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RESEARCH ARTICLE

Physiological response of lentil (*Lens culinaris* Medik) to rice residual soil moisture influenced by tillage and residue management

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Abstract

Rapid depletion of root zone soil moisture, coupled with rising atmospheric temperatures after monsoon rice cultivation, creates water shortage for rainfed winter crops, highlighting the need for moisture conservation strategies. To test this, an experiment was conducted with winter lentil (*Lens culinaris* Medik) at the university experimental farm, West Bengal, India, during the 2012-2013 and 2013-2014 growing seasons. The experiment was framed using an Augmented Factorial Design with three types of tillage, *viz.,* no tillage (NT *i.e.*, T1), minimum tillage (MT *i.e.*, T2) and conventional tillage (CT) and three residue management, *viz.*,10 cm (N1) and 20 cm (N2) rice stubble retention and rice straw mulch addition (N3). It was observed that T1N3 stored the maximum soil moisture followed by T2N3 and CT stored the least. T2N3 shaped the highest the relative leaf water content (84.9 %), Leaf Area Index (LAI) (3.7), chlorophyll content (3.0 g l^{-1}), crop growth rate (19.8 g $m^{-2}day^{-1}$) and specific leaf weight (11.8 g cm^{-2}) followed by T1N3 and the least was encountered under CT. Treatment T2N3 had significantly the higher biomass content (12.3 Mg ha^{-1}) and yield (19.4 kg ha^{-1}), resulting in higher biomass (35.2 %) and grain (37.6 %) yield over control. Hence, modification of the micro-climate by using rice straw mulch under minimum tillage needs to be adopted for lentil cultivation after monsoon rice.

Keywords: lentil; mulch; plant physiology; soil moiture; stubble height; tillage; water stress

Introduction

A huge area of land measuring 43 million ha, in India particularly, is sown with rice as a rainy season crop, out of which 19.6 Mha areas are kept fallow after harvesting of rice (1, 2). These follow lands are predominantly located in Bihar, Madhya Pradesh, Chhattisgarh, West Bengal and Odisha. India is the largest consumer of lentils and with nearly all domestically produced lentils being consumed within the country. The northern and eastern regions of the nation account for about 90 % of the production (3) and lentil is generally consumed more in this part as dal in contrast to chick pea. However, the major constraints to lentil production include the lack of irrigation facilities, declining groundwater resources, high soil evaporation rates and continuous use of long-duration monsoon rice varieties (4–6). So, the selection of lentil varieties that can thrive in just 105 to 120 mm of leftover soil moisture after a harvest of monsoon puddled-transplanted rice is the need of the hour (6). Whilst the other concern is the delayed harvest of monsoonal rice which reaches to November end, even sometimes early December that compels late sowing of lentils, resulting in a substantial compromise in yield due to sundry abiotic stresses such as drought, high temperatures (7, 8). As a consequence, farmers are often forced to leave their land fallow rice cultivation. It would be a boon to farmers if there is any practice available in particular to enhance plant establishment and output following rice. One way to accomplish this would be the replacement long-duration rice cultivars with short-duration (120–130 days) varieties (9). Furthermore, since rice would be harvested during October, it will be a greater move to cultivate lentil seeds onto short-duration, high-yielding rice types as relay crop. Consequently, it becomes obvious that the expanding of rice-lentil cropping system requires matching agro-technology, which has yet to receive adequate attention.

Additionally, the destruction of soil aggregates resulting in the formation of massive soil masses upon puddling is a common issue that remains major challenge in cultivating post-rice crops. As this soil dries up, it gets cracked and murky resulting in the compromise of Water Holding Capacity (WHC) and failure to hold as much water and making the challenge of starting a second crop worsen (10). While others have observed a drop of soil moisture from more than 350 mm to 150 mm in a duration of merely 130 days in a 1 m profile, which unfortunately modified the appropriate flowering and pod setting at the later period of crop ages (9). The fast decline of soil moisture with time during post rainy season results in mid- and –terminal drought at flowering and pod-filling stages that adversely affects the productivity of lentils (11). So, the developing and implementing certain soil moisture conservation strategies into action which allows the soil to retain moisture for a longer time like conservation tillage practices, including No-Tillage (NT) or pair cropping and Minimum Tillage (MT), have been proposed to farmers as alternatives to Conventional Tillage (CT). The introduction of conservation tillage increases the micropore count, which retains the soil moisture for a more extended period and supplies the plant slowly throughout the growing period (12). An advantage of NT or paira cropping is that seeds can be broadcast 10–15 days before harvesting of paddy eventually allowing more time to utilize the soil moisture retaining in the profile and establish succeeding crops, particularly lentils. One of the most important aspects of conservation tillage for conserving soil moisture is residue retention. Standing rice stubbles create a localized shade effect that protects the soil surface from direct sunlight and reduces the evaporation of soil water, therefore retaining soil moisture. Soil moisture retention and root growth are both improved when provided with standing rice stubbles of certain heights (20 cm) (6). Other potential benefits of residue retention include suppression of weeds, improvement in soil quality, enhanced water infiltration, soil water storage, *etc.* (13, 14). The combined effect of conservation tillage with residue retention as standing stubles and straw mulch remains unexplored under rainfed contion although it presumes potential in water retention.

With due consideration of the above facts and findings reported by multiple researchers (4-9, 11-14), in this particular study, two different land management practices namely NT and MT were adopted and tested against CT, following rice harvest along with residue retention using the pulse lentil. This study was set out to accomplish two main goals: first, to determine how three contrasting tillage practices under different levels of standing residue and surface mulch affected the root zone soil water storage (0-400 mm) and evaporation (0-30 mm) and second, to assess the physiological response of lentils and any changes in yield that occurred during the transition from CT to NT and MT *vis-à-vis* residue retention. We hypothesized that: (i) surface mulch and standing residues reduce the evaporational loss of water from soil surface and able to retain more water during lentil growth; (ii) The abundance of micro-pores under NT and MT increase the retention time of soil water and supply to plant for longer time in comparison to CT; and (iii) the enhance amount of soil water storage and retention impact on plant physiology, growth and yield of lentil. The objectives of the study can be put through as - 1) to study the depth-wise distribution pattern of soil moisture under different tillage practices with varied stubble height and surface mulch retention; 2) to observe the plant growth and physiological responses under these treatments with varied soil water storage situation and 3) to notice the interaction effect of tillage and residue retention practices in the improvement of grain yield. To increase crop yields in tropical regions with post-rainy rice-fallow conditions, this study might reassure advisors and farmers that changing residue management practices to maximize soil water conservation is essential.

Material and Methods

Site and soil information

A field experiment with winter lentil (*Lens culinaris* Medik) was conducted over two consecutive lentil growing seasons (2012-13 and 2013-14) at A-B Block Seed Farm, Kalyani of Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal (22.99˚N; 88.43˚E, 13m msl). The site falls under a hot and humid subtropical climate, receiving 1470 mm of annual rainfall of which approximately 50 mm and 88.4 mm were received during the study period 2012-13 and 2013-14 respectively. The soil of the experimental site possess hyperthermic characteristics (Aeric Haplaquept, US Soil Taxonomy, Soil Survey Staff, 2003) (15) having clay loam texture (32-37 % sand, 26-30 % silt and 37-41% clay), medium to high bulk density (1.41-1.71 Mg m^{-3}), 60-68 % water holding capacity, low hydraulic conductivity (0.01-1.24 mm h^{-1} at 0-30 cm soil depth), neutral pH (6.7-7.2), low organic matter content (0.76-1.25 %) as well as low NPK. The hydro-physico-chemical properties of the soils of the experimental site are given in Table 1.

Experimental details

Lentil (*Lens culinaris* Medik) was cultivated on the land just before the harvesting of monsoon rice short-duration rice (110 days variety, IET 4786) served as preceding crop for the experiment. The rice was transplanted on the 21st July during both the years at the age of 21 days in rows. A fertilizer dose of 80:40:40 as $N:P_2O_5:K_2O$ along with 10 t ha^{-1} well decomposed Farm-Yard Manure (FYM) was applied as the recommended dose in rice. FYM was applied at the time of land preparation 15 days before the transplanting of rice. Half of N and full doses of P and K were applied as basal during transplanting and 1/4th of N was top dressed twice at tillering and flowering stages. The rice was harvested on its maturity in the first week of November, keeping stubble height 10 cm (short) and 20 cm (tall). The yield of rice ranged from 3400 to 3800 kg ha^{-1} for the two consecutive years.

The entire experiment was statistically framed as augmented split-plot design (16) in triplicates. In this design, the method of tillage application [Two: No tillage (T1) and Minimum tillage (T2)] was in the main plot, use of residues [Three: 10 cm residue (N1); 20 cm residue (N2) and Rice straw

Table 1. Basic hydro-physico-chemical properties of the soil of the experimental site

Soil depth (mm)	Soil properties											
	Sand (%)	Silt (%)	Clay (%)	Textural class	Bulk density (g cm^{-3})	WHC (%)	Hydraulic conductivity (mm h^{-1})	pH	Organic Matter Content (%)	Available N (kg ha^{-1})	Available P_2O_5 (kg ha^{-1})	Available K_2O (kg ha^{-1})
0-50	34	29	37	Clay loam	1.41	68	1.24	7.1	1.25	198.0	37.3	262.3
50-100	34	29	37		1.52	66	0.96	7.2	1.23	188.6	36.1	255.4
100-200	33	30	37		1.61	63	0.54	6.7	1.14	185.2	35.2	252.2
200-300	35	26	39		1.66	62	0.01	6.8	1.06	174.1	33.9	251.3
300-400	32	27	41		1.71	60	-	6.7	0.89	168.4	33.3	244.2
400-500	37	26	37		1.74	60	-	6.7	0.76	158.8	32.4	241.3

[WHC= water holding capacity]

mulch (N3)] was in the sub-plot and conventional tillage [CT (Farmers' practice)] are treated as augmented plots (control). Therefore, the entire experiment involves a total of seven experimental units, represented as 2×3+1. Augmented design, in fact, is performed to reduce the number of replicated treatments. The stubble height of 10 and 20 cm contributed 0.31-0.33 kg m^{-2} (3.1-3.3 ton ha^{-1}) and 0.43-0.46 kg m^{-2} (4.3-4.6 ton ha^{-1}) residues in the lentil field under NT and MT systems, respectively; while incorporation of rice straw accumulated 5.2-5.3 ton ha^{-1} residue in field. Each experimental unit was 5 m × 4 m in size and replicated thrice. Strips of land 0.75 m wide acted as buffer areas between replications. In augmented designs, the goal was to compare existing CT treatment with new treatment combinations (T1N1, T1N2, T1N3, T2N1, T2N2 and T2N3).

Soaked lentil seed @ 60 kg ha^{-1} was sown by broadcasting 15 days before rice harvesting in T1 plots; seed @ 30 kg ha^{-1} was sown by drilling the surface soil using tyne in T2 plots immediately after harvesting of rice and in CT plots @ 30 kg ha^{-1} of seed was sown using tyne 10 days after harvesting of rice by preparing land using power tiller and laddering. 2 % DAP spray was made at the development stage and mid-season stage as well. Quizlofop-ethyl, a post-emergence herbicide, was applied after 10 days of rice harvesting to check weed emergence and regrowth of the cut stubbles (ratooning). More than 80 % seed germination occurred in both the cropping seasons, maintaining plant populations in the range 155-162 plants m^{-2} with 10-20 % seed loss in the case of T1; more than 90 % seed germination and 142-148 plants m^{-2} with 5-10 % seed loss in the case of T2 and CT. CT was taken as the check treatment. Lentil variety B-77 was taken for the experiment. Lentil harvesting occurred at different times due to variations in sowing time and crop development stages (Table 2). Fig. 1 shows the hypothetical illustrations which depicts the possible alterations in soil pore characteristics and corresponding pathway through which evaporative losses of soil moisture owing to different tillage and residue management practices. The results of the experiments are to be correlated with the hypothesis for the actual amount of soil moisture stored in different practices and their influence on plant growth and grain yield of lentil.

Table 2. Length of crop development stages (days) under different tillage and residue management practices in 2012-13 and 2013-14 crop seasons

Treatment	Period (days)				Total number of days
	Initial (seedling)	Development (Vegetative)	Mid-season (Flowering to pod formation)	Late-season (Maturity)	
No tillage (T_1)	30	45	35	20	130
Minimum tillage (T_2)	30	40	30	20	120
Conventional tillage (CT, Control)	30	30	30	20	110

Treatment	Period (days)				Total number of days
	Initial (seedling)	Development (Vegetative)	Mid-season (Flowering to pod formation)	Late-season (Maturity)	
R-NTZ R-NTR R-NTM	30	45	35	20	130
R-MTZ R-MTR R-MTM	30	40	30	20	120
CT	30	30	30	20	110

Based on the crop coverage as stated by Allen *et al*. (1998)

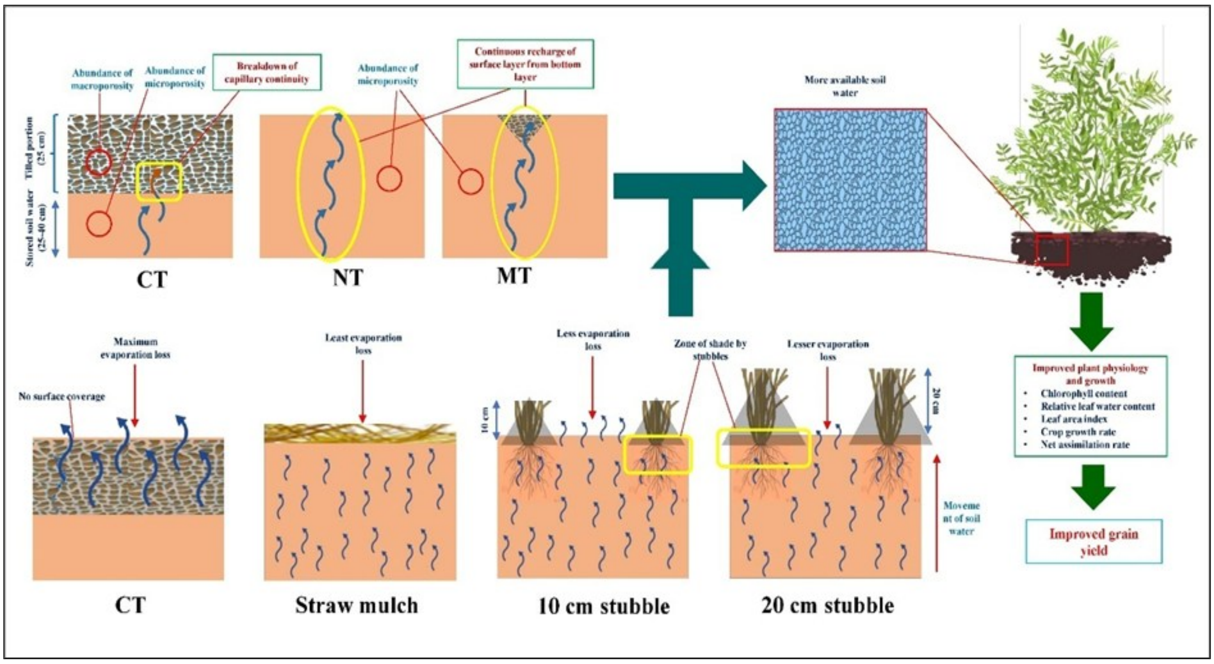


Fig. 1. The hypothetical mechanism of soil moisture conservation in different tillage and residue management packages in the experiment.

Observations

Soil water content in the 0-50 mm surface layer was measured gravimetrically using a core sampler of dimension 50 mm in both diameter and length at 10-day intervals. Profile soil moisture for 50-100, 100-200, 200-300 and 300-400 mm were measured by a PR2/6 profile probe soil moisture meter (Delta-T Devices Ltd., Cambridge, UK) at 10-day intervals. Calibration of the profile probe moisture meter was performed in the field before the experiment where the access tube was carefully installed up to 1000 mm depth to avoid air gaps, ensuring proper contact between the access tube and surrounding soil. The soil was saturated and allowed it to drain to field capacity. The reading of profile probe was taken from three depths (100, 200 and 300 mm) and simultaneously soil samples at corresponding depths were collected (n=64 for each depth) with a screw auger for gravimetric analysis. The volumetric moisture content thus calculated from bulk density and water loss (oven-dry at 105 °C for 24 hr) and was plotted in calibration graph with the profile probe readings. Typically, a linear equation is derived as y = 1.033x, showing a coefficient of determination (R^2) value of 0.925 ($p \leq 0.01$), where, y and x are soil water content, measured by soil auger and PR2/6 profile probe moisture meter. Bulk density measurement was made following the method of (17) at 15-day intervals.

Five plant samples were collected randomly from each plot during the initial, development, mid-season and late-season stages for the measurement of leaf RWC, indicator for water status of plant (18), chlorophyll concentration (19), Leaf Area Index (LAI, an index estimated using leaf area occupied per plant and ground area covered by the plant(20)) and specific leaf weight (SLW, indicating the thickness and density of leaves (21)), considering the average of the triplicates.

Crop growth rate is the rate of dry matter production per unit ground area per unit time which was calculated by using the following formula and expressed as g m^{-2} day^{-1} (22).

$$CGR = \frac{(W_2 - W_1)}{(t_2 - t_1)} \times \frac{1}{A}$$

where, W_1= dry weight of the plant (g m^{-2}) at time t_1; W_2= dry weight of the plant (g m^{-2}) at time t_2; (t_2 - t_1) = Time interval in days; A = unit land area (m^2). Relative Growth Rate (RGR) is the rate of increase in dry weight per unit dry weight already present and is expressed in g $g^{-1}day^{-1}$. RGR at various stages was calculated as suggested previously (20).

$$RGR = \frac{(InW_2 - INW_1)}{(t_2 - t_1)}$$

where, W_1= dry weight of plants (g) at time t_1; W_2= dry weight of plants (g) at time t_2. The crop growth rate as well as RGR was studied between two growth stages: (i) as initial to development stage ($CGR_{ini\text{-}dev}$; $RGR_{ini\text{-}dev}$) and (ii) at the development to mid-season stage ($CGR_{dev\text{-}mid}$; $RGR_{dev\text{-}mid}$).

Maximum above-ground, as well as below-ground dry biomass (total biomass), was measured at initial, development, mid-season and late-season stages concerning different treatments by taking three plant samples from each plot in each replication randomly. Plant samples were collected by uprooting the whole plant by soil excavation. After excavation, the samples were slaked by dipping them into water washed with gently flowing water and oven dried at 60℃ for more than 48 hrs.

Statistical analysis

The treatment details were evaluated in augmented split-plot design (16) with three replications. In this design, the method of tillage application [Two: No tillage (T1) and Minimum tillage (T2)] was in the main plot, use of residues [Three: 10 cm residue (N1); 20 cm residue (N2) and rice straw mulch (N3)] was in the sub-plot and conventional tillage (Farmers' practice) are treated as augmented plots (control). Data (means ± se) were analyzed by ANOVA procedures of SPSS window-based design. Differences in means among tillage treatments were compared (the LSD test) and considered significant at $p \leq 0.05$. The comparison also incurred between two residues and the control system as mean, as well as individuals. The interaction effects of tillage and residue were also evaluated. The factor analysis was based on the Pearson correlation matrix and Euclidean distances.

Results and Discussion

Climatic conditions prevail

The meteorological observations recorded during the study period are presented in Table 3. Higher rainfall was being recorded during 2012-13 (88.4 mm) as compared to 2013-14 (79.2 mm). Maximum temperature ranges from 29.0-36.2 °C (mean 28.9 °C) during 2012-13, while during 2013-14, the maximum temperature ranges from 24.3-33.9 °C (mean 29.2 ° C). Likewise, the mean minimum temperature record as 17.2 and 16 °C during 2012-13 & 2013-14, respectively. Mean relative humidity value of 50.4 and 59.3 % were being recorded during 2012-13 and 2013-14, respectively. Open evaporation value (mean) 1.9 and 1.8 mm day^{-1} were being recorded during 2012-13 and 2013-14, respectively. The bright sunshine hour values ranging from 5.3-8 (mean 6.8) and 4.5-8.2 (mean 6.7) were also recorded during 2012-13 and 2013-14, respectively. The overall variations in the weather parameters observed were at par indicating the variations of plant response to weather during both the growing seasons (2012-13 & 2013-14) be minimum.

Temporal dynamics of soil water distribution pattern & root zone soil water storage (mm) at different critical growth stages

The distribution of volumetric soil water throughout the growing period of lentils under different tillage and mulch systems at various soil depths (0-50, 50-100, 100-200, 200-300 and 300-400 mm) is shown in Fig. 2A-E. The soil moisture depletion patterns were similar in both years (2012-13 and 2013-14); therefore, data from both years are pooled and discussed in this section.

Moisture differences were most prominent at the 0-20 cm soil depth, with the differences becoming less significant at lower depths. The normal trend of soil moisture depletion showed that initial lower depletion, except for CT, up to early phases of crop growth (25-30 DAS); thereafter, depletion occured faster most prominently from the 10-20 cm soil layer. It is apparent from these figures that soil water content decreased with the growth of plants and irregular peaks observed in due course were because of the occurrence of rainfall. Throughout the lentil growth (110-120 days), soil water content varied from 15-25 % at 20-30 cm and 15-30 % at the 30-40 cm depth; where the 0-20 cm extraction was recorded maximum *i.e.*, 5-35 %. However, considering the first three depths, CT always resulted in the lowest soil water content and NT appeared to be the highest soil water content treatment among the tillage practices. So far as residue management strategies are concerned, N3 was apparent to result in higher soil water storage in the profile as compared to N1 and N2; where N2 stored more soil moisture as compared to N1. The rate of decline in soil moisture as well differed among the different treatment combinations. The T1N3 stored the maximum soil moisture much higher than T2N3 at 0-5 and 5-10 cm soil depths; however, that difference was minimized at 10-20 cm. The effect of 20 cm stubble height (N2) in soil water storage capacity was observed more under MT (T2) as compared to NT (T1).

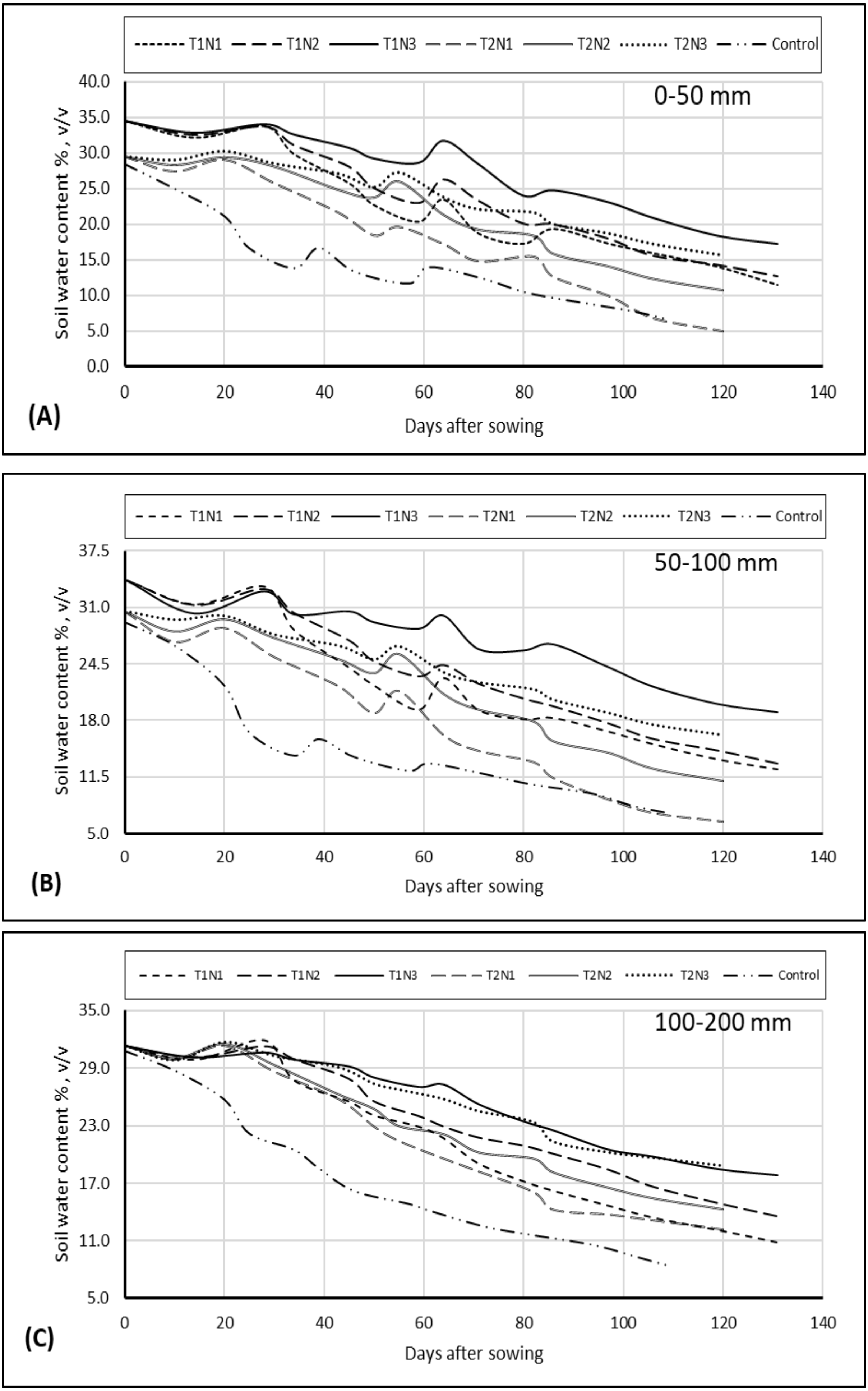
As shown in Fig. 3 T1N1 exhibit a steep slope, indicating rapid depletion of soil water compared to the rest of the treatment combinations. However, the depletion of

Table 3. Meteorological data recorded of experimental site in two study years

Parameters	Month						Total/Average
	October	November	December	January	February	March	
Total rainfall (mm)							
2012-13	29.0	50.2	7.3	1.9	0.0	0.0	*88.4
2013-14	24.5	0.0	0.0	0.0	28.5	26.2	*79.2
Maximum air temperature (°C)							
2012-13	33.5	29.5	25.3	24.7	24.0	36.2	#28.9
2013-14	31.4	30.0	27.0	24.3	28.5	33.9	#29.2
Minimum air temperature (°C)							
2012-13	22.5	17.3	11.7	9.6	21.8	20.0	#17.2
2013-14	23.9	16.4	12.5	10.4	13.7	18.9	#16.0
Relative humidity (%)							
2012-13	59.5	55.4	59.2	49.0	45.0	34.0	#50.4
2013-14	78.8	55.6	58.5	62.5	52.8	47.4	#59.3
Mean open evaporation (mm day^{-1})							
2012-13	2.5	1.5	1.0	1.1	2.0	3.5	#1.9
2013-14	1.6	1.7	1.0	1.1	1.8	3.3	#1.8
Bright sunshine hour							
2012-13	7.6	6.5	5.3	5.6	7.6	8.0	#6.8
2013-14	4.5	8.1	6.2	5.9	7.4	8.2	#6.7

* indicates total value

# indicates average value


T1N1
T1N2
T1N3
T2N1
T2N2
T2N3
Control
0-50 mm
Soil water content %, v/v
Days after sowing
(A)
50-100 mm
(B)
100-200 mm
(C)

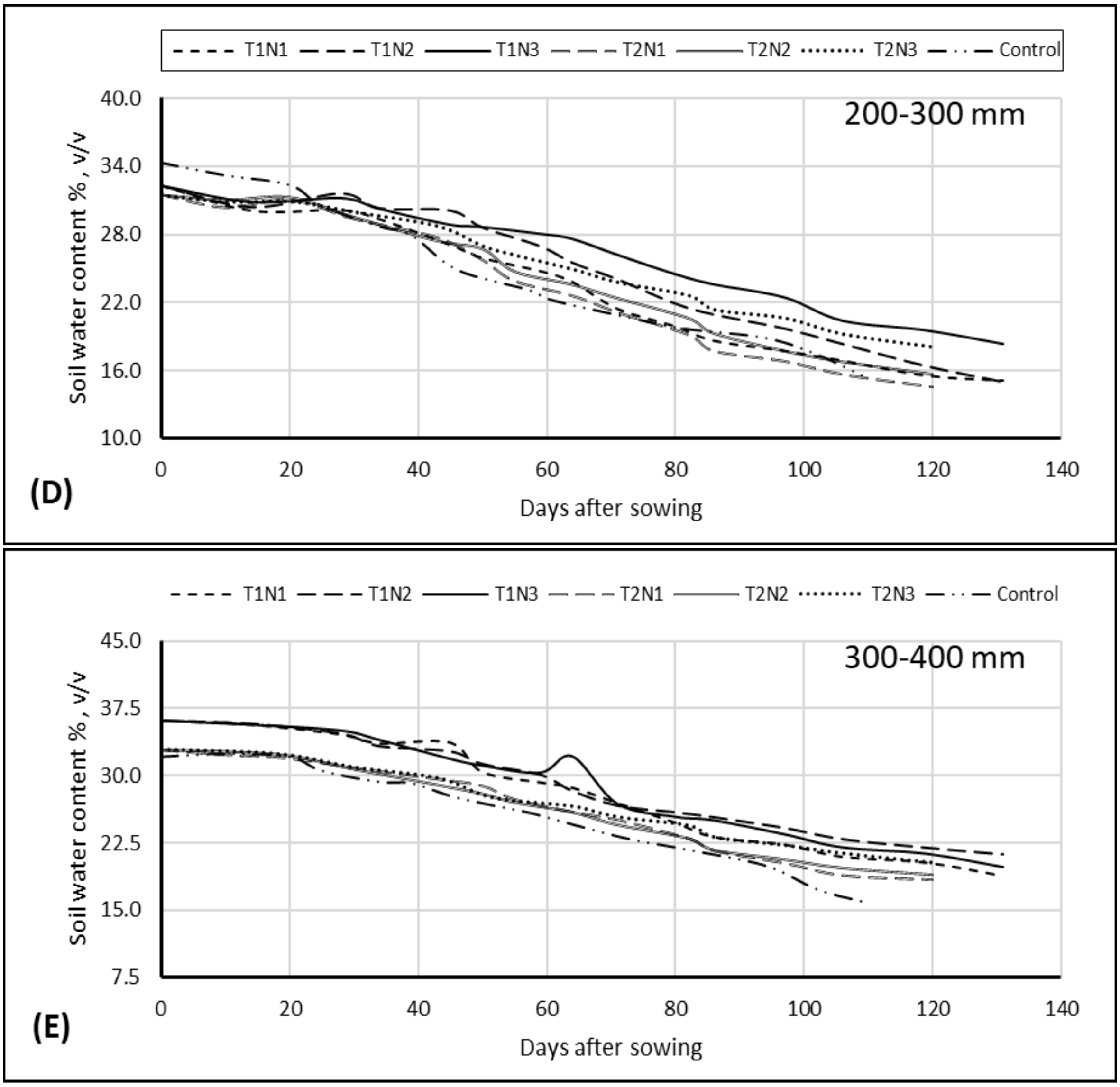


Fig. 2 (A- E). Distribution of soil moisture distribution in root zone depth (0-400 mm) under tillage (T) and residue management (N) (Pooled data of 2012-2013 and 2013-2014).

[No tillage (T1) and Minimum tillage (T2); retention of 10 cm rice stubble height (N1); retention of 20 cm rice stubble height (N2); no stubble height and application of rice straw as mulch (N3); control treatment *i.e.* Conventional tillage (CT)]

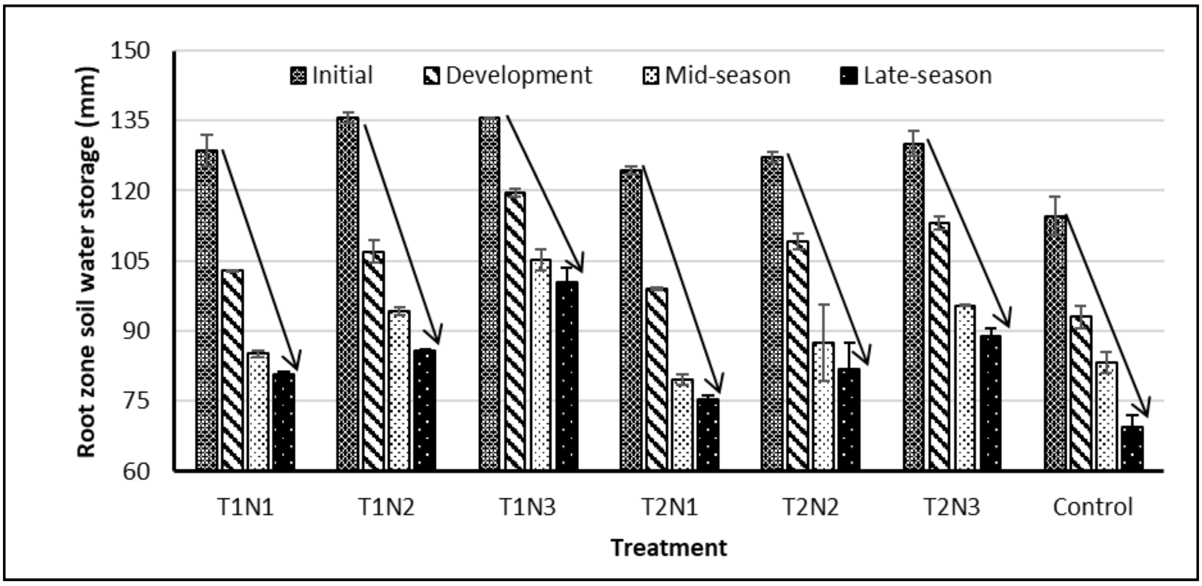


Fig. 3. Root zone soil water storage (mm) at different critical growth stages of lentil under tillage (T) and residue management (N) (Pooled data of 2012-2013 and 2013-2014).

[No tillage (T1) and Minimum tillage (T2); retention of 10 cm rice stubble height (N1); retention of 20 cm rice stubble height (N2); no stubble height and application of rice straw as mulch (N3); control treatment *i.e.* Conventional tillage (CT)] moisture from CT was noticed less at 0-5 cm and 5-10 cm soil layers as compared to the 10-20 cm layer, which could be due to the capillary recharge of the upper layer from the lower layer moisture remaining at higher soil water potential. By approaching the late-season stage, CT had negligible amounts of soil water content in the profile remaining for depletion. The treatment combination T2N3 was apparent to have the least depletion, indicating better soil water storage. Treatment T2N3 was noticed as an intermediate for soil water storage during the cropping period.

Table 4 shows the root zone soil water storage at different critical growth stages *i.e.,* initial, development, mid-season and late-season stages and highlights the significant effects of tillage (T), residue (N) and their interaction (T×N). Irrespective of residue management strategies, NT consistently stored the maximum soil water throughout the lentil growth period, showing 8.6 % and 14.0 % higher storage than MT and CT respectively during the initial stage; 3.3 % and 15.3 %, during the development stage; 12.2% and 13.3 % during the mid-season stage and 5.8 % and 24.1 % during late-season stage. Among the residue management strategies, N3 resulted in 4.7 and 1.0 % higher soil water storage during the initial stage; 13.2 and 7.1 % during the development stage; 18.0 % and 9.6 % during the mid-season stage; and 14.6 % and 10.6 % higher storage during the late-season stage as compared to N1 and N2 respectively (pooled value) (Table 4). So far, the different treatment combinations are concerned, T1N3 always provided the greatest root zone soil water storage in all the critical growth stages *i.e.* 135.5, 119.6, 105.3 and 100.5 mm at initial, development, mid-season and late-season stages, respectively; while the least was marked in CT (Fig. 3).

From the initial to the development stage, the maximum depletion occurred under N1 followed by N2. Initially, the depletion was less from N3, while it became comparable to N2 at the development to the mid-growth stage. N2 depleted 71 % higher soil moisture under T2 than that of T1 at the development to mid-growth stages. In the case of N3, soil moisture depletion was 22 % and 39 % higher in T2 as compared to T1 during the development to mid and mid to maturity stages of lentils, respectively (Fig. 3). The least amount of soil moisture depletion occurred under T1N3 followed by T2N3. In contrast, the maximum depletion was observed under T1N1 and T2N1. Overall depletion pattern followed the order: CT> T2N1> T1N1> T2N2> T1N2> T2N3> T1N3.

The figures (Fig. 2A-E, Fig. 3) depicted lower soil water content under CT throughout the growth period, primarily due to the higher water loss from soil by evaporation from the tilled soil surface with no surface coverage. The downward movement of water from the 0-20 cm layer to the lower 30-40 cm layer was negligible due to the potential moisture difference causing upward movement of soil moisture. Additionally, under CT, the moderate slope of soil water depletion was observed at 0-5 and 5-10 cm soil layers, while the moisture depleted in steep slopes at layers below 10 cm. These incidences pointed out the fact that there was steady

Table 4. Root zone soil water storage (mm) at critical growth stages of lentil under the influence of different tillage and residue management systems

Treatment		Initial			Development			Mid-season			Late-season		
		Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled
T_1N_1		136.3	121.0	128.6	108.8	97.1	103.0	90.0	80.2	85.1	78.7	82.4	80.6
T_1N_2		143.5	128.0	135.7	116.1	97.9	107.0	99.6	88.9	94.2	86.4	85.5	85.9
T_1N_3		143.8	127.3	135.5	126.6	112.7	119.6	108.2	102.5	105.3	95.8	105.2	100.5
T_2N_1		130.0	118.9	124.5	100.9	97.1	99.0	78.6	80.4	79.5	68.3	82.5	75.4
T_2N_2		130.9	123.5	127.2	106.6	111.8	109.2	87.1	87.8	87.4	76.6	87.0	81.8
T_2N_3		136.9	123.1	130.0	116.0	110.0	113.0	100.2	90.7	95.5	90.0	87.6	88.8
Control		119.7	109.5	114.6	100.2	85.9	93.1	83.9	82.6	83.3	69.5	69.1	69.3
Mean of	T_1	141.2	125.4	133.3	117.2	102.6	109.9	99.2	90.5	94.9	87.0	91.0	89.0
	T_2	121.9	121.9	121.9	106.3	106.3	106.3	86.3	86.3	86.3	85.7	85.7	85.7
	N_1	133.1	120.0	126.5	104.8	97.1	101.0	84.3	80.3	82.3	73.5	82.5	78.0
	N_2	137.2	125.8	131.5	111.4	104.9	108.1	93.3	88.3	90.8	81.5	86.2	83.9
	N_3	140.4	125.2	132.8	121.3	111.4	116.3	104.2	96.6	100.4	92.9	96.4	94.6
ANALYSIS OF VARIANCE													
CD at 5 % level													
		Y1	**Y2**	**Pooled**	**Y1**	**Y2**	**Pooled**	**Y1**	**Y2**	**Pooled**	**Y1**	**Y2**	**Pooled**
T		1.813	1.535	1.125	1.376	1.388	0.926	1.474	1.788	1.097	1.564	1.819	1.136
N		2.220	1.881	1.378	1.685	1.700	1.134	1.805	2.190	1.344	1.916	2.228	1.392
T×N		3.140	NS	1.949	NS	2.404	1.603	2.553	3.097	1.901	NS	3.151	1.968
Control V/S Rest		3.391	2.873	2.105	2.574	2.596	1.731	2.757	3.345	2.053	2.926	3.404	2.126

[Y1 = 2012-13; Y2 = 2013-14; T = Tillage; T1 = No tillage; T2 = Minimum tillage; N = Residue; N1 = 10 cm residue; N2 = 20 cm residue; N3 = Rice straw mulch; Control = Conventional tillage (CT); and NS = not significant] soil water flux from the lower layer to the upper layer of soil and then that water was expensed as atmospheric evaporation and plant uptake. This pattern of soil water movement through capillary pores has also been observed in earlier researches (23, 24). Generally, the tillage practices alter the soil's pore characteristics and in particular, the macro- and mesopores network of the local soil causing more evaporative loss from soil (25); while the connectivity of the pore below the tilled layer (> 20 cm) was undisturbed which could supply the stored soil moisture from lower layer through the micropore channels. However, the supply of moisture from the lower layer to the upper layer was slow and most importantly, that supply could not match the higher extraction rate of soil moisture from the 0-20 cm. In such conditions, conservation of moisture in NT and MT played a significant role (26) explaining better water storage near the surface (0-30 cm) owing to minimal mechanical disturbance of soil structure and well connected and elongated meso and micropore systems in the active soil layer (27).

On the other hand, the early sowing of seeds before harvesting of previous rice crops, as in NT, prevented direct exposure of soil surface to sunlight and thus, resulted in the higher soil water content (28). Although MT had the equivalent amount of soil moisture with CT during sowing period, the least disturbed soil with higher proportion of micropores and more residue retention as standing rice stubbles ensured greater moisture conservation during later period of crop growth stages, unlike CT. Similar results were also reported (5, 6, 29). Higher soil moisture content and water holding capacity, increased water storage and reduced water deficit under the retention of straw mulch have been reported (30, 31). Tall standing rice stubbles (20 cm) effectively reduced soil evaporation by shading the soil surface, thus increasing the available water for transpiration. This ultimately resulted in increased water productivity (32-34). While, during maturity, NT utilized more moisture than MT which might possibly be due to easier evaporative loss from crack developed in NT treatments (23). Another reason behind this could be the continued growth of plants under NT at later stages (toal duration of 135 days against MT - 120 days and CT - 120 days of crop life) as sustained by the continuous soil moisture supply (4). Maximum storage of soil moisture as evidenced by straw mulching coupled with NT was also previously reported (35-37).

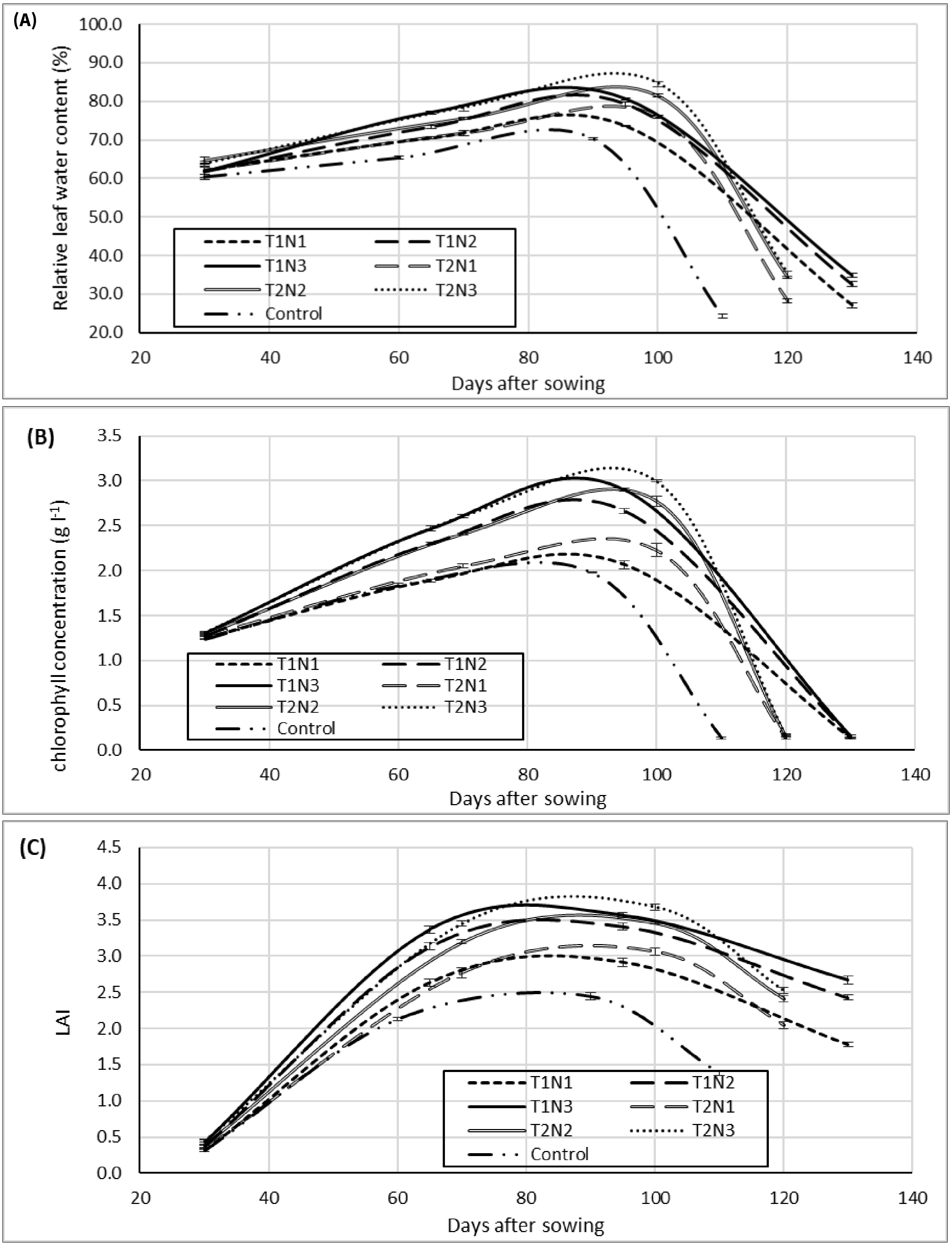
In another context, the compacted soil layers NT, which in turn decreased root length density at the upper soil layers (38) and because of the impeded root development caused lesser uptake of soil moisture during the initial growth period; while CT's increased root penetration owing to favourable soil condition flourished growth initially (39). Thereafter, in conditions of reduced water supply to tilled layer under CT, it became difficult for crop roots to absorb sufficient amounts of water at mid and late stages of growth which coupled with excessive evaporative demand, interfered with the normal physiological activity of plants (40). In contrast, coupled, better moisture conservation through crop residue retention under NT and MT, coupled with reduced soil temperature, resulted in improved water uptake. Higher soil moisture retention with reduced evaporation resulted in higher RWC in the leaves as well (41). Similarly, scientists found positive effects of conservation tillage on leaf water status (39, 42). Hypothetically, more conservation of soil moisture shall lead to more grain yileds, however, in our experiment T1N3, even though had the highest soil moisture conservation, couldn't provide the best grain yield production, but M2T3 did. We believed, the undisturbed soil surface in T1 (NT) systems resulted a poor root growth during the intial stages of crop as compared to minimum tilled T2 (MT) and properly tilled CT (control) and thereby the grain production in T1 got negative impact.

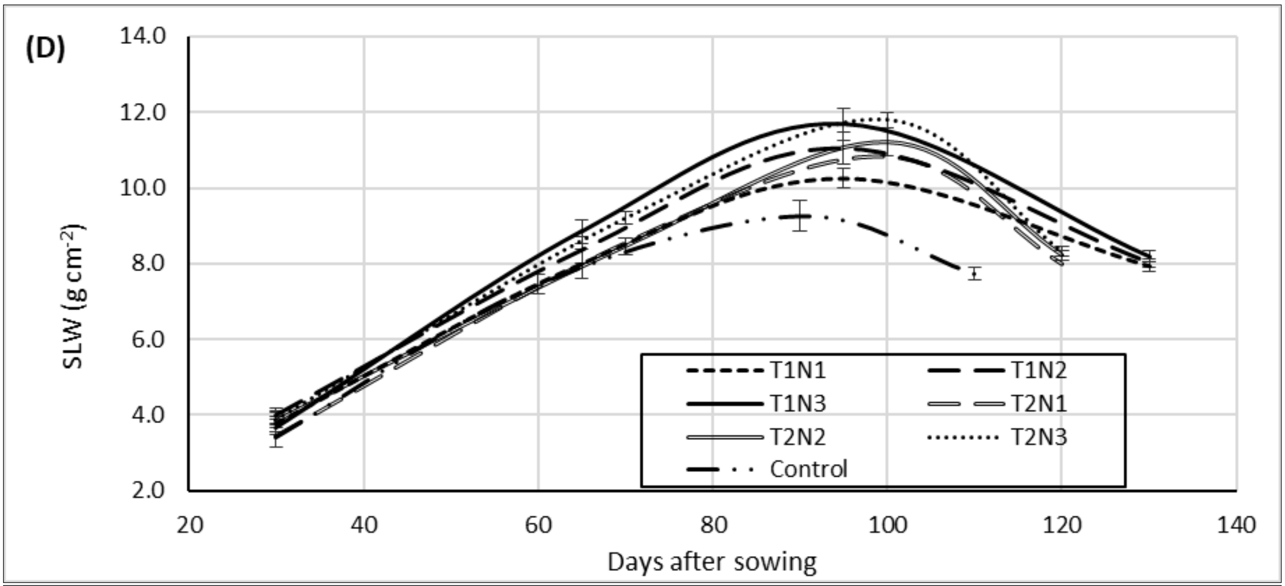
Different lentil growth parameters as affected by different tillage and residue management

Results from Table 5 indicate that both tillage and residue management had a statistically significant effect on all the previously investigated parameters. Additionally, the interaction effect of tillage and residue was found statistically significant in the case of Relative Water Content (RWC), Specific Leaf Weight (SLW), biomass and yield; however, it was insignificant in the case of chlorophyll concentration as well as LAI. All the growth parameters showed a gradual increase in growth from the initial stage till the mid-season stage and then fell in the late-season stage (Fig. 4A-E). In the case of RWC and chlorophyll concentration, sharp falls were recorded after the mid-season stage; while slight drop in LAI, SLW and total biomass were also noticed at the late season stage after attaining peaks at the mid-season stage. Similar sharp falls were also encountered in the case of RWC and chlorophyll concentration after peaking at the mid-season stage (Fig. 5A-B). The general trend of plant physiological parameters shows that the NT improved these parameters initially more than that of MT; while at mid and development stages, MT produced maximum values of these and thereafter these dropped sharply. On the other hand, NT continued its physiological activities at a higher rate than MT at later stages of crop growth. In all the cases, CT produced the lowest values throughout its growth period.

Results revealed that T2N3 had the highest RWC, LAI, chlorophyll concentration and SLW (84.9 %, 3.7, 3.0 g l^{-1} and 11.8 g cm^{-2}, respectively) followed by T1N3 and the least was encountered under CT (70.4 %, 2.4, 2.0 g l^{-1} and 9.3 g cm^{-2}, respectively), which was statistically significant at $p \leq 0.05$ during mid-season growth period. Further, N3 was apparent to have 10.6, 38.1, 20, 11.4 and 37.6 % higher RWC, chlorophyll concentration, LAI, SLW and biomass, respectively over N1 and 2.9, 7.4, 5.9, 5.4 and 13.6 % higher over N2, at the mid-season stage.

RWC was advocated as an indicator of water status in drought situations (43); while other discussed the changes of RWC as a result of increase in the heat load on the plant (44). So, enhancing soil moisture reserve and subsequent alleviation of drought stress through improved RWC and chlorophyll content was observed under mulch than without mulch (45). A significant ($p \leq 0.05$) increase in LAI by 0.5-1.2 units under mulching as compared to unmulched plots was observed (46). Fig. 6A demonstrates a positive correlation between improved soil moisture content with RWC in plant leaves. Further, the plants were more turgid and succulent having higher RWC in


(A)
Relative leaf water content (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
20
40
60
80
100
120
140
Days after sowing
T1N1
T1N2
T1N3
T2N1
T2N2
T2N3
Control
(B)
chlorophyll concentration (g l-1)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
20
40
60
80
100
120
140
Days after sowing
T1N1
T1N2
T1N3
T2N1
T2N2
T2N3
Control
(C)
LAI
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
20
40
60
80
100
120
140
Days after sowing
T1N1
T1N2
T1N3
T2N1
T2N2
T2N3
Control



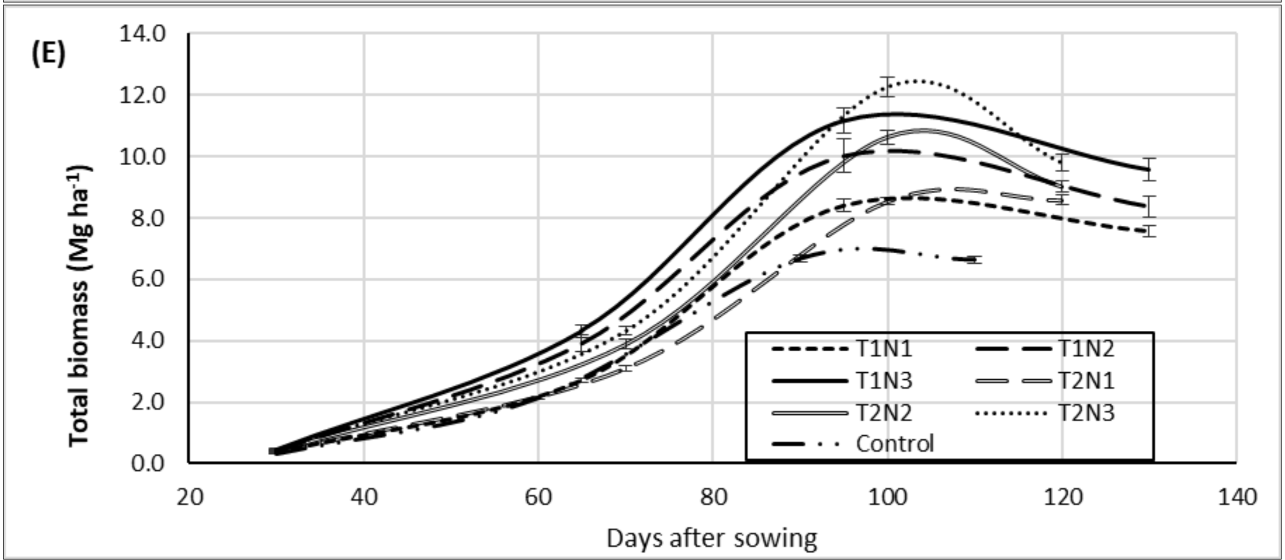


Fig. 4. The influence of tillage and residue management on plant physiology – (A) relative leaf water content, (B) chlorophyll concentration, (C) LAI, (D) SLW and (E) biomass of lentil throughout the crop growth period with respect to different treatment combinations (Pooled data of 2012-2013 and 2013-2014).

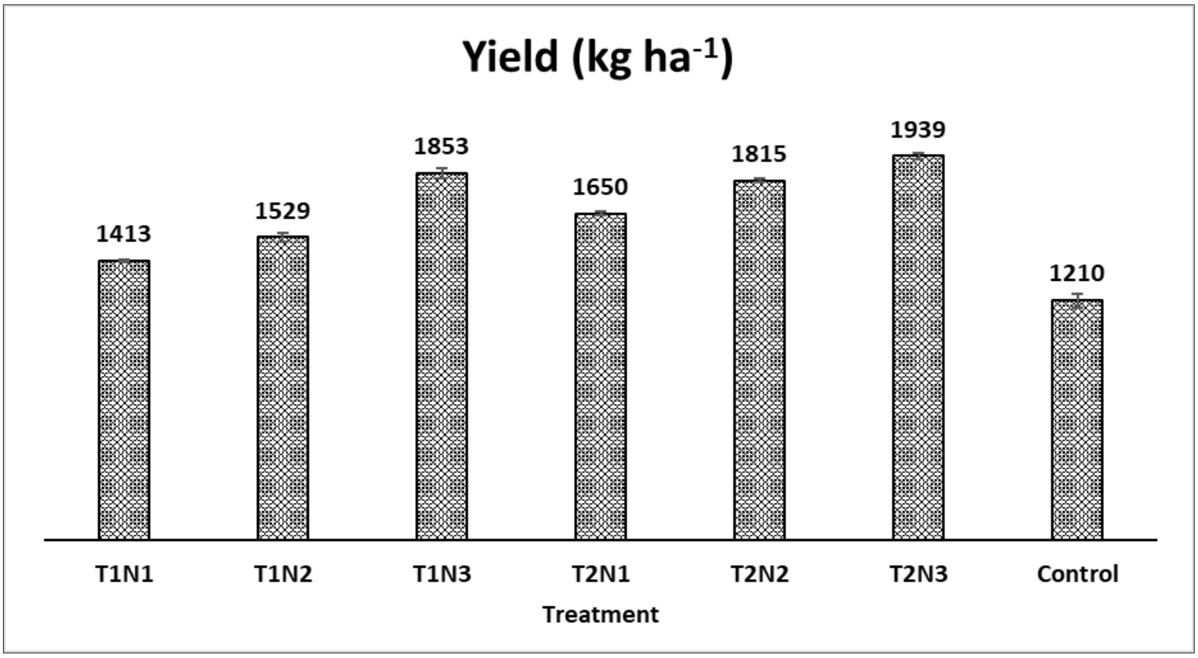


Fig. 5. Grain yield of lentil under tillage (T) and residue management (N) (Pooled data of 2012-2013 and 2013-2014).

[No tillage (T1) and Minimum tillage (T2); retention of 10 cm rice stubble height (N1); retention of 20 cm rice stubble height (N2); no stubble height and application of rice straw as mulch (N3); control treatment i.e. Conventional Tillage (CT)]

Table 5. Different growth parameters of lentil as affected by different tillage and residue management systems at mid-season stage (except yield, which was recorded during harvesting)

Treatment	Relative leaf water content (%)			Chlorophyll concentration (g l^{-1})			LAI			Specific leaf weight (g cm^{-2})			Biomass (Mg ha-1)			Yield (kg ha^{-1})			Percent increase in yield over control
	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	
T_1N_1	75.2	72.1	73.6	2.1	2.1	2.1	3.0	2.8	2.9	10.7	9.8	10.2	8.9	8.0	8.4	1457	1368	1413	14.2
T_1N_2	79.9	78.6	79.3	2.7	2.7	2.7	3.5	3.4	3.4	11.4	10.7	11.0	10.6	9.5	10.0	1598	1460	1529	20.9
T_1N_3	82.0	79.2	80.6	2.9	2.9	2.9	3.6	3.6	3.6	12.1	11.3	11.7	11.7	10.6	11.2	1805	1900	1853	34.6
T_2N_1	77.5	74.4	76.0	2.2	2.2	2.2	3.1	3.0	3.1	11.0	10.7	10.8	9.0	8.0	8.5	1650	1650	1650	26.7
T_2N_2	82.3	80.6	81.5	2.9	2.7	2.8	3.5	3.4	3.5	11.4	11.0	11.2	11.1	10.1	10.6	1762	1869	1815	33.5
T_2N_3	86.3	83.3	84.8	3.0	3.0	3.0	3.7	3.7	3.7	12.3	11.3	11.8	12.4	12.1	12.3	1938	1940	1939	37.6
Control	71.4	69.4	70.4	2.0	2.0	2.0	2.5	2.4	2.4	9.8	8.8	9.3	7.3	6.1	6.7	1232	1188	1210	-
Mean of T_1	79.0	76.6	77.8	2.5	2.5	2.5	3.4	3.2	3.3	11.4	10.6	11.0	10.4	9.3	9.9	1620	1576	1598	
Mean of T_2	79.5	79.5	79.5	2.6	2.6	2.6	3.4	3.4	3.4	11.0	11.0	11.0	10.1	10.1	10.1	1819	1819	1819	
Mean of N_1	76.3	73.3	74.8	2.1	2.2	2.1	3.1	2.9	3.0	10.9	10.2	10.5	9.0	8.0	8.5	1553	1509	1531	
Mean of N_2	81.1	79.6	80.4	2.8	2.7	2.7	3.5	3.4	3.4	11.4	10.9	11.1	10.9	9.8	10.3	1680	1664	1672	
Mean of N_3	84.1	81.3	82.7	3.0	2.9	2.9	3.6	3.6	3.6	12.2	11.3	11.7	12.1	11.4	11.7	1872	1920	1896	
ANALYSIS OF VARIANCE																			
CD at 5 % level																			
	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	
T	0.401	0.265	0.228	0.056	0.043	0.033	0.056	0.043	0.034	NS	0.212	0.138	0.38	0.12	0.19	0.378	0.510	0.301	
N	0.491	0.325	0.279	0.069	0.053	0.041	0.069	0.053	0.041	0.245	0.259	0.169	0.46	0.15	0.23	0.463	0.625	0.368	
T×N	0.694	0.459	0.394	NS	0.075	NS	NS	NS	NS	NS	0.366	0.239	NS	0.21	0.32	NS	0.884	0.521	
Control V/ S Rest	0.750	0.496	0.426	0.105	0.081	0.063	0.105	0.081	0.063	0.374	0.396	0.258	0.70	0.22	0.35	0.707	0.955	0.563	

the plots with tall stubbles as compared to short stubbles i.e., the plants performed better where there was more water in the profile (24). Fig. 6A-D show the increment of RWC, LAI, biomass and chlorophyll content with the improved root zone soil water storage. A similar correlation was developed (R^2= 0.66, p≤ 0.05) (24, 47). Additionally, the higher soil temperature in tall stubbles might be responsible for higher leaf growth which leads to good canopy cover *i.e.*, LAI and RWC (24). An artificial barrier was created by mulching as well as keeping 20 cm standing stubbles and these might have helped in a slow and steady supply of water to plants. The favourable hydrothermal regime resulting from tall stubbles under MT might have resulted in the encouragement of root growth of lentils and thus enhanced utilization of conserved soil moisture thus achieving the highest growth under T2N3.

Crop Growth Rate (CGR) and Relative Growth Rate (RGR)

The CGR during initial to development ($CGR_{ini-dev}$) and development to mid-season ($CGR_{dev-mid}$) as well as the RGR during initial to development ($RGR_{ini-dev}$) and development to mid-season ($RGR_{dev-mid}$) were also critically studied (Table 6). Results suggested statistically significant effects of tillage and residue management as well as the interaction effects of tillage and residue management (T×N) on $CGR_{ini-dev}$ and $CGR_{dev-mid}$ as well.

The treatment combinations T1N3 and T2N3 were at par so far $CGR_{ini-dev}$ is taken into consideration(12.9 and 12.8 g m^{-2} day^{-1}, respectively) and the least was encountered with CT (6.1 g m^{-2} day^{-1}). The $CGR_{ini-dev}$ was found 34.1 and 10.1 % higher under N3 than N1 and N2, respectively. Among the tillage systems, MT (11.9 g m^{-2} day^{-1}) outperformed NT and CT (10.8 and 6.1 g m^{-2} day^{-1}, respectively) if we consider the $CGR_{ini-dev}$. However, during development to the mid-season stage T2N3 (19.8 g m^{-2} day^{-1}) attained the highest CGR; T1N3 (17.1 g m^{-2} day^{-1}) and T2N2 (16.9 g m^{-2} day^{-1}) were found at par and the least being recorded under CT again (15.1 g m^{-2} day^{-1}). Among the residue management strategies, N3 (18.5 g m^{-2} day^{-1}) achieved 24.9 and 13.0 % higher $CGR_{dev-mid}$ significantly over N1 and N2 respectively. Water storage impacts on the closure of stomata, which protects the water in the cells; this, in the same way, reduces the photosynthesis rate by stopping CO_2 from entering the cells and, thus, slows down the growth rate of the plant (44, 48). Another perspective by scientists is that plants generally shed their leaves temporarily during water stress to save water through the reduction of transpiration, which may reduce the CGR in plants (49, 50). Therefore, the rapid reduction of soil moisture under CT impaired plant growth, while conservation tillage improved both soil water usage and crop growth and the findings are in parallel with the findings of many scientists (51). Higher soil moisture was being resulted under 20 cm stubbles height than 10 cm height and in mulched plots than unmulched. These all soil moisture storage inturn consequenced a positive relation with CGR and NAR as observed in the Fig. 7A-B which proved the significance of root zone soil water storage in improving crop growth as CGR and NAR increment.

During initial to development stage ($RGR_{ini-dev}$),

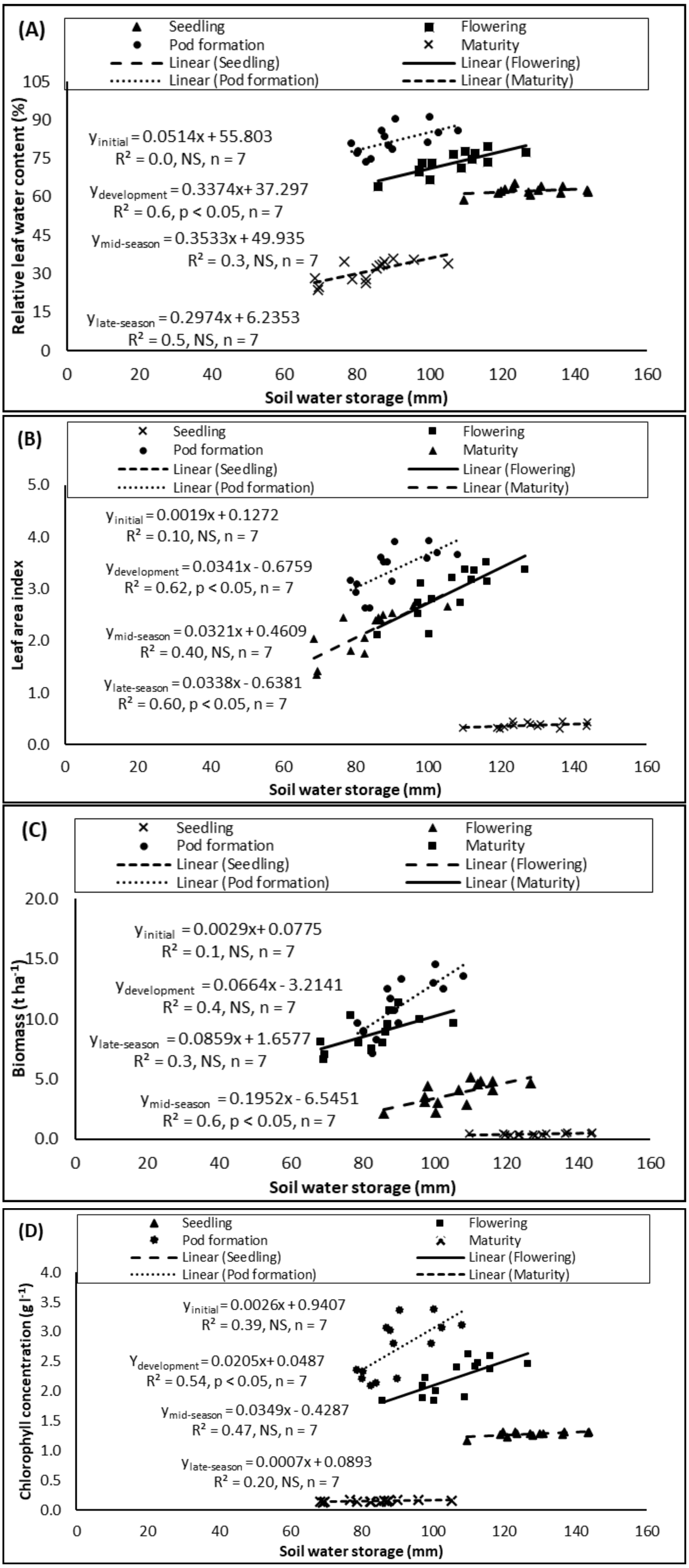


Fig. 6. Relationship of (A) RWC, (B) LAI, (C) biomass and (D) chlorophyll content with root zone soil water storage under the tillage and residue management in lentil.

Table 6. Crop Growth Rate (CGR) and Relative Growth Rate (RGR) of lentil under the influence of different tillage and residue management systems

Treatment		CGR (g m^{-2} day^{-1})						RGR (g g^{-1} day^{-1})					
		Initial to development			Development to mid-season			Initial to development			Development to mid-season		
		Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled	Y1	Y2	Pooled
T_1N_1		7.2	8.5	7.9	15.7	12.8	14.2	0.016	0.023	0.020	0.0055	0.0046	0.0051
T_1N_2		11.4	11.9	11.7	16.6	13.9	15.2	0.017	0.023	0.020	0.0041	0.0037	0.0039
T_1N_3		11.9	13.9	12.9	19.0	15.3	17.1	0.017	0.023	0.020	0.0044	0.0035	0.0039
T_2N_1		8.9	9.4	9.1	15.0	12.1	13.6	0.020	0.020	0.020	0.0048	0.0040	0.0044
T_2N_2		10.6	12.5	11.5	18.7	15.0	16.9	0.017	0.023	0.020	0.0047	0.0037	0.0042
T_2N_3		11.8	13.9	12.8	21.0	18.7	19.8	0.018	0.021	0.019	0.0047	0.0039	0.0043
Control		5.9	6.2	6.1	17.0	13.1	15.1	0.015	0.023	0.019	0.0075	0.0066	0.0070
	T_1	10.2	11.4	10.8	17.1	14.0	15.5	0.017	0.023	0.020	0.0047	0.0039	0.0043
	T_2	11.9	11.9	11.9	15.3	15.3	15.3	0.021	0.021	0.021	0.0039	0.0039	0.0039
Mean of	N_1	8.0	8.9	8.5	15.4	12.5	13.9	0.018	0.022	0.020	0.0052	0.0043	0.0047
	N_2	11.0	12.2	11.6	17.7	14.4	16.1	0.017	0.023	0.020	0.0044	0.0037	0.0041
	N_3	11.8	13.9	12.9	20.0	17.0	18.5	0.018	0.022	0.020	0.0045	0.0037	0.0041
ANALYSIS OF VARIANCE													
CD at 5 % level													
		Y1	**Y2**	**Pooled**	**Y1**	**Y2**	**Pooled**	**Y1**	**Y2**	**Pooled**	**Y1**	**Y2**	**Pooled**
T		NS	0.33	0.25	0.69	0.42	0.38	0.0007	0.0017	NS	NS	NS	NS
N		0.52	0.40	0.31	0.85	0.52	0.47	NS	NS	NS	0.00012	0.00024	0.00013
T × N		0.74	NS	0.44	1.20	0.73	0.67	0.0012	NS	NS	0.00018	0.00033	0.00018
Control V/S rest		0.79	0.61	0.48	NS	0.79	0.72	0.0012	NS	NS	0.00019	0.00036	0.00019

[Y1 = 2012-13; Y2 = 2013-14; T = Tillage; T1 = No tillage; T2 = Minimum tillage; N = Residue; N1 = 10 cm residue; N2 = 20 cm residue; N3 = Rice straw mulch; Control = Conventional Tillage (CT); and NS = not significant

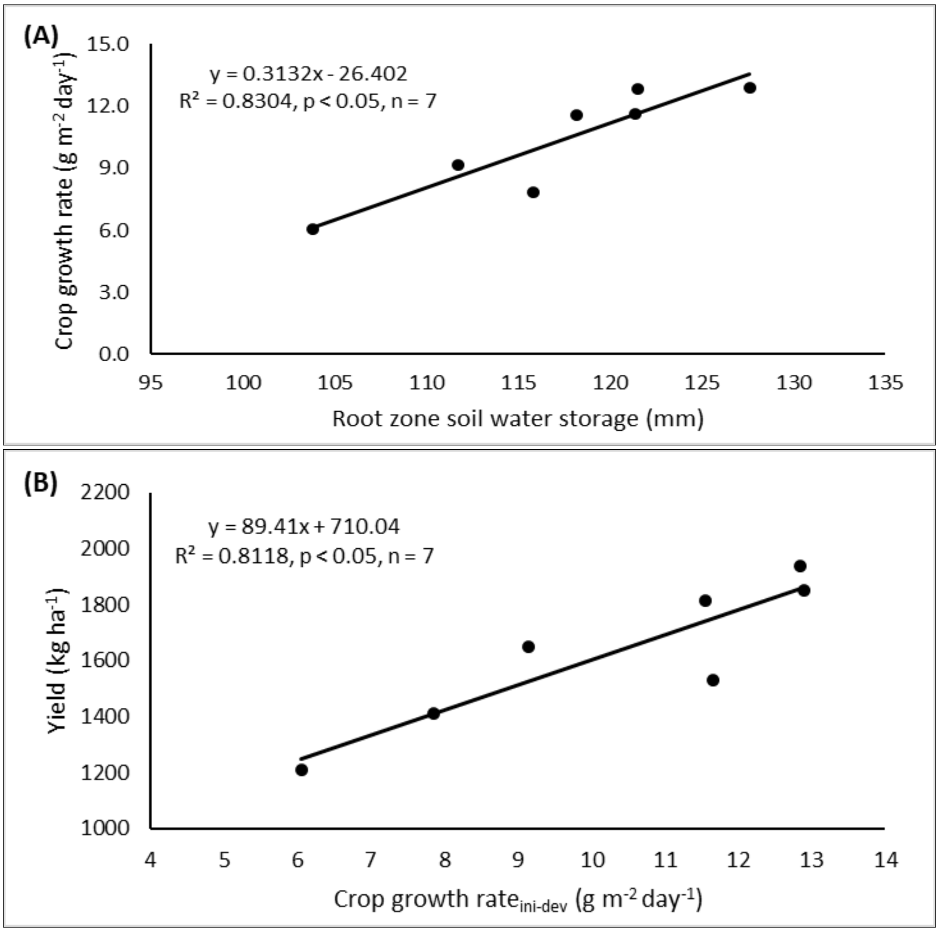


Fig. 7. Relationship of (A) CGR and root zone soil water storage and (B) CGR and grain yield of lentil under the tillage and residue management treatments.

statistically insignificant effects of tillage (T), residue management (N) and their interaction effects (T×N) on RGR were found. However, significant effects of N as well as the interaction effects of T×N were noticed during $RGR_{dev-mid}$ and the effect of different tillage (T) on $RGR_{dev-mid}$ stood statistically insignificant. Among the N systems (irrespective of T systems), N1 (0.0047 g g^{-1} day^{-1}) was witnessed to have the highest $RGR_{dev-mid}$ over N2 and N3. Further, it was also evident that N1 had 12.8 % higher $RGR_{dev-mid}$ over both N2 and N3 (Table 6). In a contrasting observation, CT appeared to have the highest $RGR_{dev-mid}$ (0.0070 g g^{-1} day^{-1}) and the least was seen in T1N3 (0.0039 g g^{-1} day^{-1}). The time period of different growth stages could have a impact in this phenomenon. It is worth to note that RGR is calculated on the basis of dry weight attained by a crop as a function of time duration incurred. In our experiment, CT appeared to have spent lesser duration (30 days) during both initial to development ($RGR_{ini-dev}$) and development to mid-season stage ($RGR_{dev-mid}$) during its life cycle. On the other hand, NT had the longest duration (130 days) of crop growth followed by MT (120 days), of which the of NT consumed 45 days during $RGR_{ini-dev}$ and 35 days during $RGR_{dev-mid}$. Likewise, the $RGR_{ini-dev}$ and $RGR_{dev-mid}$ were 40 and 30 days, respectively. Lesser time duration taken in the particular growth stage could be the responsible factor for CT with the highest $RGR_{dev-mid}$ even though it was associated with lesser crop growth (CGR) in this experiment, however, the interpretation still calls for more exploration in the field.

Yield and total biomass content

Statistically significant effect of both tillage and residue management on yield as well as biomass content of lentils was recorded. The interaction effect of T×N was also analyzed statistically significant as well (Table 5). T2N3 had the significantly highest biomass content as well as yield (12.3 Mg ha^{-1} and 19.4 kg ha^{-1} respectively) and the least was seen under CT (6.7 Mg ha^{-1} and 12.1 kg ha^{-1} respectively), which was statistically significant at $p \leq 0.05$. The yield under T2N3 was 37.6 % higher than the control, while T1N3 and T2N2 resulted in yield increment of 34.6 % and 33.5 % respectively compared to control (CT). Irrespective of residue management strategy, MT had 12.1 and 33.5 % higher yield over NT and CT respectively. Likewise, irrespective of tillage systems N3 provided 19.5 and 12.1 % higher yield over N1 and N2, respectively which could have been resulted from better plant activities under minimum tillage and mulching plots (Fig. 7).

The variabilities in yield production concerning different treatments could be justified through multiple possible reasons like how much water was conserved, how much time water can supply to plants, how much water stress occurred, evaporative demand, how much physiology was affected by moisture content perspective etc. Many scientists have justified these phenomena (1, 52). Also, NT and MT combined with crop residues mulch improved soil water storage and increased crop yield (27). Furthermore, better root aeration (9) and crop nutrient uptake (53) were also determining factors that affected physiological processes and yield generation; where crop residues act as nutrient storage areas and their decomposition and consistent release boosted the nutrient availability by the actions of microbes, resulting in enhanced dry matter accumulation and grain yield. MT produced better yield over NT mainly because of the better establishment of the plant by the good seed placement into the soil produced with hand tyne coupled with water availability throughout the growing period. On the other hand, though NT stored sufficient soil moisture, the seed placement on soil surface hindered the initial prime root establishment and simultaneous growth of the plant (4, 6).

There has been 6-28 % higher yield of lentil under tall stubble-cutting height as compared to short stubble height for three consecutive years. Increasing rice stubble height in rice-lentil relay cropping can enhance the water productivity (WP) of lentil using both short and long-duration rice (23). The reduction in yield and poor physiological activities of plants under CT could be explained by the fact that there was lesser soil water supply mainly at later stages of crop growth along with the deterioration of soil physical properties. The established correlations among yield versus $CGR_{ini-dev}$ shows a significant ($R^2 = 0.8118$, $p \leq 0.05$) positive correlation (Fig. 7A-B). The established equation is represented as:

$$\text{Yield} = 89.41\,(CGR_{ini-dev}) + 710.04\ ;\ R^2 = 0.8118,\ p \leq 0.05$$

In most climates, removing all crop residues from the field leads to a deterioration of soil physical properties, plant physiology like RWC, LAI, chlorophyll and ultimately the grain yield (44, 54).

Conclusion

Based on the results of the present study, it can be concluded that the retention of stubble residues, along with an application of straw mulch, conserved the maximum amount of soil moisture in the root zone, highlighting the effectiveness of conservation tillage under rainfed situations. Minimum tillage, with improved soil-water-root contact, facilitated consistent plant stand and growth from the early vegetative to maturity improving crop physiological variability as compared to no-tillage or conventional tillage. Lentil seed yield was found highest under minimum tillage with a 10 cm stubble height and straw mulch application (T2N3) followed by minimum tillage with a 20 cm stubble height (T2N2). Hence, for better seed-soil contact, minimum tillage with standing rice stubbles or with an application of straw mulch produced the best alternative for lentil cultivation in rice residual soil moisture as compared to no-tillage or conventional tillage in this sub-tropical region. From the result obtained, it is also concluded that, surface mulch and standing stubble maximized water retention and prevented water loss from the soil profile and thereby the first hypothesis is accepted. NT (T1) and MT (T2), in comparison to CT, enhanced productivity of the test crop of the experiment and thereby the second hypothesis is also accepted. Statistically significant variations are being noted in moisture conservation through the different practices implemented in the study and thereby the third hypothesis is also accepted. To evaluate the different hypothesis framed in the experiment, we set different objectives involving multiple numbers of observation, analysis, interpretation etc. which were all accomplished satisfactorily.

Crop residue retention for maintaining taller subble height (20 cm) and storing and/or collection for crops residues for using as mulches remains a great challenges. In majority of the areas, farmers prefer the crop residue to be burnt off as it happens to be the easiest way to diposed them off, which in turn makes the soil to prone to degradation. The legislations regarding such points could be addressed for policy making to prevent burning and /or other ill management of residues in the country. Further, advanced technologies suited to the current scenario of Indian agriculture and by taking due consideration of farmers' need and potential regarding the matter could be addressed in an appropriate scientific and social approach. More research in the field of correlation between soil moisture conservation versus crop performance owing to tillage applications, particulary the RGR, separation of evaporative and transpirational loss of moisture from from soil profiles, yield etc.

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Authors' contributions

All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by KCS, PK, RN, MS and PKS. The first draft of the manuscript was written by KCS and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Conceptualization, Methodology, writing- original draft preparation, formal analysis and investigation were done by KCS. Methodology, review writing, editing, data curation, visualization and supervision, resources were done by PKB. RN, HJB, MS, PKS, TAB and DS performs the formal analysis and data curation.

Compliance with ethical standards

Conflict of interest: Plant Science Today requires authors to declare all competing interests concerning their work. All submitted manuscripts must accompany 'competing interests' statement listing all competing interests. If nothing to declare, mention - Authors do not have any conflict of interests to declare.

Ethical issues: None

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