Plant Bulletin Vol 5, (1) 2026: 20-30 ISSN: 2959-3379 (Print), 2959-3387 (Online)

Research Article

Effects of Tillage Systems and Legumes-based Intercropping on Soil Health and Cotton Yield

Hamza Raheem[*1,4], Abdul Ghaffar[1], Muhammad Habib-ur-Rahman[1], Muhammad Baqir Hussain[2], Muhammad Mahmood Iqbal[3], Muhammad Aqeel Sarwar[4], Zubair Ahmed[4], Tayyub Hussain[4]

[1]*Department of Agronomy, MNS-University of Agriculture, Multan, Pakistan*
[2]*Department of Soil and Environmental Sciences, MNS-University of Agriculture, Multan, Pakistan*
[3]*Cotton Research Institute, Multan, Pakistan*
[4]*Crop Sciences Institute, National Agricultural Research Centre, Islamabad, Pakistan*
Correspondence: Hamza Raheem, hamza6959@parc.gov.pk

ABSTRACT

Conservation agriculture practices like zero tillage and legume intercropping promote sustainable crop production and improve soil health. An experiment was conducted to evaluate the effects of conventional and zero tillage methods, nitrogen levels and intercropped legumes on soil health and production of cotton. The treatments for the study included: two tillage systems (conventional and zero), two nitrogen levels [(recommended dose (225 kg ha^{-1}) and 20% reduced dose (180 kg ha^{-1})] and four cropping systems (sole cotton, cotton + mung bean, cotton + cluster bean and cotton + cowpea). Results revealed that cotton growth was better in the plots under conventional tillage and number of bolls per plant and average boll weight were 7% and 4% higher in conventional tillage plots compared with those of zero tillage plots. Seed cotton yield was 7% higher in the conventional tillage plots compared with the yield of zero tillage plots. There was no major effect of nitrogen levels on soil health parameters while growth and yield of cotton crop and intercropped legumes were better in plots where recommended dose of nitrogen was used. The findings of the study also revealed that mung bean grown as intercrop showed maximum number of pods (37) and yield (231 kg ha^{-1}) and its intercropping resulted in 2% more seed cotton yield than the yield obtained under the plots where sole cotton was grown. Soil health was observed to be improved in the plots under zero tillage and bulk density was 17% less in the zero tillage plots. Meanwhile soil moisture, soil N, P and K contents were 3%, 13%, 9% and 2% higher respectively under zero tillage plots than plots under conventional tillage. This study, along with other conservation agriculture practices, can promote zero tillage and legume intercropping for sustainable farming.

Keywords: conservation farming, microbial activity, nutrient cycling, soil fertility, sustainable agriculture, zero tillage.

INTRODUCTION

Cotton is a leading fiber crop all over the world and has yearly contribution to the economy of more than $600 billion all over the globe (Ashraf *et al.*, 2019). In Pakistan, cotton was cultivated on an area of 2.04 million hectares with an average yield of 590 kg/ha and production of 7.08 million bales (Pakistan Economic Survey, 2024-25).

Around the world, especially in arid to semi-arid regions, low fertility and poor soil quality are the major issues due to climatic conditions. Additionally, intensive tillage and cotton monoculture have a negative impact on soil quality and agricultural yields. (Das *et al.*, 2018). Conventional management techniques significantly reduce cotton crop production and profitability due to inefficient use of water resources and evaporation losses (Koech and Langat, 2018). Conservation tillage practices and organic manuring are very helpful in this context to enrich soil with nutrients, minimize water losses and increase profitability reducing cost of production (Moraru and Rusu, 2012). Zero tillage is a technique which is helpful in improving the crop production in

Article History

Received: October 31, 2025, Revised: December 07, 2025, Accepted: December 29, 2025, Published: February 20, 2026.

https://doi.org/10.55627/pbulletin.005.01.1657

sustainable manner without any disturbance of soil (Saturnino *et al.*, 2002). Zero tillage has the ability to establish a healthier soil environment in conservation agriculture with less soil disturbance and greater crop yield with minimal environmental impact (Busari *et al.*, 2015). With the use of zero tillage technology, cotton production and quality can be improved while system profitability is increased (Abbas *et al.*, 2016). Due to lower production costs and less residue management, zero tillage systems can be more profitable than conventional systems. Intercropping involves the alteration in cropping system in such a way so that the productivity increases with utilizing the resources in an efficient way (Manasa *et al.*, 2018). Cotton crop productivity under the intercropping system is mainly dependent upon the selected intercrop sown in cotton field. The addition of various legumes like mung bean, mash bean, cowpea in cotton crop as intercrop is considered profitable in terms of system productivity as these intercrops have shorter life cycle and also have the ability to utilize less water. These intercrops are reported to enhance the production of cotton when grown as intercrop in cotton field (Khan *et al.*, 2001; Khan and Khaliq, 2004).

Additionally, intercropping legumes with cotton has several benefits, such as reducing soil erosion and nutrient leaching losses and controlling weeds and pests (Kumar and Kumar, 2006). Leguminous plants can fix nitrogen from the air which improves soil nitrogen status. Leguminous intercrops improve nitrogen balance which is good for companion cotton and may be even a high-yielding cereal crop that needs a lot of nutrients in the future (Rusinamhodzi *et al.*, 2006; Adu-Gyamfi *et al.*, 2007). Intercropping legumes is a well-known technique for enhancing soil fertility and health; several studies have recently characterized intercropping as the optimal approach to enhance soil physical properties (Srinivasarao *et al.*, 2012; Lal, 2015). A promising strategy to increase cotton productivity, improve soil health and sustain the system is to intercrop cotton with leguminous crops using zero tillage techniques (Saleem *et al.*, 2022). The hypothesis of the study was that zero tillage along with legumes intercropping will improve soil health and produce sustainable cotton yield. The experiment was conducted i) to determine the effects of zero tillage technique on the soil health and productivity of cotton planted on permanent beds; ii) to evaluate the performance of cotton-legume intercropping.

MATERIALS AND METHODS

Experimental Site

The field experiment was conducted at research farm of MNS-University of Agriculture, Multan, Pakistan (30°9'35"N 71°26'41"E). The experimental site had permanent raised beds since the last two years in zero tillage plot.

Soil Sampling

Soil samples were collected from 0-15 cm depth of the soil for evaluating the effects of tillage systems, nitrogen levels and cropping systems on the soil physical, chemical and biological properties after the harvest of cotton.

Weather Data

Weather data for crop growing season (2022) was collected from metrological observatory of MNS-University of Agriculture Multan (Fig. 1).

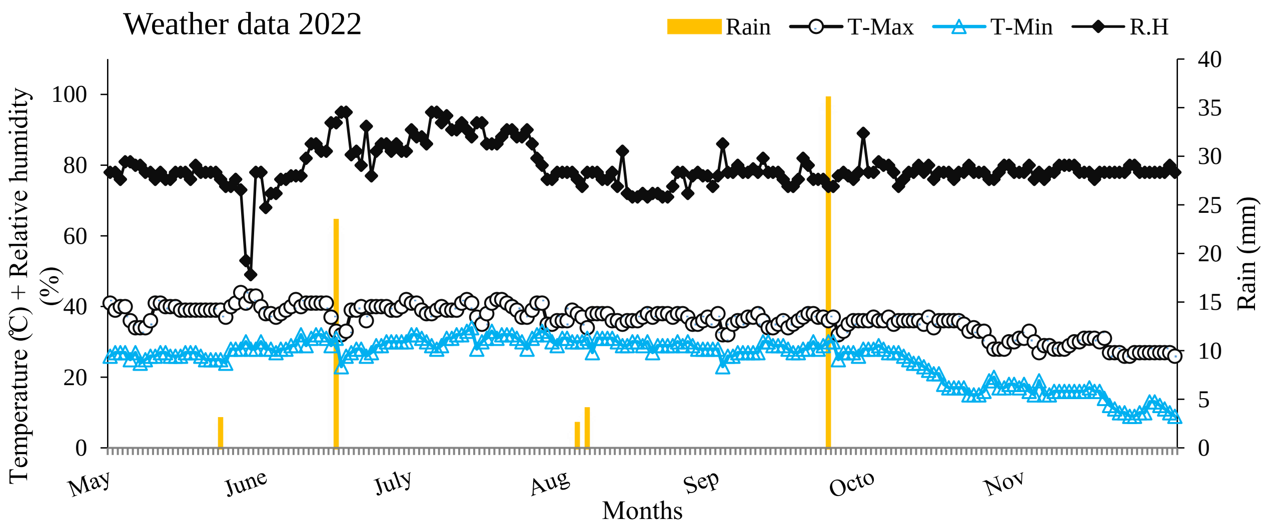

Figure 1. Data of weather elements including temperature (℃), relative humidity (%) and rain (mm) during the cotton growing season-2022

Treatments

The treatments were comprised of two treatments of tillage systems in main plots (CT = Conventional tillage, ZT = Zero tillage), two treatments of nitrogen (N) levels in sub-plots [(N_1 = Recommended dose of N (225 kg/ha), N_2 =

https://doi.org/10.55627/pbulletin.005.01.1657

Reduced dose of N (180 kg/ha)] and four treatments of cropping systems in sub-sub plots (C_1 = Sole cotton, C_2 = Cotton + Mung bean, C_3 = Cotton + Cluster bean, C_4 = Cotton + Cowpea). Experiment was conducted in Randomized Complete Block Design (RCBD) with split-split plot arrangements having three replications.

Crop Husbandry

In conventional tillage plots, the land was ploughed and prepared using tillage implements while no tillage implements were used in plots of zero tillage. In zero tillage, permanent raised beds (since last two years) were used. The individual plot size was 10 m × 8 m. Cotton seed was delinted with sulfuric acid (H_2SO_4) before sowing. Cotton variety NIAB-878 was sown manually in both zero and conventional tillage treatments at seed rate of 20 kg ha^{-1} on 10^{th} May 2022 and at planting geometry of 75 × 15 cm. Fertilizers were applied as recommended except nitrogen treatments. Intercrops mung bean, cluster bean and cowpea were sown after 30 days of cotton crop sowing. Intercropping was done on beds by keeping distance of 22.5 cm away from cotton. All agronomic practices were kept same except treatments.

Data Collection

Soil Physical Parameters

The bulk density of soil was estimated using the protocol defined by ICARDA Manual (2013). Soil sample was taken from the area of no vegetation with the help of iron core. Then, it was collected from core and oven dried at 105 ^{0}C till it attains the constant weight. Bulk density was estimated using the formula:

$$Bulk\ Density\ (gcm^{-3}) = \frac{Oven\ dry\ weight\ of\ soil\ sample\ (g)}{Volume\ of\ soil\ sample\ (cm^3)}$$

Soil porosity was measured from bulk density by using formula:

$$Soil\ Porosity\ (\%) = \frac{Particle\ density - Bulk\ density}{Particle\ density} \times 100$$

Soil Nutrients

The soil nitrogen (N) contents were measured using the technique as described by Amule (2015) via digestion, distillation and titration procedure. Soil sample of 05 g was digested and then distilled in distillation unit using the reagents (boric acid, potassium permanganate and sodium hydroxide). Later on, titration was done using H_2SO_4 which gave the sample pink color. Meanwhile, blank sample was also run and final concentration was measured using formula:

$$Total\ Nitrogen\ (\%) = \frac{R\ (Titer\ reading - Blank\ reading) \times Normality\ of\ the\ acid \times Atomic\ weight\ of\ N}{Sample\ weight\ (g) \times 1000} \times 100$$

For soil phosphorus estimation, ion of the soil sample was extracted using reagent (0.5 M $NaHCO_3$) after fine grinding of soil sample. After completion of extraction process, sample was filtered in tubes and coloring agent was poured in tubes for appearance of blue color. The blue color is directly proportional to the amount of P present in the sample of soil. The reading of sample was noted by using UV-visible spectrophotometer (CECIL CE7400S) at wavelength of 880 nm (Olsen *et al.*, 1954).

For soil K estimation, extraction process was carried like in case of P estimation and then filtration was done using filter paper. Readings for K were noted using the methodology of Isaac and Kerber (1971) on Flame photometer (BWB technologies XP) and calculated using formula:

$$Extractable\ K\ (ppm) = Reading\ (ppm) \times 20$$

Soil Electrical Conductivity (EC)

Soil EC weas measured using pH meter. Soil sample and water were put in the beaker in the ratio of 1:2. The solution was continuously stirred and electrode of pH meter was inserted in the beaker for measuring the soil EC (Dwivedi and Baghel (2015).

Soil Microbial Population

Soil microbial population was measured following three steps i.e. agar plate preparation, serial dilution preparation and pouring of dilutions on Starkey's agar plates. Agar plate was prepared using reagents (0.25 g KH_2PO_4, $MgSO_4.7H_20$, Glucose 0.75 g, peptone 0.25 g, (NH4)2 SO4 0.25 g and water) and media was stirred on magnetic stirrer. Later on, media was autoclaved and cooled. For serial dilutions, soil was added in tubes containing 100 ml of water and then autoclaved and different levels of dilutions were prepared. Then, the dilutions were poured on agar plates and colony forming units (CFU) were counted using the formula:

$$CFU\ per\ ml\ of\ sample = \frac{Number\ of\ colonies}{Amount\ plated} \times Dilution$$

Cotton Crop Parameters

Height of 10 plants was taken using measuring tape from each plot and then taken average. Total number of bolls and numbers of opened bolls per plant were counted from five randomly selected plants in each plot and then taken average. For calculating average boll weight (g), seed cotton of 45 bolls from each plot was picked, weighted and averaged. Seed cotton yield (kg ha^{-1}) was

https://doi.org/10.55627/pbulletin.005.01.1657

calculated by picking seed cotton from respective whole plots, weighted (kg) and converted into kg per hectare:

$$Seed\ cotton\ yield\ (kgha^{-1}) = \frac{Seed\ cotton\ yield\ \left(\frac{kg}{plot}\right) \times 10000\ m^2}{Net\ plot\ area\ (m^2)}$$

Ginning outturn (GOT) was determined by weighing the lint collected from each sample. Using a single roller electric ginner, we eliminated dust and other impurities from sun-dried seed cotton samples before weighing and ginning them.

$$GOT\ (\%) = \frac{Weight\ of\ the\ lint\ (kg)}{Weight\ of\ seed\ cotton\ (kg)} \times 100$$

Statistical Analysis

All the data was analyzed using Fisher's analysis of variance (ANOVA). The difference in treatment means was compared using HSD Tukey's test at 5 % probability level (Steel *et al.*, 1997). Statistix 8.1© was used to statistically examine the data.

RESULTS

Soil Health Parameters

Physical Traits

The various tillage system (TS) and cropping systems (CS) had significant effect on soil bulk density and soil porosity while effect of nitrogen levels (N) was found non-significant. The interaction (TS × N × CS) was found non-significant for soil physical parameters. Between different TS, zero-tillage (ZT) resulted in lower BD of soil (1.1233 g cm^{-3}) and higher soil porosity (55.45%) compared with conventional tillage (CT). Meanwhile, among CS, intercropping of legumes (C_2 = cotton + mung bean, C_3 = cotton + cluster bean, C_4 = cotton + cowpea) improved soil BD and porosity compared with C_1 (sole cotton). The lowest BD (1.1933 g cm^{-3}) and highest porosity (53.438 %) were recorded in C_2 and that was statistically at par with C_3 (Table 1).

Soil Nutrients

The various tillage system (TS) and cropping systems (CS) had significant effect on soil nutrients (N, P, K) while nitrogen levels (N) significantly affected soil N only. The interaction (TS × N × CS) was found significant for soil K (Fig. 2). Between different TS, the highest soil N (0.05 %), P (17.716 ppm) and K (250.48 ppm) were recorded under zero tillage (ZT) compared with conventional tillage (CT). Similarly, among CS, highest soil N (0.0497%), P (18.61 ppm) and K (252.87 ppm) were recorded in C_2 (cotton + mung bean). In case of nitrogen levels, N_1 (recommended dose of N) showed higher N content (0.0485%) compared with N_2 (20% reduced dose of N) (Table 1).

Soil Electrical Conductivity (EC)

The various tillage system (TS) and nitrogen levels (N) had significant effect on soil EC while effect of various cropping systems (CS) was found non-significant. The interaction (TS × N × CS) was found non-significant for soil EC. Between different TS, zero tillage (ZT) resulted in lower EC (2.2392 dS m^{-1}) compared with conventional tillage (CT). Between different N, N_1 showed lower EC value (2.3604 dS m^{-1}) compared with N_2 (Table 1).

Soil Microbial Population

The various tillage system (TS) and cropping systems (CS) had significant effect on soil microbial population (MP) while the effect of nitrogen levels (N) was found non-significant. The interaction (TS × N × CS) was found non-significant for soil MP. Between different TS, zero tillage (ZT) resulted in higher MP (599169 CFU g^{-1}) compared with conventional tillage (CT). Among CS, highest MP value (580230 CFU g^{-1}) was recorded in C_2 (cotton + mung bean) that was statistically at par with C_3 (cotton + cluster bean) (Table 1).

Cotton Crop Traits

The various tillage system (TS), nitrogen levels (N) and cropping systems (CS) had significant effect on cotton plant height (PH), seed cotton yield and ginning outturn (GOT). TS had significant effect on opened bolls per plant while N had significant effect on total bolls per plant and average boll weight. The interaction (TS × N × CS) was found significant for seed cotton yield only (Fig. 3). Interaction was significant for seed cotton yield. Between different TS, cotton crop grown under conventional tillage (CT) showed higher PH (154.31 cm), opened bolls per plant (24.25), seed cotton yield (2589.2 kg ha^{-1}) and GOT (36.762%) as compared to zero tillage (ZT). Between different N, higher PH (156.71 cm), total bolls per plant (27), average boll weight (2.7546 g), seed cotton yield (2605.7 kg ha^{-1}) and GOT (36.813%) were recorded in N_1 (recommended dose of N). Among CS, PH (154.7 cm) was maximum in C_1 (sole cotton), statistically at par with C_2 (cotton + mung bean). Highest seed cotton yield (2561 kg ha^{-1}) was recorded in C_2 (cotton + mung bean), statistically at par with C_3 (cotton + cluster bean). There was no statistical difference among CS in case of GOT (Table 2).

https://doi.org/10.55627/pbulletin.005.01.1657

Table 1. Effect of tillage system, nitrogen level and cropping system on the soil health

	Bulk Density (g cm^{-3})	Porosity (%)	N (%)	P (ppm)	K (ppm)	Electrical Conductivity (dS m^{-1})	Microbial Population (CFU g^{-1})
Tillage System (TS)							
CT	1.3963 a	46.107 b	0.0443 b	16.232 b	245.33 b	2.5079 a	529916 b
ZT	1.1233 b	55.450 a	0.0500 a	17.716 a	250.48 a	2.2392 b	599169 a
HSD ($p \leq 0.05$)	0.0488	3.4188	0.002375	0.8557	1.7956	0.1630	26695
Nitrogen Level (N)							
N_1	1.2513	51.013	0.0485 a	17.651	248.42	2.3604 b	566025
N_2	1.2683	50.544	0.0458 b	16.298	247.40	2.3867 a	563060
HSD ($p \leq 0.05$)	NS	NS	0.00262	NS	NS	0.0229	NS
Cropping System (CS)							
C_1	1.3283 a	48.276 c	0.0415 b	14.558 b	247.46 b	2.4158	555339 b
C_2	1.1933 c	53.438 a	0.0497 a	18.610 a	252.87 a	2.4700	580230 a
C_3	1.2417 bc	51.525 ab	0.0486 a	17.915 a	249.08 b	2.3517	566218 ab
C_4	1.2758 ab	49.875 bc	0.0488 a	16.813 a	242.21 c	2.2567	556384 b
HSD ($p \leq 0.05$)	0.0658	2.1445	0.002076	2.0150	2.0149	NS	22679
TS × N	NS	NS	NS	NS	NS	**	NS
TS × CS	NS	NS	NS	NS	**	NS	NS
N × CS	NS	NS	NS	NS	**	NS	NS
TS × N × CS	NS	NS	NS	NS	**	NS	NS

** = Significant ($p \leq 0.01$); NS = non-significant. Two means that are not sharing a same letter differ significantly at $p \leq 0.05$.

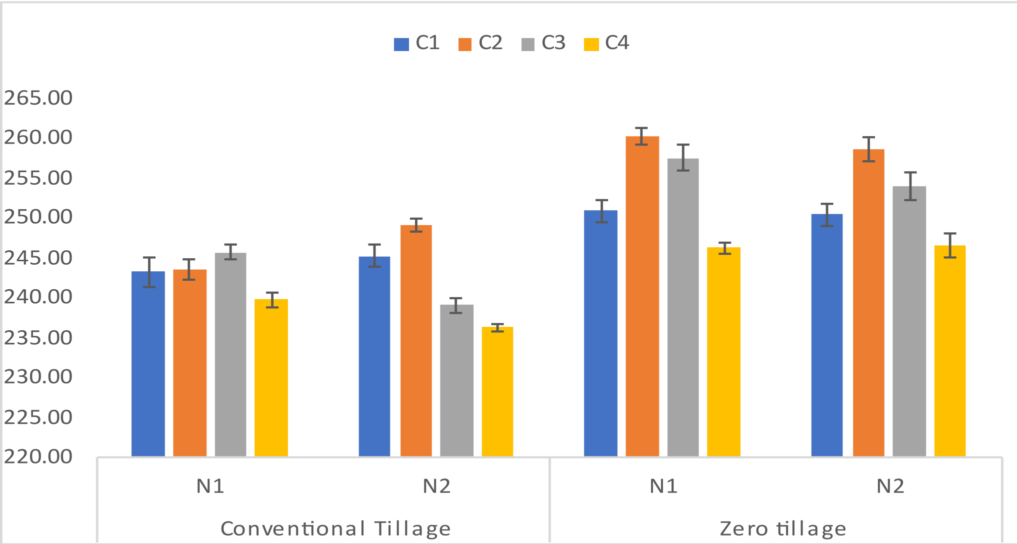

Figure 2. Effect of tillage systems, nitrogen level and cropping systems on soil K

https://doi.org/10.55627/pbulletin.005.01.1657

Table 2. Effect of tillage system, nitrogen levels and cropping system on the cotton growth and yield

	Plant Height (cm)	Total Bolls per Plant	Opened Bolls per Plant	Average Boll Weight (g)	Seed Cotton Yield (kg ha^{-1})	Ginning Outturn (%)
Tillage System (TS)						
CT	154.31 a	26.125	24.250 a	2.7408	2589.2 a	36.762 a
ZT	147.50 b	24.500	23.000 b	2.6387	2463.1 b	35.950 b
HSD ($p \leq 0.05$)	2.9235	NS	0.8228	NS	13.073	0.2657
Nitrogen Level (N)						
N_1	156.71 a	27.000 a	24.500	2.7546 a	2605.7 a	36.813 a
N_2	145.10 b	23.625 b	22.750	2.6250 b	2446.6 b	35.900 b
HSD ($p \leq 0.05$)	2.4509	2.1321	NS	0.0206	18.326	0.1617
Cropping System (CS)						
C_1	154.70 a	25.500	23.750	2.6692	2514.0 b	36.225 a
C_2	150.58 ab	25.250	23.750	2.7300	2561.0 a	36.550 a
C_3	148.87 b	25.250	23.250	2.6900	2529.5 ab	36.200 a
C_4	149.47 b	25.250	23.750	2.6700	2500.2 b	36.450 a
HSD ($p \leq 0.05$)	4.9028	NS	NS	NS	33.084	0.3775
TS × N	NS	NS	NS	NS	**	**
TS × CS	NS	NS	NS	NS	**	NS
N × CS	NS	NS	NS	NS	**	**
TS × N × CS	NS	NS	NS	NS	*	NS

** = Significant ($p \leq 0.01$); * = Significant ($p \leq 0.05$) NS = non-significant. Two means that are not sharing a same letter differ significantly at $p \leq 0.05$.

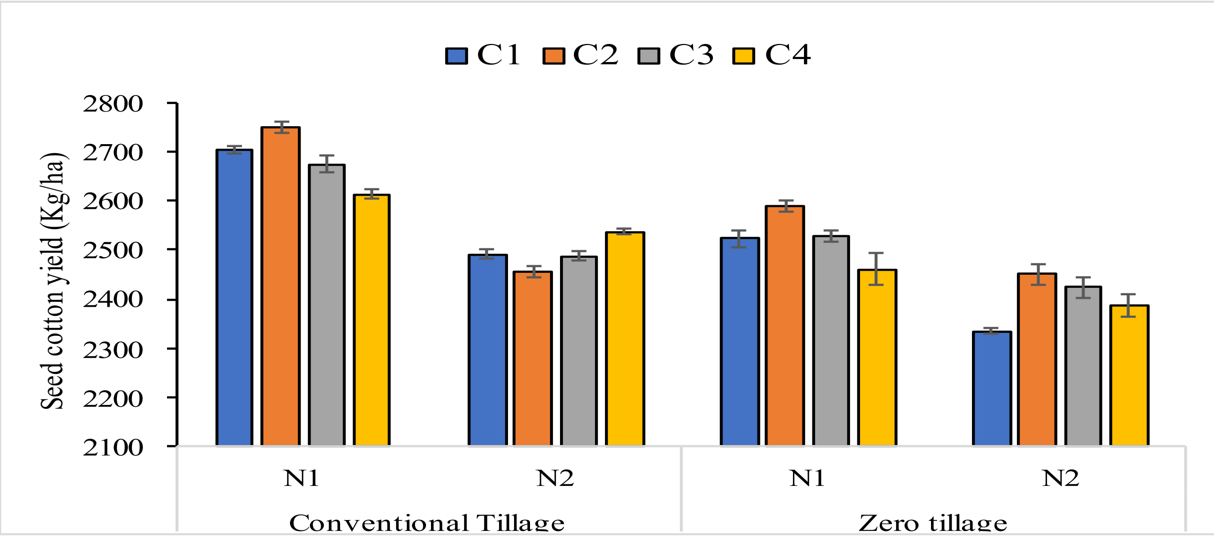

Figure 3. Effect of tillage systems, nitrogen level and cropping systems on seed cotton yield

Intercrops Parameters

The nitrogen levels (N) and cropping systems (CS) had significant effect on intercrops attributes including plant height (PH), pods per plant and yield while various tillage system (TS) significantly affected the PH and yield. The interaction (TS × N × CS) was found significant for intercrops yield. Between different TS, intercrops grown under conventional tillage (CT) showed higher PH (27.667 cm) and yield (196.5 kg ha^{-1}) compared to zero tillage (ZT). Between different N, higher PH (28.333 cm), pods per plant (36) and yield (196.25 kg ha^{-1}) were recorded in N_1 (recommended dose of N).

https://doi.org/10.55627/pbulletin.005.01.1657

Among CS, higher PH (27.75 cm) was recorded in C_2 (cotton + mung bean), which was statistically at par with C_3 (cotton + cluster bean). Meanwhile, higher pods per plant (37) and yield (231 kg ha^{-1}) were recorded in C_2 (Table 3).

Table 3. Effect of tillage system, nitrogen levels and cropping system on the growth and yield of intercrops

	Plant Height (cm)	**Pods per Plant**	**Yield (kg ha^{-1})**
Tillage System (TS)			
CT	27.667 a	34.833	196.5 a
ZT	25.333 b	32.5	180.92 b
HSD ($p \leq 0.05$)	1.0774	NS	4.1931
Nitrogen Level (N)			
N_1	28.333 a	36 a	196.25 a
N_2	24.667 b	31.333 b	181.18 b
HSD ($p \leq 0.05$)	1.891	1.1657	2.1352
Cropping Systems (CS)			
C_2	27.75 a	37 a	231 a
C_3	26.875 ab	33 b	179.38 b
C_4	24.875 b	31 b	155.75 c
HSD ($p \leq 0.05$)	2.8027	2.1937	2.6695
TS × N	NS	NS	*
TS × CS	NS	NS	**
N × CS	NS	NS	**
TS × N × CS	NS	NS	**

** = Significant ($p \leq 0.01$); * = Significant ($p \leq 0.05$); NS = non-significant. Two means that are not sharing a same letter differ significantly at $p \leq 0.05$.

Observations recorded of system productivity

Land Equivalent Ratio (LER)

Land Equivalent Ratio (LER) for the intercropping of various legumes (Mung bean, Cluster bean, Cowpea) in cotton crop remained significant under both conventional and zero tillage plots of the experiment as shown in Fig. 2.3. Highest LER value (1.63) was observed in the plots of conventional tillage where Mung bean was intercropped in cotton under the recommended dose of nitrogen followed by the LER (1.61) in Mung bean intercropping under lower nitrogen level and cluster bean intercropping (1.61) under recommended nitrogen dose. While lowest LER in the conventional tillage plots was observed where cowpea was intercropped under lower dose of nitrogen. Meanwhile, under the zero-tillage practice, maximum LER (1.59) was observed under cotton + mung bean intercropping and recommended dose of nitrogen application and lowest LER was observed in the plots of zero tillage where cotton + cowpea intercropping was done and lower dose of nitrogen was applied (Fig. 4).

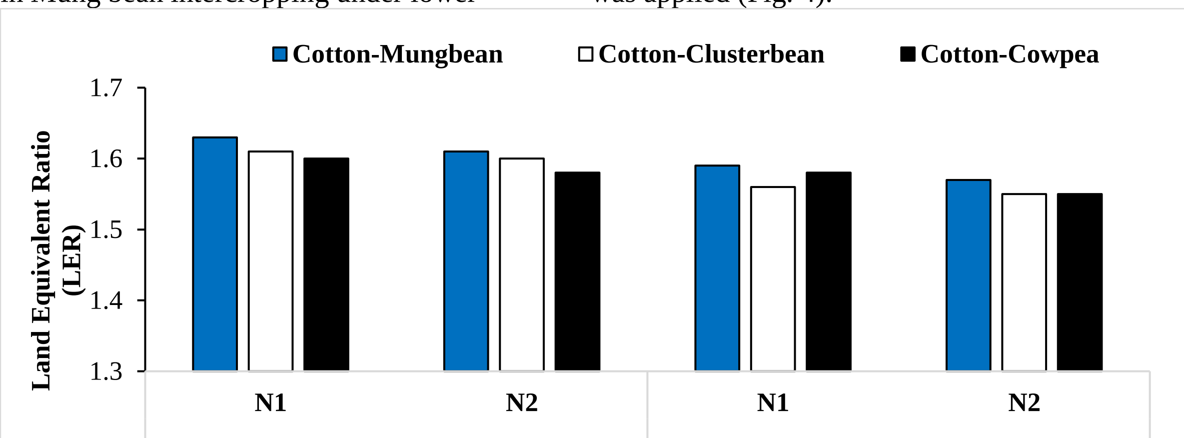

Figure 4. Land Equivalent Ratio (LER) of legumes intercropping in cotton crop under different tillage systems and nitrogen levels.

https://doi.org/10.55627/pbulletin.005.01.1657

DISCUSSION

Cotton is the major crop of our country which contributes a lot in the agriculture sector but intensive agriculture along with conventional tillage practices and cropping system causes decline in the system sustainability and soil degradation. Adoption of zero tillage along with other conservation practices resulted in more soil organic matter contents and improves the biological, physical and chemical properties of soil thus protecting it from further degradation (Li *et al*., 2020; Rahmati *et al*., 2020). Like zero tillage, some other sustainable practices like intercropping and cover cropping are much important for reattaining the soil fertility status and productivity (Brussaard *et al*., 2007). Especially the legumes intercropping in our main crop like cotton along with other conservation practices can enhance the crop yield and overall system productivity (Baritz *et al*., 2017). Legumes like mung bean, cluster bean and cowpea are considered for their well-known role in fulfilling the N need of main crop by fixing the atmospheric N in soil through there special structure known as nodules by making the positive association (Fustec *et al*., 2010).

Many research trials reported that N is crucial mineral for better cotton production in the areas of Pakistan. Deficiency of N at any stage either vegetative or reproductive may cause decline in overall yield of crop because of early senescence caused by N deficiency (Girma *et al*., 2007). Meanwhile the production of cotton crop under conventional tillage practices along with the complete dose of required N is not economically suited for farmers also causing environmental issues. Thus, adoption of conservation practices like zero tillage along with the balanced N application can be a sustainable step towards attaining the better cotton yield along with environmental safety (Usman *et al*., 2014).

Zero tillage (ZT) practice is a conservation technique which improves the soil health and other attributes of soil (Busari *et al*., 2015). Our results showed that ZT reduced soil bulk density significantly compared to conventional tillage (CT) as earlier reported by Topa *et al.*, (2021). Soil porosity also increased under ZT which is in correspondence of findings by Yang *et al.*, (2021). ZT increases the availability of minerals like N, P and K and also improves organic matter of soil due to minimal disturbance of soil thus improving the overall health of soil (Bhatt, 2017; Sayed *et al*., 2020). ZT increased soil nutrient (N, P, K) contents, also earlier reported by Lv *et al.*, (2023). Soil electrical conductivity (EC) was lower under ZT which is in correspondence with findings by Lilienfein *et al.*, (2000). The soil microbial population in our results increased under ZT which may be due to less soil disturbance and better soil physical health (Moran *et al*., 2008; Baritz *et al*., 2017). These results are also in correspondence with those of Rajpoot *et al*., (2018), who also reported similar findings of increment on soil microbial population under ZT practice. ZT resulted in higher N contents and higher microbial mass compared to CT, also reported by Mathew *et al.*, (2012).

A review by Dugassa, (2023) reported that legume intercropping improves soil physical health lowering soil bulk density, which is according to the results of our study; cotton + mung bean intercropping, at par with cotton + cluster bean, significantly reduced soil bulk density compared to solo cotton sowing. These results are also in correspondence with Ganeshamurthy *et al.*, (2006) and Xu *et al.*, (2021). Soil porosity increased where mung bean and cluster bean were intercropped in cotton which relates with findings by Xu *et al.,* (2021). Soil nutrients (N, P, K) contents were higher in legumes-intercropped cropping systems compared to sole cotton, also reported by Dugassa, (2023). Our results showed better availability of mineral elements for crop production under ZT and legumes intercropping which are in correspondence with the findings of Duggan *et al.*, (2005) and Page *et al.*, (2020). In our findings, mung bean intercropped in cotton, statistically at par with cluster bean, significantly increased soil microbial population compared with solo cotton sowing (Lai *et al.*, 2022). A higher microbial population recorded in leguminous intercropping might be attributed to the greater biomass of legume intercrops (Dhima *et al*., 2007; Rahman *et al*., 2021).

The results of our study concluded that cotton crop yield and yield contributing parameters like plant height, opened bolls per plant, ginning outturn etc. were better under the plots of conventional tillage which might be because of the fact that cotton crop roots may penetrate better and acquire their requirements of water and mineral elements from soil in better way to fulfill the actual need of crop for better production. Also, the findings of another study by Mitchel *et al.*, (2017) were in correspondence with our finding that yield attributes of cotton crop are better in the plots where conventional tillage was practiced in the initial years of study.

The findings of our study showed that attributes of legumes intercrops like plant height and seed yield were higher in the plots where conventional tillage was adopted and same findings were already reported by Nawar *et al.*, (2010). The reason behind this may be that legumes crops may utilize better N from soil under proper beds formed for crop cultivation providing ideal circumstances for a crop to grow and produce enough yield (Ghanbari *et al.*, 2010). Meanwhile some other studies also concluded that

https://doi.org/10.55627/pbulletin.005.01.1657

conventional tillage increases legumes intercrops yield (Bedoussac and Justes, 2010).

CONCLUSION

The results of our trial indicated that seed cotton yield was higher in conventional tillage as the zero-tillage practice takes some time for stable production. However, the soil health results indicated that zero tillage significantly improves the physical, chemical and biological properties of soil in terms of EC, bulk density, soil porosity and NPK contents compared to the plots where conventional tillage was practiced. Likewise, the intercropping of legumes positively interacts with cotton yield and mung bean intercropping in cotton resulted in higher yield of cotton even under the less N dose as the amount of N is compensated from legumes N fixing ability, compared to the sole cotton crop yield. Conclusively zero tillage practice along with mung bean intercropping resulted in sustainable cotton yield and better soil health.

ACKNOWLEDGEMENT

We highly acknowledge Soil & Water Testing Laboratory, Fatima Fertilizer Company Pvt. Ltd. Multan for soil analysis services.

DECLARATION OF INTEREST

All authors declare no conflict of interest regarding the publication of this research paper.

REFERENCES

Abbas, H.G., Mahmood, A. & Ali, Q. (2016). Zero tillage: a potential technology to improve cotton yield. Genetika, 48(2), 761-776.

Adu-Gyamfi, J.J., Myaka, F.A., Sakala, W.D., Odgaard, R., Vesterager, J.M. & Høgh-Jensen, H. (2007). Biological nitrogen fixation and nitrogen and phosphorus budgets in farmer-managed intercrops of maize–pigeonpea in semi-arid southern and eastern Africa. Plant and soil, 295(1), 127-136.

Baritz, R., Wiese, L., Verbeke, I., & Vargas, R. (2017). Voluntary guidelines for sustainable soil management: global action for healthy soils. In International yearbook of soil law and policy 2017 (pp. 17-36). Cham: Springer International Publishing.

Bedoussac, L., & Justes, E. (2010). Dynamic analysis of competition and complementarity for light and N use to understand the yield and the protein content of a durum wheat–winter pea intercrop. Plant and soil, 330(1), 37-54.

Bhatt, R. (2017). Zero tillage impacts on soil environment and properties. Journal of Environmental and Agricultural Sciences, 10, 1-19.

Brussaard, L., De Ruiter, P. C., & Brown, G. G. (2007). Soil biodiversity for agricultural sustainability. Agriculture, ecosystems & environment, 121(3), 233-244.

Busari, M. A., Kukal, S. S., Kaur, A., Bhatt, R., & Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. International soil and water conservation research, 3(2), 119-129.

Dhima, K. V., Lithourgidis, A. S., Vasilakoglou, I. B., & Dordas, C. A. (2007). Competition indices of common vetch and cereal intercrops in two seeding ratio. Field Crops Research, 100(2-3), 249-256.

Dugassa, M. (2023). The role of cereal legume intercropping in soil fertility management: Review. Journal of Agriculture and Aquaculture, 5(1), 4.

Duggan, B. L., Yeates, S. J., & Constable, G. A. (2005). Bed preparation techniques and herbicide tolerance technology for tropical dry season cotton production. Tropical Agriculture, 82(3), 233.

Fustec, J., Lesuffleur, F., Mahieu, S., & Cliquet, J. B. (2010). Nitrogen rhizodeposition of legumes. A review. Agronomy for sustainable development, 30(1), 57-66.

Ganeshamurthy, A. N., Masood Ali, M. A., & Rao, C. S. (2006). Role of pulses in sustaining soil health and crop production. Indian Journal of Fertilisers, 1(12), 29-40.

Ghanbari, A., Dahmardeh, M., Siahsar, B. A., & Ramroudi, M. (2010). Effect of maize (Zea mays L.)-cowpea (Vigna unguiculata L.) intercropping on light distribution, soil temperature and soil moisture in arid environment. Journal of Food, Agriculture and Environment, 8(1), 102-108.

Girma, K., Teal, R., Freeman, K., Boman, R., & Raun, W. (2007). Cotton lint yield and quality as affected by cultivar and long-term applications of N, P, and K fertilizers. In 15th annual 2017 NUE Conference, Baton Rouge, LA (pp. 12-19).

Khan, M. B., & Khaliq, A. (2004). Study of mungbean intercropping in cotton planted with different techniques. Journal of Research (Science), 15(1), 23-31.

Khan, M. B., Akhtar, M., & Khaliq, A. (2001). Effect of planting patterns and different intercropping systems on the productivity of cotton (Gossypium hirsutum L.) under irrigated conditions of Faisalabad. International Journal of Agriculture & Biology, 3(4), 432-435.

Koech, R., & Langat, P. (2018). Improving irrigation water use efficiency: A review of advances, challenges and opportunities in the Australian context. Water, 10(12), 1771.

Lai, H., Gao, F., Su, H., Zheng, P., Li, Y., & Yao, H. (2022). Nitrogen distribution and soil microbial community characteristics in a legume–cereal intercropping system: A review. Agronomy, 12(8), 1900.

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. Sustainability, 7(5), 5875-5895.

Li, Y., Li, Z., Chang, S. X., Cui, S., Jagadamma, S., Zhang, Q., & Cai, Y. (2020). Residue retention promotes soil carbon accumulation in minimum tillage systems: Implications for conservation agriculture. Science of the Total Environment, 740, 140147.

Lilienfein, J., Wilcke, W., Vilela, L., do Carmo Lima, S., Thomas, R., & Zech, W. (2000). Effect of no‐tillage and conventional tillage systems on the chemical composition of soil solid phase and soil solution of Brazilian Savanna Oxisols. Journal of Plant Nutrition and Soil Science, 163(4), 411-419.

Lv, L., Gao, Z., Liao, K., Zhu, Q., & Zhu, J. (2023). Impact of conservation tillage on the distribution of soil nutrients with depth. Soil and Tillage Research, 225, 105527.

Manasa, P., Maitra, S., & Reddy, M. D. (2018). Effect of summer maize-legume intercropping system on growth, productivity and competitive ability of crops. International Journal of Management, Technology and Engineering, 8(12), 2871-2875.

Mathew, R. P., Feng, Y., Githinji, L., Ankumah, R., & Balkcom, K. S. (2012). Impact of no‐tillage and conventional tillage systems on soil microbial communities. Applied and Environmental Soil Science, 2012(1), 548620.

Meena, R. S., Das, A., Yadav, G. S., & Lal, R. (Eds.). (2018). Legumes for soil health and sustainable management (p. 541). Singapore: Springer.

Mitchell, J. P., Shrestha, A., Mathesius, K., Scow, K. M., Southard, R. J., Haney, R. L., ... & Horwath, W. R. (2017). Cover cropping and no-tillage improve soil health in an arid irrigated cropping system in California's San Joaquin Valley, USA. Soil and Tillage Research, 165, 325-335.

Moran, P. J., & Greenberg, S. M. (2008). Winter cover crops and vinegar for early-season weed control in sustainable cotton. Journal of Sustainable Agriculture, 32(3), 483-506.

Moraru, P. I., & Rusu, T. (2012). Effect of tillage systems on soil moisture, soil temperature, soil respiration and production of wheat, maize and soybean crops. Journal of Food, Agriculture and Environment, 10, 445-448.

Nawar, A. I., Al-Fraihat, A. H., Khalil, H. E., & El-Ela, A. M. A. (2010). Response of faba bean to tillage systems different regimes of NPK fertilization and plant interspacing. International Journal of Agriculture and Biology, 12, 606-610.

Page, K. L., Dang, Y. P., & Dalal, R. C. (2020). The ability of conservation agriculture to conserve soil organic carbon and the subsequent impact on soil physical, chemical, and biological properties and yield. Frontiers in sustainable food systems, 4, 31.

Pakistan Economic Survey 2024-25 (2025). Finance Division. Government of Pakistan. Available at: https://www.finance.gov.pk/survey_2025.html

Prabukumar, G., & Uthayakumar, B. (2006). Use of organics for crops for crop production under rainfed situation. Agriculture Rev, 27(3), 208-215.

Rahmati, M., Eskandari, I., Kouselou, M., Feiziasl, V., Mahdavinia, G. R., Aliasgharzad, N., & McKenzie, B. M. (2020). Changes in soil organic carbon fractions and residence time five years after implementing conventional and conservation tillage practices. Soil and Tillage Research, 200, 104632.

Rajpoot, S. K., Rana, D. S., & Choudhary, A. K. (2018). Bt-cotton–vegetable-based intercropping systems as influenced by crop establishment method and planting geometry of Bt-cotton in Indo-Gangetic plains region. Current Science, 115(3), 516-522.

Rusinamhodzi, L., Murwira, H. K., & Nyamangara, J. (2006). Cotton–cowpea intercropping and its N2 fixation capacity improves yield of a subsequent maize crop under Zimbabwean rain-fed conditions. Plant and soil, 287(1), 327-336.

Saleem, M. F., Ghaffar, A., Rahman, M. H. U., Imran, M., Iqbal, R., Soufan, W., ... & El Sabagh, A. (2022). Effect of short-term zero tillage and legume intercrops on soil quality, agronomic and physiological aspects of cotton under arid climate. Land, 11(2), 289.

Saturnino, H. M., Landers, J. N., & Campos, E. (2002). The environment and zero tillage. CEP, 70760, 533.

Srinivasarao, C., Venkateswarlu, B., Lal, R., Singh, A. K., Vittal, K. P. R., Kundu, S., ... & Singh, S. P. (2012). Long-term effects of soil fertility management on carbon sequestration in a rice–lentil cropping system of the indo-gangetic plains. Soil science society of America journal, 76(1), 168-178.

Topa, D., Cara, I. G., & Jităreanu, G. (2021). Long term impact of different tillage systems on carbon pools and stocks, soil bulk density, aggregation and nutrients: A field meta-analysis. Catena, 199, 105102.

https://doi.org/10.55627/pbulletin.005.01.1657

Ur Rahman, M. H., Ahmad, I., Wang, D., Fahad, S., Afzal, M., Ghaffar, A., ... & Nasim, W. (2021). Influence of semi-arid environment on radiation use efficiency and other growth attributes of lentil crop. Environmental Science and Pollution Research, 28(11), 13697-13711.

Usman, K., Khan, N., Khan, M. U., Yazdan Saleem, F., & Rashid, A. (2014). Impact of tillage and nitrogen on cotton yield and quality in a wheat-cotton system, Pakistan. Archives of Agronomy and Soil Science, 60(4), 519-530.

Xu, Q., Xiong, K., Chi, Y., & Song, S. (2021). Effects of crop and grass intercropping on the soil environment in the karst area. Sustainability, 13(10), 5484.

Yang, Y., Wu, J., Zhao, S., Mao, Y., Zhang, J., Pan, X., ... & van der Ploeg, M. (2021). Impact of long-term sub-soiling tillage on soil porosity and soil physical properties in the soil profile. Land Degradation & Development, 32(10), 2892-2905.

https://doi.org/10.55627/pbulletin.005.01.1657