b
	T_2	1,271 ± 154a	1,310 ± 128a	103.16 ± 18a	115.09 ± 25a
	T_3	1,006 ± 118c	1,028 ± 147c	50.75 ± 26c	52.08 ± 12c
Variety (V)	V_1	1,154 ± 154a	1,177 ± 102a	79.35 ± 12a	85.95 ± 14a
	V_2	1,084 ± 112	1,109 ± 98b	72.18 ± 10b	77.36 ± 16b

S_1, Early sowing (1st week of November) after the harvesting of short duration Kharif rice; S_2, Delayed sowing (last week of November) after the harvesting of long duration Kharif rice; T_1, Relay cropping; T_2, Zero tillage; T_3, Conventional tillage; V_1, Lentil short duration: L4717; V_2, Lentil long duration: Moitri. Significant at $P \leq 0.05$. NS, Non-significant at $p \geq 0.05$. Values are means ± SEM ($n = 3$). Different letters indicate significant differences between means.

yield attributes and yield in the zero tillage plots. There were varietal differences in the number of pods $plant^{-1,}$ too, owing to the genetic potential (Table 1).

A similar observation regarding the test weight of lentils was found regarding sowing time, tillage, and variety in lentils where the early November sowed crop resulted in higher test weight (18.75 and 18.93 g) (Table 1). Tillage treatments could be arranged as zero tillage (19.30 and 19.95 g) > relay cropping (18.70 and 18.64 g) > conventional tillage (18.00 and 17.85 g) regarding this parameter during 2018–19 and 2019–20. The higher yield attributes in zero tillage plots of lentil crops are also similar to the results of earlier work (Bandyopadhyay et al., 2018; Chauhan et al., 2019; Quddus et al., 2020). The L4717 variety recorded a higher test weight (18.90 and 19.05 g) in both the years of study than the long-duration variety *Moitri* (18.45 and 18.60 g).

Lentil yield also varied significantly with the time of sowing, tillage, and variety. For 2018–19 and 2019–20, early sowing recorded a 2.08 and 7.53% increase over the delayed sowing of lentils in the investigation, respectively (Table 2). The results of delayed sowing were in accordance with Sita et al. (2017) where the high sensitivity of lentil crops to high temperature resulted in a negative impact on the reproductive stage followed by a yield reduction. Zero tillage resulted in a higher yield among the tillage treatments followed by relay cropping (Table 2).

Zero tillage had the advantage of better depth and moisture availability. The L4717 variety produced 6.46 and 5.34% higher seed yields than Moitri during the study period of the year 2018–19 and 2019–20, respectively. It is reported that lentil genotypes with a short duration can produce higher seed yield if they efficiently partition the photosynthetic assimilates into economic profit (Kumar and Srivastava, 2015; Mukherjee et al., 2020). This may be the reason for the higher yield in L4717. Further, the yield attributing parameters and seed yield of lentil was found to achieve far superior values in 2019–20 as compared to 2018–19 probably due to improved organic carbon content (0.05%) as well as receiving a greater amount of rainfall that increased the soil moisture reserve in the 2nd year of study which helped in better utilization of water resource attributing to better reproduction and yield advantages.

3.3. Impact on total *N* Uptake

Total N uptake also varied significantly following a similar pattern of higher total N uptake (80.28 and 87.24 kg ha^{-1}) in early sown lentils during both years. Similar findings were reported previously by experimental results (Kumar et al., 2016; Neenu et al., 2017). Higher nutrient content and uptake with the early planted

TABLE 3 Effect of sowing time, tillage, and variety on the phenology of lentil crops sown after monsoon rice harvesting.

ANOVA		Days to flower initiation		Flowering to pod initiation		Pod initiation to maturity		Sowing to maturity	
		2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
Sowingcondition (S)	S1	43.2 ± 0.2b	43.9 ± 0.5	20.3 ± 0.1b	20.9 ± 0.5b	39.0 ± 0.2b	39.2 ± 0.3b	110.4 ± 0.1b	112.1 ± 0.2b
	S2	43.9 ± 0.1a	44.7 ± 0.2a	21.0 ± 0.2a	21.7 ± 0.4a	39.8 ± 0.1a	39.9 ± 0.5a	113.0 ± 0.2a	114.7 ± 0.1a
Tillage (T)	T1	43.3 ± 0.1b	43.6 ± 0.2b	20.6 ± 0.1b	21.1 ± 0.2b	39.6 ± 0.2b	39.6 ± 0.1b	111.2 ± 0.2b	112.4 ± 0.1b
	T2	39.6 ± 0.2c	40.4 ± 0.2c	18.0 ± 0.1c	18.4 ± 0.1c	36.0 ± 0.2c	36.4 ± 0.2c	100.1 ± 0.1c	102.1 ± 0.2c
	T3	47.8 ± 0.1a	48.9 ± 0.1a	23.4 ± 0.2a	24.4 ± 0.1a	42.6 ± 0.1a	42.7 ± 0.1a	123.7 ± 0.2a	125.7 ± 0.1a
Variety (V)	V1	42.8 ±	43.6 ±	20.0 ±	20.5 ±	38.7 ±	38.8 ±	109.3 ±	110.9 ±
	V2	44.2 ±	45.0 ±	21.3 ±	22.1 ±	40.2 ±	40.3 ±	114.1 ±	115.9 ±

S_1, Early sowing (1st week of November) after the harvesting of short duration Kharif rice; S_2, Delayed sowing (last week of November) after the harvesting of long duration Kharif rice; T_1, Relay cropping; T_2, Zero tillage; T_3, Conventional tillage; V_1, Lentil short duration: *L4717*; V_2, Lentil long duration: Moitri. Significant at $P \leq 0.05$. NS, Non-significant at $P > 0.05$. Values are means ± SEM ($n = 3$). Different letters indicate significant differences between means.

crop were due to the more extended vegetative phase of the product, leading to the efficient use of growth resources and hence higher dry matter production. Zero-tilled plots (103.16 and 115.09 kg ha^{-1}) were noted to have maximum total N uptake by lentil grain and stover, followed by relay cropped and conventionally tilled plots during 2018–19 and 2019–20, respectively (Table 2). An earlier finding also documented the highest total N uptake in zero tillage as compared to other tillage practices (Bandyopadhyay et al., 2018). Higher nutrient content and uptake were observed under zero tillage might be because it can promote root growth and development and improve soil macro-aggregates and soil microbial activities as it endorsed good soil conditions through less soil disturbance. Similar observations regarding total N uptake by lentils among the varieties tested were found where the L4717 variety resulted in a significantly superior value (79.35 and 85.95 kg ha^{-1}) during both years due to the difference between the varieties regarding the number of nodules plant^{-1} (Table 2).

3.4. Impact on phenology and GDD

The duration of the lentil crop significantly increased with the delay in sowing from the 1st week of November to the last week of November in the experiment. On average, the early sowing took relatively fewer days from planting to maturity (110.4 and 112.1 days) and went through different phenophases, such as days to flowering, flowering to pod initiation, and pod initiation to maturity compared to the late sowing, which needed more days (113.0 and 114.7 days) to reach maturity in both survey years (Table 3).

The early November sown crops' accelerated phenological stages could be caused primarily by the temperature difference between them. For the crop planted in late November, when temperatures during vegetative growth were much colder and closer to the base temperature of the crop, growth was temporarily halted, delaying the attainment of phenophases at the optimum time. The results follow the results of earlier works (Islam et al., 2008; Sen et al., 2016) across different locations. Among the tillage operations followed, zero tillage treated plots took the lowest number of days for attaining sowing to maturity (100.1 and 102.1 days), followed by relay cropped plots in both the years of study. The minimal soil disturbance that reduces soil water loss through lower evaporation may account for faster growth in zero tillage systems. The softened seedbed helped in rapid emergence (Basir et al., 2011; Edalat and Naderi, 2016). The short-duration lentil variety L4717 recorded the minimum number of days in each of the growth stages noted (days to flower initiation, 42.8 and 43.6 days, flowering to pod initiation, 20.0 and 20.5 days, pod initiation to maturity, 38.7 and 38.8 days) in both years as compared to the long-duration variety *Moitri* (Table 3) due to their faster growth habit and good climate advantages. The interaction effect of sowing condition, tillage, and variety was not significant on the phenophase attainment of the lentil crops during two consecutive years.

Among the different treatment combinations, the $S_1T_1V_2$ (early sowing + relay cropping + *Moitri*) and $S_1T_3V_2$ (early sowing + conventional tillage + Moitri) combinations were noted to have

TABLE 4 Growing degree days (°C day) of lentil canopy at different phenophases grown under different combinations of sowing time, tillage, and variety after monsoon rice harvesting.

Treatment	Days to flower initiation		Flowering to pod initiation		Pod initiation to maturity		Life cycle sowing to maturity	
	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
$S_1T_1V_1$	797.50	794.00	256.40	284.35	480.50	456.05	1694.82	1715.88
$S_1T_1V_2$	804.50	811.00	259.95	296.60	524.60	489.80	1762.88	1792.50
$S_1T_2V_1$	641.25	738.60	190.80	196.55	466.55	432.45	1426.72	1501.95
$S_1T_2V_2$	646.05	772.30	204.80	205.45	485.00	470.80	1470.13	1594.98
$S_1T_3V_1$	661.15	878.20	287.30	283.15	667.50	627.60	1794.72	1958.10
$S_1T_3V_2$	677.05	893.70	313.90	320.45	718.10	674.20	1900.15	2077.70
$S_2T_1V_1$	556.15	582.40	262.65	264.65	648.40	607.10	1600.35	1592.80
$S_2T_1V_2$	568.15	598.45	291.95	278.60	723.65	672.90	1734.65	1700.73
$S_2T_2V_1$	464.75	480.30	256.15	223.95	673.80	622.45	1494.30	1445.25
$S_2T_2V_2$	496.15	504.95	269.40	238.05	723.50	660.40	1597.88	1527.53
$S_2T_3V_1$	612.25	588.15	386.85	378.80	952.40	928.20	2073.07	2018.43
$S_2T_3V_2$	625.15	606.45	424.25	437.90	1017.45	1007.75	2196.60	2189.08

S_1, Early sowing (1st week of November) after the harvesting of short duration Kharif rice; S_2, Delayed sowing (last week of November) after the harvesting of long duration Kharif rice; T_1, Relay cropping; T_2, Zero tillage; T_3, Conventional tillage; V_1, Lentil short duration: L4717; V_2, Lentil long duration: Moitri. Significant at $P \leq 0.05$. NS, Non-significant at $P > 0.05$.

the highest accumulated GDD (804.50 and 893.70°C day) from emergence to flower initiation period during the two consecutive years. Mean gathered GDD from flowering to pod initiation (424.25 and 437.90°C day), pod initiation to maturity (1017.45 and 1007.75°C day), and life cycle, i.e., sowing to maturity (2196.60 and 2189.08°C day), recorded the highest value in the $S_2T_3V_2$ (delayed sowing + conventional tillage + *Moitri*) combination for both the years, respectively (Table 4).

The mean air temperature was higher for the late November sown crop than the early November sown crop, which staggered the phenological development of the delayed planted crop at the vegetative growth phase due to the unavailability of favorable weather parameters. Hence the accumulated GDD was higher in the late November sown crop than in the early November sown one. Notably, under both the sowing conditions, zero-tilled plots of lentils recorded the lowest accumulation of GDD compared to the other tillage treatments. This might be due to the lower time requirement of zero-tilled plots of lentils to attain different phenophases and complete their life cycle as compared to relay cropped and conventional tillage plots. That the short-duration varietal combination was less superior regarding GDD accumulation than the longer-duration varietal mix might be due to fewer days required for attaining phenophases across their lifecycle during the winter season of both years.

3.5. Relationship between growth, yield parameters, and total *N* uptake

The correlation studies among the different parameters of lentils (plant height, dry aerial biomass accumulation, LAI, and no. of nodules plant^{-1} at periodic observations) with total N uptake and seed yield depicted a significant positive correlation between themselves in the present investigation (Figure 7). The findings from the correlogram revealed that no. of nodules plant^{-1} at 45 DAS (0.962***), plant height at 45 DAS and 75 DAS (0.979***, 0.978***), dry aerial biomass accumulation at harvest (0.885***), and LAI at 75 DAS (0.977***) possessed the highest positive significant correlation values concerning the total N uptake of the lentil crops among all the observations. The no. of nodules plant^{-1} at 45 DAS (0.913***), plant height at 45 DAS and 75 DAS (0.944***, 0.943***), dry aerial biomass accumulation at 45 DAS (0.839***), and LAI at 75 DAS (0.960***) possessed the highest positive significant correlation values concerning seed yield in the study during 2018–19 and 2019–20. The seed yield also showed a significant positive correlation (0.973***) with the total N uptake of the lentil crops in the experiment, as assumed to be a highly dependent factor mentioned by earlier researchers (Kumar et al., 2016). From the above findings, it is evident that the number of nodules plant^{-1} at the vegetative stage is an important determining factor for lentil crops' N uptake. N uptake occurs throughout the vegetative and reproductive phases, reflecting its effect on plant height and LAI. The highest correlation value regarding dry aboveground biomass accumulation and seed yield in the vegetative stage indicates that better vegetative growth due to better plant vigor leads to higher lentil seed yield.

3.6. Impact on economics

The results indicated a particular trend of highest gross return (Rs. 82,660 and 93,237), net return (Rs. 51,220 and 59,257), and B:C ratio (2.63 and 2.74) under the treatment combination of earlier sowing + zero tillage + short duration variety in the

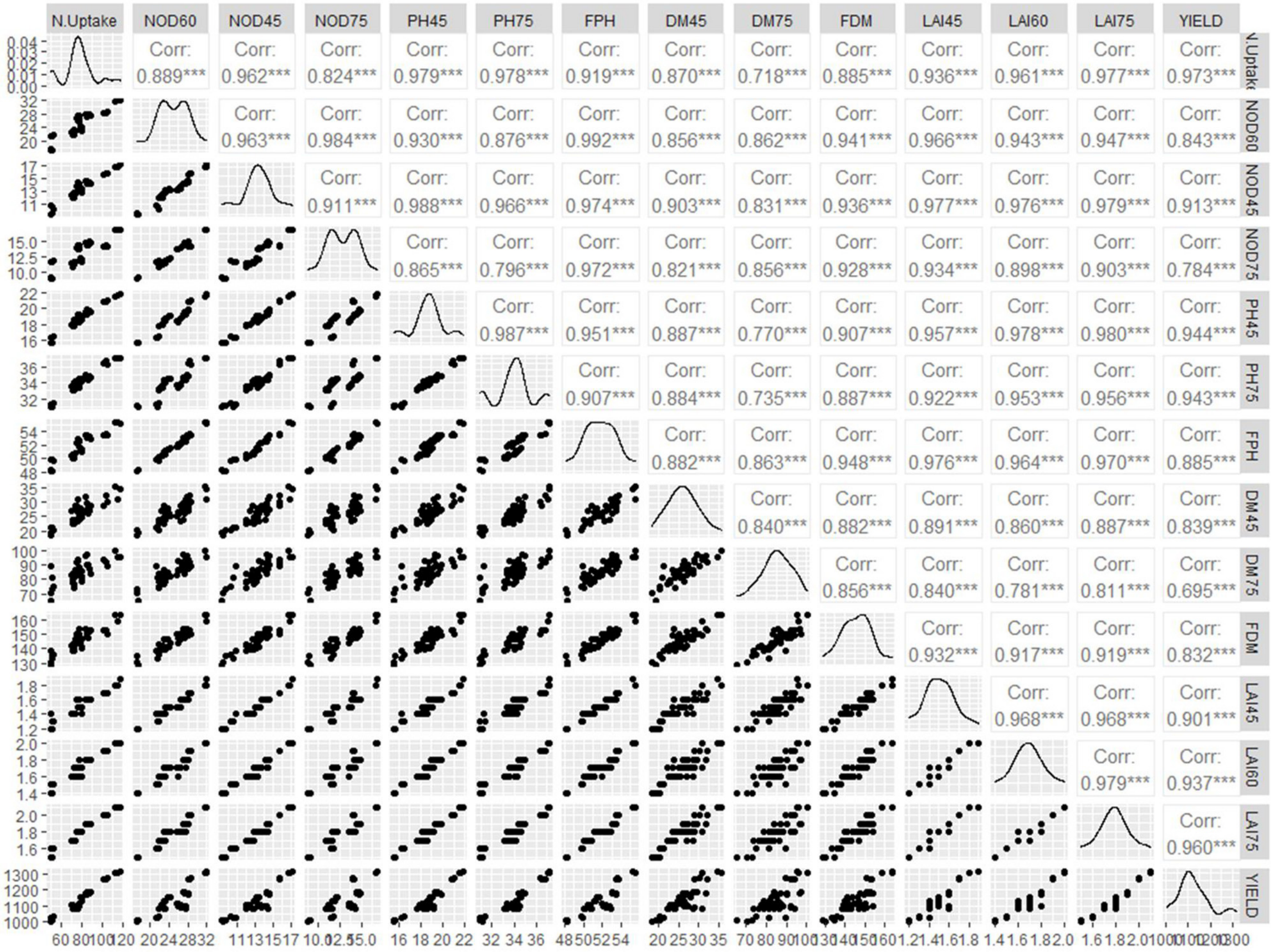

FIGURE 7
Correlogram showing Pearson correlation coefficient of growth and nodulation parameters with nitrogen uptake and seed yield. NOD 45, number of nodules plant^{-1} at 45 DAS; NOD 60, number of nodules plant^{-1} at 60 DAS; NOD 75, number of nodules plant^{-1} at 75 DAS; PH 45, Plant height at 45 DAS; PH 75, Plant height at 75 DAS; FPH, Plant height at harvest; DM 45, Dry aerial biomass accumulation at 45 DAS; DM 75, Dry aerial biomass accumulation at 75 DAS; FDM, Dry aerial biomass accumulation at harvest; LAI 45, Leaf Area Index at 45 DAS; LAI 60, Leaf Area Index at 60 DAS; LAI 75, Leaf Area Index at 75 DAS.

experiment with a near lowest cost of cultivation (Rs. 31,440 and Rs. 33,980) for the lentil crops during both the years of investigation (Table 5). Similar findings regarding sowing time were found in previous research by Islam et al. (2008) and Rao et al. (2016), who reported that optimum sowing time ensures a lesser cost of cultivation along with a much higher return in winter pulses across different locations of India. The findings of Visha Kumari et al. (2019) and Sasode et al. (2020) regarding the economic analysis of winter pulses also supported the results of the present investigation regarding the economic benefits of zero tillage among different tillage operations.

4. Conclusion

With the prevailing emissions scenario, within this century, the Indo-Gangetic plains are going to experience a 3–30% decrease in winter rainfall as revealed by CMIP6 model simulations. A temperature increase of 3°C is indicated under the lower Shared Socioeconomic Pathways (SSPs 1–3) whereas an increase of 4.8°C is indicated under the higher SSP conditions. This emphasizes the importance of introducing improved cultural practices along with the selection of suitable drought-tolerant varieties. The present study clearly indicated that the introduction of reduced or zero tillage and short-duration lentil cultivars helps in regaining moisture within the profile and significantly contributes to the overall productivity of lentils in terms of ensuring superiority in growth, nodulation, phenophasic development, yield, nitrogen uptake, and the economics of cultivation in lentil crops. Early November is the ideal planting time for lentils cultivated under residual moisture conditions. These combinations of various treatments can help the farmers, especially in the rainfed/dryland region to have more yield by mitigating early cessation of the monsoon season along with sparse winter rainfall.

TABLE 5 Effect of sowing time, tillage, and variety on the economics of lentil crops sown after monsoon rice harvesting.

Treatment	Cost of cultivation (Rs.)		Gross return (Rs.)		Net return (Rs.)		B:C ratio	
	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20	2018–19	2019–20
$S_1T_1V_1$	30,940	33,480	68,773	74,286	37,833	40,806	2.22	2.22
$S_1T_1V_2$	31,240	33,780	66,350	71,439	35,110	37,659	2.12	2.11
$S_1T_2V_1$	31,440	33,980	82,660	93,237	51,220	59,257	2.63	2.74
$S_1T_2V_2$	31,615	34,155	75,924	87,078	44,309	52,923	2.40	2.55
$S_1T_3V_1$	32,815	35,480	65,688	70,028	32,873	34,548	2.00	1.97
$S_1T_3V_2$	32,990	35,655	61,532	66,348	28,542	30,693	1.87	1.86
$S_2T_1V_1$	30,940	33,480	67,883	73,667	36,943	40,187	2.19	2.20
$S_2T_1V_2$	31,240	33,780	65,759	70,598	34,519	36,818	2.10	2.09
$S_2T_2V_1$	31,440	33,980	80,950	89,523	49,510	55,543	2.57	2.63
$S_2T_2V_2$	31,615	34,155	73,827	83,871	42,212	49,716	2.34	2.46
$S_2T_3V_1$	32,815	35,480	63,195	66,495	30,380	31,015	1.93	1.87
$S_2T_3V_2$	32,990	35,655	60,184	64,127	27,194	28,472	1.82	1.80

Price of lentil grain and stover = Rs. 60 kg^{-1} and Rs. 1 kg^{-1} (2018–19), Rs. 65 kg^{-1} and Rs. 1.50 kg^{-1} (2019–20).
S_1, Early sowing (1st week of November) after the harvesting of short-duration kharif rice; S_2, Delayed sowing (last week of November) after the harvesting of long-duration kharif rice; T_1, Relay cropping; T_2, Zero tillage; T_3, Conventional tillage; V_1, Lentil short duration: L4717; V_2, Lentil long duration: Moitri.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

Conceptualization, investigation, and methodology: BM, MK, RN, KA, and KP. Validation, writing—original draft preparation, and visualization: BM, MK, RN, KA, VV, PB, SA, and KP. Formal analysis: BM and AH. Data curation: BM, VV, SA, AL, and AH. Writing—review and editing: BM, VV AH, SA, MS, and AL. Funding acquisition: AH and SA. All authors have read and agreed to publish the current version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1151111/full#supplementary-material

References

Ali, M., and Gupta, S. (2012). Carrying capacity of Indian agriculture: pulse crops. *Curr. Sci.* 102, 874–881.

AOAC (1995). *Official Methods of Analysis, 16th Edn*. Washington, DC: Association of Official Analytical Chemists.

Bandyopadhyay, P. K., Halder, S., Mondal, K., Singh, K. C., Nandi, R., and Ghosh, P. K. (2018). Response of lentil (*Lens culinaries*) to post-rice residual soil moisture under contrasting tillage practices. *Agric. Res.* 7, 463–479. doi: 10.1007/s40003-018-0337-3

Basir, A., Jan, M. T., Arif, M., and Khan, M. J. (2011). Response of tillage, nitrogen and stubble management on phenology and crop establishment of wheat. *Int J Agric Biol.* 18, 1–8. doi: 10.17957/IJAB/14.0030

Chandran, M. A. S., Banerjee, S., Mukherjee, A., Nanda, M. K., and Kumari, V. V. (2022). Evaluating the long-term impact of projected climate on rice-lentil-groundnut cropping system in Lower Gangetic Plain of India using crop simulation modelling. *Int. J. Biometeorol.* 66, 55–69. doi: 10.1007/s00484-021-02189-8

Chauhan, A., Chourasia, A., Singh, P., and Jha, A. (2019). Effect of different tillage and weed management practices on growth and yield of chickpea. *J. Plant Dev. Sci.* 11, 273–279.

Choudhary, A. K. (2009). Role of phosphorus in pulses and its management. *Indian Farmers Digest* 42, 32–34.

Edalat, M., and Naderi, R. (2016). Interaction effect of tillage and irrigation methods on phenology, yield and water productivity of three wheat cultivars. *Biol. Forum Int. J.* 8, 93–102.

Erenstein, O., and Laxmi, V. (2008). Zero tillage impacts in India's rice–wheat systems: a review. *Soil Tillage Res.* 100, 1–14. doi: 10.1016/j.still.2008.05.001

FAOSTAT (2019). Available online at: https://www.fao.org/faostat/en/ (accessed January 12, 2019).

Gomez, K. A., and Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research*. New York, NY: John Willey and Sons, Inc., 180.

Islam, S., Nanda, M. K., and Mukherjee, A. K. (2008). Effect of date of sowing and spacing on growth and yield of rabi pigeon pea (*Cajanus cajan* (L.) Millsp.). *J. Crop Weed* 4, 7–9.

Jogloy, C., Jaisil, P., Akkasaeng, C., Kesmala, T., and Jogloy, S. (2010). Heritability and correlation for components of crop partitioning in advanced generations of peanut crosses. *Asian J. Plant Sci.* 10, 60–66. doi: 10.3923/ajps.2011.60.66

Kumar, J., Gupta, S., Gupta, P., Dubey, S., Tomar, R. S. S., and Kumar, S. (2016). Breeding strategies to improve lentil for diverse agro-ecological environments. *Indian J. Genet. Plant Breeding* 76, 530–549. doi: 10.5958/0975-6906.2016.00071.7

Kumar, J., and Srivastava, E. (2015). Impact of reproductive duration on yield and its component traits in lentil. *Legume Res.* 38, 139–148. doi: 10.5958/0976-0571.2015.00077.6

Maji, S., Das, A., Nath, R., Bandyopadhyay, P., Das, R., and Gupta, S. (2019). "Cool season food legumes in rice fallows: an Indian perspective," in *Book: Agronomic Crops, vol 1* (Springer), 561–605. doi: 10.1007/978-981-32-9151-5_25

Mukherjee, B., Reja, M. H., Nalia, A., Ghosh, A., and Nath,. R. (2020). Assessment of medium duration lentil varieties in New Alluvial Zone of West Bengal. *J. Crop Weed* 16, 138–141. doi: 10.22271/09746315.2020.v16.i1.1284

Neenu, S., Ramesh, K., Ramana, S., and Somasundaram, J. (2017). Effect of cultivars and sowing dates on nutrient uptake and yield of chickpea under aberrant climatic conditions in black soils of Central India. *Adv. Res.* 12, 1–11. doi: 10.9734/AIR/2017/37624

Nuttonson, M. Y. (1955). Wheat climatic relationship and use of phenology in ascertaining the thermal and photo thermal requirements of wheat. *Am. Inst. Crop Ecol.* Washington, DC.

Pradhan, A., Nag, S. K., and Mukherjee, S. C. (2018). Thermal requirement of small millets in Chhattisgarh plateau under rainfed cropping situation. *J Agro Meteorol.* 20, 244–245. doi: 10.54386/jam.v20i3.554

Quddus, M. A., Naser, H. M., Siddiky, M. A., Ali, M. R., Mondal, A. T. M. A. I., and Islam, M. A. (2020). Impact of zero tillage and tillage practice in chickpea production. *J. Agric. Sci.* 12, 106–118. doi: 10.5539/jas.v12n4p106

Rao, P. V., Reddy, A. S., Babu, J. S., and Ramana, M. V. (2016). Effect of sowing time and supplemental irrigation on yield and economics of rabi Pigeon pea (*Cajanus cajan* L. Millsp.). *Int. J. Res. Agric. Sci.* 3, 316–319.

Sah, S., Singh, R. N., and Nain, A. S. (2019). Impact of different dates of sowing and irrigation levels on Chickpea Nodulation. *Int. J. Curr. Microbiol. Appl. Sci.* 8, 705–714. doi: 10.20546/ijcmas.2019.811.085

Sasode, D. S., Joshi, E., Jinger, D., Sasode, R. S., Gupta, V., and Singh, Y. K. (2020). Conservation tillage and weed management practices effect on weeds, yield and profitability of cowpea (*Vigna unguiculata*). *Indian J. Agric. Sci.* 90, 86–90. doi: 10.56093/ijas.v90i1.98548

Saxena, N. P., Erskine, W., Kumar, J., and Johansen, C. (2000). "Regional opportunities for cool season food legumes for sustainable and enhanced food production, and crop diversification in the Indo Gangetic Plain," in *Legumes in Rice and Wheat Cropping Systems of the Indo-Gangetic Plain - Constraints and Opportunities* (Patancheru: International Crops Research Institute for the Semi-Arid Tropics), 200–218.

Schloerke, B., Cook, D., Larmarange, J., Briatte, F., Marbach, M., Thoen, E., et al. (2021). *GGally: Extension to 'ggplot2' R package version 2.1.2.* Available online at: https://CRAN.R-project.org/package=GGally (accessed January 10, 2023).

Sen, S., Ghosh, M., Mazumdar, D., and Dolui, S. (2016). Effect of sowing date and variety on phenology and yield of lentil during rabi season. *J. Crop Weed* 12, 135–138.

Singh, O., Singh, D. K., Singh, A., Singh, R. P., Pandey, S., Bajpai, A. K., et al. (2022). Increasing productivity of lentil (*Lens culinaris*) using improved varieties under alluvial soil of uttar pradesh by cluster front line demonstrations. *Legume Res.* 45, 492–496. doi: 10.18805/LR-4704

Singh, S. S., Singh, A. K., and Sundaram, P. K. (2014). Agro technological options for upscaling agricultural productivity in eastern Indo Gangetic plains under impending climate change situations: a review. *J. Agri Search* 1, 55–65.

Sita, K., Sehgal, A., Kumar, J., Kumar, S., Singh, S., Siddique, K. H. M., et al. (2017). Identification of high-temperature tolerant lentil (*Lens culinaris* Medik.) genotypes through leaf and pollen traits. *Front. Plant Sci.* 8, 744. doi: 10.3389/fpls.2017.00744

Tripathi, A. (2016). Productivity enhancement of lentil (*Lens culinaris* Medik) through integrated crop management technologies. *Legume Res.* 39, 999–1002. doi: 10.18805/lr.v0iOF.9436

Tyagi, P. K. (2014). Thermal requirements, heat use efficiency and plant responses of chickpea (*Cicer arietinum* L.) cultivars under different environment. *J. Agrometeorol.* 16, 195–198. doi: 10.54386/jam.v16i2.1520

Venugopalan, V. K., Nath, R., Sengupta, K., Pal, A. K., Banerjee, S., Banerjee, P., et al. (2022). Foliar spray of micronutrients alleviates heat and moisture stress in lentil (Lens culinaris Medik) grown under rainfed field conditions. *Front. Plant. Sci.* 13, 847743. doi: 10.3389/fpls.2022.847743

Visha Kumari, V., Banerjee, P., Nath, R., Sengupta, K., Sarath Chandran, M. A., and Kumar, R. (2019). Effect of foliar spray on phenology and yield of Lentil sown on different dates. *J. Crop Weed* 15, 54–58. doi: 10.22271/09746315.2019.v15.i3.1237

Visha Kumari, V., Nath, R., Sengupta, K., Banerjee, S., Dutta, D., and Karmakar, S. (2021). Effect of sowing and micronutrients foliar spray on lentil (*Lens culinaris*) in West Bengal. *Indian J. Agric. Sci.* 91, 573–576. doi: 10.56093/ijas.v91i4.112678

Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis*. New York, NY: Springer-Verlag New York. doi: 10.1007/978-3-319-24277-4_9

Yadav, M. R., Parihar, C. M., Jat, S. L., Singh, A. K., Kumar, R., Yadav, R. K., et al. (2017). Long term effect of legume intensified crop rotations and tillage practices on productivity and profitability of maize vis-a-vis soil fertility in North-Western Indo-Gangetic Plains of India. *Legume Res.* 40, 282–290. doi: 10.18805/lr.v0i0.7583