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Managing Tillage Operation and Manure to Restore Soil Carbon Stocks in Wheat–Maize Cropping System

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ABSTRACT

Increasing soil organic matter (SOM) contents improve the resilience of productive soil for future sustainability particularly in poor soil (<1% SOM). This study sought to elucidate how tillage and N fertilizer sources affect soil bulk density, soil organic carbon (SOC) and soil total N (TN) in 0- to 20-cm soil depth. Treatments included minimum till (MT), conventional till (CT), deep till (DT), and twelve N treatments (60 and 120 kg urea N ha^{-1}, 10 and 20 Mg farmyard manure [FYM] ha^{-1}, 10 Mg soybean residue [SR] ha^{-1} and their combinations along with a control). The experiment was designed in randomized complete block design with split plot arrangement. Soil bulk density increased for DT toward the end of the experiment than CT or MT. The sequestration rates of SOC of MT was 22% higher than DT. The FYM retuned more SOC than SR, however SR returned more TN than FYM. Application of FYM as well as SR sequestered more C than urea or control. Conclusively, SOC returned was increased with 10 Mg FYM ha^{-1} along with 30 kg urea N ha^{-1} but TN with 10 Mg SR ha^{-1} in CT plots. This practice can therefore increase soil quality and productivity, and thus is considered a sustainable approach for soils deficient in organic matter.

Core Ideas

- Minimum tillage improved C stock than shallow or deep tillage.
- The addition of urea increased SOC contents in SR plots than FYM.
- C Stocks in FYM and SR fertilized plots was about 3- to 4-fold greater than control.
- Soybean residue build N stock principally in less plowed plots.

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Building soil carbon (C) and nitrogen (N) stocks using soil and crop management practices is a major focus for the agronomist to mitigate atmospheric CO_2 and minimized CO_2 losses (Fahad et al., 2013; Fahad et al., 2014a, 2014b; Fahad et al., 2015a, 2015b; Fahad et al. 2016a, 2016b, 2016c, 2016d; Fahad et al., 2017). Beside the environmental benefits, the increased N storage also improve soil quality (Rahman et al., 2016) and reduce the cost of N fertilization (Khan et al., 2015; Sönmez et al.,2016; Turan et al., 2017; Turan et al., 2018). Soil organic matter (SOM) relies on soil C and N inputs (Sanaullah et al., 2012) and can directly affect the crop production (Khan et al., 2018). Increasing soil organic C (SOC) by 0.35 Mg C ha^{-1} yr^{-1} increased the wheat grain yield by 13.4% (Han et al., 2018), indicating the importance of SOC.

The decreases in SOM in conventional tillage (CT, without crop residue addition) is due to limited external C and N inputs. In contrast, tillage and spreading organic residue on the soil surface, along with N fertilization, increased C and N stocks (Muhammad et al., 2018; Sainju et al., 2006). It is widely reported that conversion to minimum tillage (MT) and addition of organic residue to the soil can sequester more C than CT. Wolff et al. (2018) reported that MT increased SOC by 8.4% in Ap horizon in 7 yr. Similarly, more N storage with MT was documented by Muhammad et al. (2018). Tillage systems have high impact on SOC as well as TN and can interact with organic amendments for improving the soil properties (Khan et al., 2015; Khan et al., 2014; Muhammad et al., 2018). Thus, we

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Abbreviations: CT, conventional till; DT, deep till; FYM, farmyard manure; MT, minimal till; SOC, soil organic carbon; SOM, soil organic matter; SR, soybean residue; TN, total nitrogen.

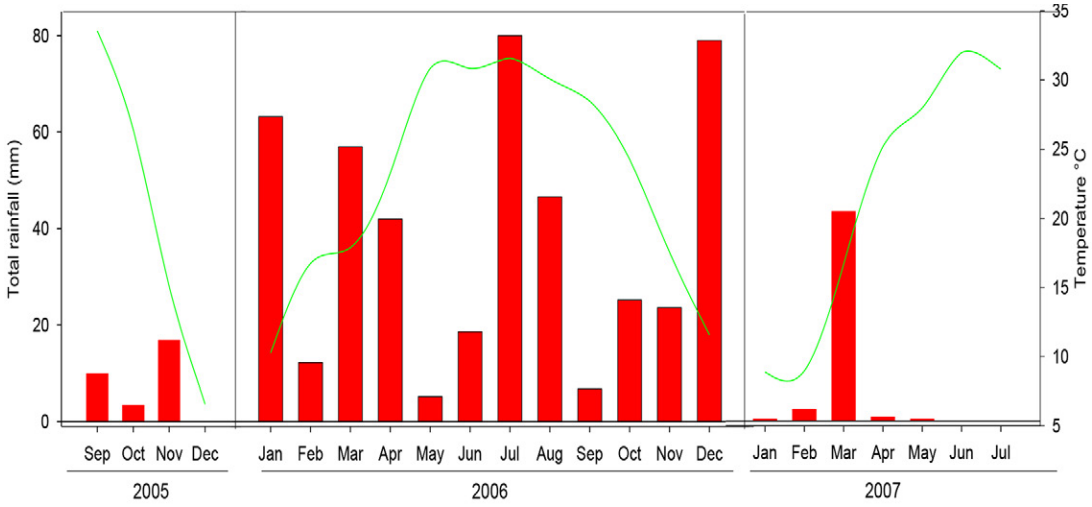


Fig. 1. Total monthly rainfall (mm) and average temperature during the experimental period at the experimental area.

define our first hypothesis that MT will sequester more SOC than CT or DT systems.

Returning organic residue to the soil and N fertilization can increase SOC (Khan et al., 2018) and TN both in tilled and non-tilled systems (Somerville et al., 2018). The small farmers keep their cattle at home and/or farm and thus the available farmyard manure (FYM) from these cattle would be a useful source of readily available nutrients at the farm level (Khan et al., 2017; Muhammad et al., 2018). Due to increasing demand for dairy products, an increase in FYM production is expected. The disposal of FYM in large amounts, damping off or making heaps can lead to serious environmental risks of surface and groundwater contamination (Akhtar et al., 2018a; Ali et al., 2018). On the other hand, FYM application to cropland can increase SOM, which improves soil health and plant productivity (Akhtar et al., 2018b; Khan et al., 2009; Muhammad et al., 2018). Studies have shown that incorporation of FYM increased SOC and TN (Khan et al., 2017; Khan et al., 2018; Khan et al., 2019). Residue or manure application along with N fertilization can increase C and N storage, and improve soil quality and crop production in semiarid areas, where SOM level is less than 1% due to continuous cropping (Abbasi and Butt, 2018; Han et al., 2018; Khan et al., 2015). This led us, to devise our second hypothesis, that the organic source of N fertilizer in combination with urea will increase the C stock than sole organic or synthetic source of N fertilizer.

Limited information is available regarding the interaction of residue and manure management with synthetic N under MT system in SOM deficient areas on soil C and N stocks. Therefore, the objectives of this study were to evaluate the effects of MT, CT and DT as well as mineral N fertilization, FYM and legume residue incorporation on soil bulk density, SOC, and TN stocks in north-western Pakistan and also to quantify their effects on soil C sequestration rates.

MATERIALS AND METHODS

Description of Experimental Site

Field experiments were conducted from September 2005 to May 2007 at the Agricultural Research Farm, University of Agriculture, Peshawar (34°02' N, 71°39' E), in northwest Pakistan. The soil was silty clay loam, well drained and fine textured. Before the initiation of the experiment, soil samples (0–20 cm depth) were collected randomly, composited, and analyzed for physicochemical properties. The soil of the experimental plots in 2005 had an average pH (1:5 H_2O suspension) of 8.2; texture of 17.2% sand, 54.3% silt, 28.5% clay; SOC concentration of 6.59 g kg^{-1}; TN concentration of 0.47 g kg^{-1}; and bulk density of 1.36 g cm^{-3} in 0- to 20-cm depth. Field history shows that before the start of the experiment in 2005, soybean was cropped in the study area and was supplied with single super phosphate (18% P_2O_5) fertilizer at the rate of 80 kg P_2O_5 ha^{-1}. The study site had a wheat–maize–wheat rotation, with occasional legume inclusion during past 5 yr. Rainfall data were collected in the study area (Fig. 1).

Materials and Treatments

Seeds of wheat (*Tricitcum aestivum* L. 'Saleem-2000') and maize (*Zea mays* L. 'Kissan-92') were obtained from Agricultural Research Farm, University of Agriculture, Peshawar. Treatments consisted of factorial combinations of three tillage practices (minimum till [MT], conventional till [CT], and deep till [DT]), and twelve combinations of N fertilizer source and rate (urea, farmyard manure [FYM], soybean residue [SR], along with a control) (Fig. 2). The MT included plowing to a depth of 10 cm with a rotary field cultivator. The CT included field cultivator (tine plow) plowing to a depth of 30 cm. Deep tillage was performed by chisel plowing the soil to 45 cm depth. In both CT and DT, the soil was plowed twice across the field both in horizontal and vertical directions and was followed by rotary field cultivator. After tillage, planking and leveling was done in all plots to break the clods and smooth the field. Both CT and DT tillage operations were performed before FYM and/or SR soil incorporation; however, the rotary field cultivator operation were carried for dual purpose, i.e., for incorporation of FYM and/or SR, as well as a specific tillage operation, e.g., MT. Farmyard manure and SR were obtained from the Agricultural Research Farm and Dairy Farm of the University of Agriculture Peshawar, respectively. The FYM was stored for about three months as an open heap, whereas the soybean crop was harvested in the previous year and was stored at room temperature before soil incorporation. The N and C concentrations were 1.11 and 16.2% (FYM) and 3.12 and 18.7%

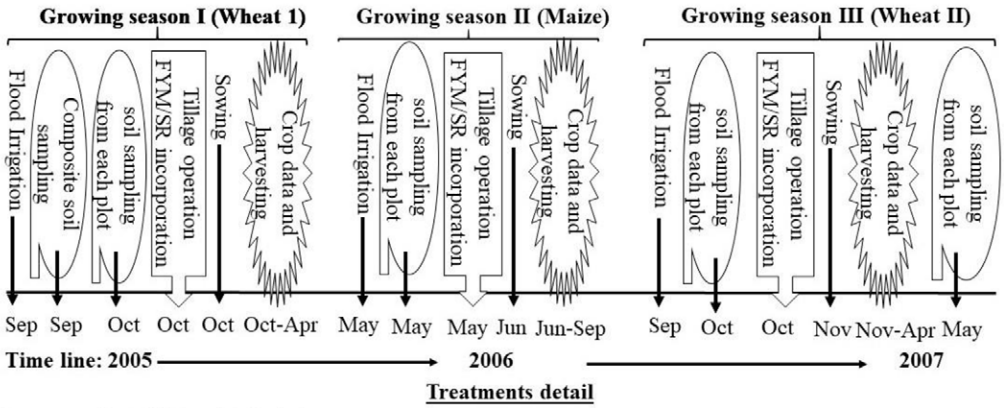


Fig. 2. Detailed pictorial representation of the experimental layout, design and treatment combinations.

(SR), respectively, on a dry-weight basis. The N was determined following kjeldahl procedure (Bremner and Mulvaney, 1982), whereas C was with the method of Nelson and Sommers (1982). Recommended rates of 60 kg P_2O_5 ha^{-1} as single super phosphate (18% P_2O_5) and sulfate of potash (60% K) were supplied at the time of sowing in each season to compensate the effects of P and K of FYM (0.25% P, 0.52% K) and SR (0.6% P, 1.01% K).

Two weeks before the start of experiment in each season, the field was irrigated uniformly by flooded irrigation, and thereafter respective tillage practices were made. The FYM and SR were shallowly incorporated (0–10 cm depth) using rotary field cultivator 45 d before sowing in 2005 for first wheat, 43 d before maize sowing, and 40 d before sowing second wheat in 2006. Urea (46% N) was applied in a split application, half at sowing and the other half after first irrigation both for wheat (25–27 d after sowing) and maize (10 d after sowing). No adverse effects of FYM and SR on germination of wheat and/or maize were detected. Rather, both wheat and maize seedling counts were greater with organic sources of fertilizers than with synthetic sources of fertilizers (Khan et al., 2009; Khan et al., 2008).

The wheat–maize–wheat cropping system consisted of three crops from 2005 to 2007. The first wheat crop was sown on 29 Oct. 2005 at a seed rate of 100 kg ha^{-1}, the second wheat crop on 5 Nov. 2006, and the maize crop on 19 June 2006 between these two wheat crops with the seed rate of 30 kg ha^{-1}. In all cases, a tractor-mounted planter equipped with row cleaner wheels was used. Maize was sown after the first wheat crop, with a consistent tillage and treatments combination in the same plot each used for wheat crop. A detailed pictorial arrangement of the experimental layout and design is provided (Fig. 2). Weeds were controlled mechanically as well as using chemical herbicides (Fenoxapronp) where necessary. In addition to rainfall, a total of eight irrigations were made to the first wheat, seven to second wheat, and six to maize crop as flood irrigation, depending on the plant requirements. All other agronomic and cultural practices were performed uniformly for all plots and for each crop.

Experimental Design

A total of 36 treatments (3 tillage practices, and 12 N-fertilization sources and rates) were arranged as two-factorial randomized complete block design with split-plot design and three replications. Tillage practices were allotted to main plots and N fertilization sources and rates to subplots. The individual subplot size was 3 m by 5 m, having ten rows spaced 30 cm apart for the wheat crop, and four rows 75 cm apart for the maize crop with a row length of 5 m.

Observations and Measurements

An undisturbed soil layer (5 cm by 20 cm) was taken using a soil core (100 cm^3) from each subplot (one per plot) every month from September 2005 to April 2007, for recording the soil bulk density. Care was taken to avoid any compression of the soil. The soil bulk density was calculated by dividing the mass of the oven-dried sample at 105°C by the volume of the soil core.

Soil samples were collected from 0- to 20-cm depth with a hand probe from three randomly selected locations in each subplot and were composited before and after each growing season as detailed in Fig. 2. The composited samples from each plot were air-dried, removed roots and debris, grounded, and sieved to 2 mm for recording the TN and SOC. Total N was determined following kjeldahl procedure (Bremner and Mulvaney, 1982). Soil organic C was determined by the modified method of Nelson and Sommers (1982), assuming 75% organic matter oxidation. The TN and SOC stocks (Mg N or C ha^{-1}) were calculated by multiplying the treatments' SOC and TN concentrations by the bulk density and soil depth, however the SOC sequestration was recorded by dividing the difference of SOC stock during 2005 and 2007 divided by the duration of the experiment.

Statistical Analysis

Data for soil bulk density, TN, and SOC were analyzed according to the procedure of Gomez and Gomez (1984) for split plot design using Genstat statistical software (GenStat, 2005). Both

Table 1. Statistical analysis along with dispersion indices for soil bulk density, soil organic carbon (SOC) and total nitrogen (TN) concertation and stocks during 2005 and 2007.

Source of variation	Bulk density	Concentration		Stock	
		TN	SOC	TN	SOC
Sampling date (D)	**	**	**	**	**
Tillage operations (T)	**	**	**	**	**
D x T	NS†	**	**	*	**
Fertilizer (F)	**	*	**	*	*
D x F	NS	**	**	*	*
T x F	NS	**	**	*	**
D x T x F	NS	NS	NS	NS	NS
Dispersion indices (%)					
D	4.82	3.87	3.92	5.12	4.29
T	7.62	3.87	4.30	7.38	5.13
F	6.38	6.71	8.96	8.34	9.33

* Significant at $p \leq 0.05$.
** Significant at $p \leq 0.05$.
† NS, Not significant.

tillage and N fertilization sources and rates were taken as main factors and fixed effects, seasons as the repetitive measured factor and also a fixed effect, similarly, all the interaction were taken as fixed effects except treatment × replication interaction which was taken as random effect. When this procedure indicated significant effects, least significance difference tests (LSD) at $p \leq 0.05$ were used to separate means. Least significant difference values are shown in the tables for comparing treatments, where significant differences in mean values are also represented by different letters.

RESULTS

Soil Bulk Density

The bulk density was not different across the tillage or treatments during initial phase of the study. However, over the course of the experimental duration, differences in soil bulk density became apparent (Table 1), both among the tillage practices and N fertilization sources (Fig. 3). Soil bulk density was similar for CT and MT but was lower than DT toward the end of the experiment. MT and CT showed a decreasing trend for soil bulk density with the passage of time, opposite to that of DT (Fig. 3a). No difference for soil bulk density was observed in plots receiving 60 or 120 kg N ha^{-1} (Fig. 3b). Minimum plowing caused less soil compaction and therefore lowered the soil bulk density when compared to control plot. Applications of FYM (Fig. 3c) and SR (Fig. 3d), exclusively or combined with urea, lowered the soil bulk density across the growth period compared to urea application alone.

Soil Organic Carbon

The SOC concentration varied between the N treatments after the first phase of experiment and continued toward the end of the experiment (Table 1). The SOC concentration was greater in treatments T4, T5, T6, and T12 (Table 2) suggesting FYM and SR inclusion had increased SOC concentration than urea application of 60 (T2) or 120 (T3) kg N ha^{-1}. The sizeable C input from FYM and SR had increased the SOC concentrations when compared to urea or control plots. However, the combined FYM/SR with urea had lowered SOC than sole FYM/SR.

Tillage and N fertilization interaction was significant for SOC concentration (Table 1; Fig. 4). In MT plots, the inclusion of FYM and SR with urea had increased the SOC concentration over the sole use of either source, i.e., FYM or SR (Fig. 4). It was further observed that sole FYM had increased the SOC concentrations in MT plots, however FYM plus urea-N in CT plots. Increasing the rate of FYM from 10 to 20 Mg ha^{-1} had positive effects on SOC concentration, but urea increases have no significant effects on SOC across any tillage system.

Soil Organic Carbon Stocks and Sequestration Rrate

The inherited SOC stock before sowing of the first wheat in 2005 was 8.9 Mg C ha^{-1}. The changes in SOC from 2005 to 2007 as influenced by tillage and N fertilizer sources (Table 1) were in the range of –2.98 (control) to 1.78 Mg C ha^{-1} (10 Mg SR + 30 kg N ha^{-1}) as shown in Table 3. These variation in SOC contents had resulted in estimated C sequestration rates of –0.72 to 0.56 Mg C ha^{-1} yr^{-1}, assuming that C sequestration was linear from 2005 to 2007. The carbon sequestration rate was twofold higher in MT than CT, while CT was higher than DT (Table 3) between 2005 and 2007. Since all the tillage system has received the same combination of fertilizers, but due to greater residue return via plant roots, the MT plots had higher SOC content and thus had higher C sequestration rate than other tillage practices. Similarly, organic sources of fertilizer produced 3- to 4-fold positive and greater SOC sequestration rates than urea and control plots. Addition of 10 Mg SR ha^{-1} $session^{-1}$ supplied 1.87 Mg C ha^{-1} $season^{-1}$ (18.7% C concentration of SR), against 10 Mg FYM ha^{-1}, which contributed 1.62 Mg C ha^{-1} (16.2% C concentration of FYM) but had almost doubled the C sequestration rate (Table 3). Similarly, the addition of high amount of FYM had increased the sequestration rate of C. It was further observed that the addition of 30 kg N ha^{-1} as urea had increased sequestration rate of C principally in 10 Mg FYM or 10 Mg SR ha^{-1} but have either decreased or have no effects when coupled with 20 Mg FYM ha^{-1}. In contrast, the addition of 60 kg N ha^{-1} as urea had decreased the C sequestration rate. This indicated that C sequestration rate was increased with 30 kg ha^{-1} urea-N but decreased with 60 kg ha^{-1} urea-N when combined with FYM or SR. Generally, the C sequestration rate for SR was higher than FYM. Balancing the original C contents, it was observed that the sequestration rate of fertilized treatments was 3- to 4-fold greater than control. Thus, MT and organic N fertilization increased C sequestration more than DT and urea application.

Soil Nitrogen Concentration and Stocks

Increasing plowing depth decreased the soil TN concentration and storage. Addition of FYM or SR, either alone or mixed with urea, led to significantly higher TN concentration than control and urea treatments (Table 1). No differences in TN concentration were observed in plots received urea N or control (Table 2). Between the organic sources, SR had higher TN concentration than FYM, whether applied alone or in combination with urea N. Increasing the FYM application rate from 10 to 20 Mg ha^{-1} had no significant effects on soil TN storage. The organic sources contain an appreciable amount of N and thus increased the TN concentration of plots receiving FYM or SR exclusively or mixed with urea N. Soybean residue and FYM contained 31.2 and 10.6 g N kg^{-1}, respectively, thus the addition of such sizeable amount of N had increased the TN of the soil.

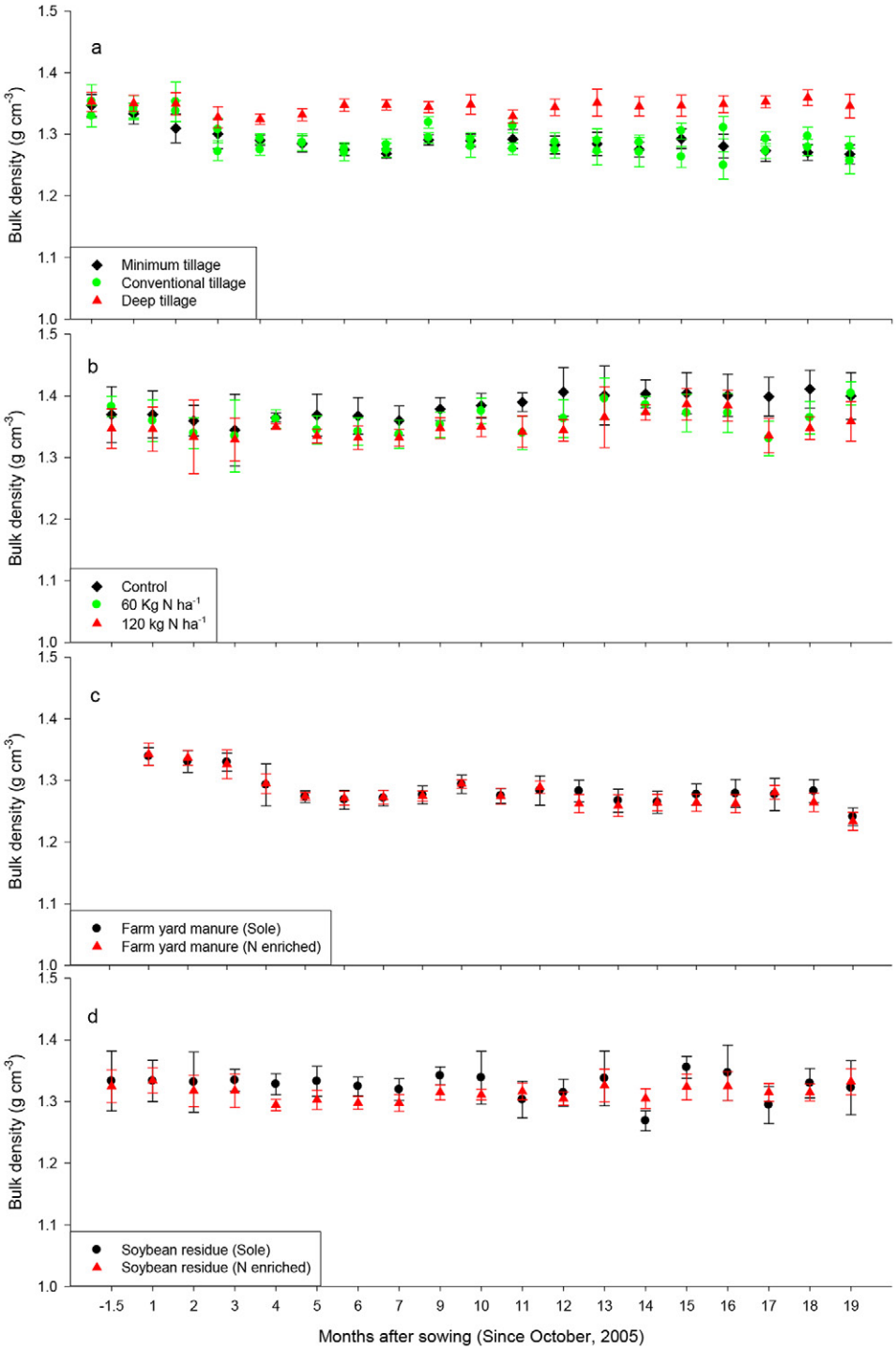


Fig. 3. Soil bulk density (g cm^{-3}) of plots subjected to a) Tillage practices, b) Fertilizer nitrogen, c) Farmyard manure and d) Soybean residue. Vertical bars show standard errors of the means.

Significant differences in fertilizer source/rate × tillage interaction for TN concentration (Table 1) revealed that TN concentration was greater in MT with SR than MT with FYM/urea (Fig. 5). Similarly, in CT the SR incorporated plots had higher TN concentration than FYM or urea. Increasing FYM doses increased the TN concentration in MT plots, but decreased in CT plots. However, when augmented with urea, the increased of FYM from 10 to 20 Mg ha^{-1} had no effects on TN concentration across all the tillage practices.

Soil total nitrogen (TN) stocks increased from 0.24 Mg N ha^{-1} (2005) to 0.52 Mg N ha^{-1} (2007) over the experimental period (Table 1, 4). Changes in TN stocks were more obvious for MT than CT or DT (Table 4). The total TN contents difference across the experimental duration ranged from 0.04 (control) to 0.68 Mg N ha^{-1} (10 Mg SR + 60 kg N ha^{-1}). TN stocks for FYM was double and for SR was 4-fold higher relative to urea and control treatments.

DISCUSSION

Tillage is the practice of working the soil with implements to provide suitable condition to raise crops. It is performed for a number of reasons included provision of suitable soil tilth for

Table 2. Response of soil total N (TN) and soil organic C (SOC) to tillage operations and nitrogen fertilization growing seasons.

Treatment†	TN concentration				SOC concentration			
	Sept. 5	May 6	Oct. 6	May 7	Sept. 5	May 6	Oct. 6	May 7
	g kg^{-1}							
Minimum tillage	0.47	0.68 a‡	0.87 a	1.09 a	6.69	5.12 a	6.48 a	7.58 a
Conventional tillage	0.48	0.66 b	0.84 b	1.05 b	6.64	4.80 ab	6.11 b	7.13 a
Deep tillage	0.47	0.59 c	0.74 c	0.91 c	6.51	4.39 b	5.39 c	6.50 b
$LSD_{0.05}$	NS§	0.01	0.021	0.021	NS	0.59	0.40	0.17
T1 Control	0.47	0.47 e	0.54 g	0.60 h	6.20	3.74 d	4.04 d	4.28 d
T2 UN-60	0.47	0.50 e	0.58 g	0.65 gh	6.19	5.34 d	4.89 d	4.68 d
T3 UN-120	0.47	0.50 e	0.58 g	0.68 g	6.21	3.82 d	4.42 d	4.66 d
T4 FYM-10	0.47	0.60 d	0.74 f	0.91 g	7.00	5.45 abc	6.94 abc	8.05 abc
T5 FYM-20	0.47	0.62 d	0.76 ef	0.94 ef	6.93	5.63 ab	7.08 ab	8.48 ab
T6 FYM-10 + UN-30	0.47	0.60 d	0.76 ef	0.94 ef	7.02	5.91 a	7.46 a	8.87 a
T7 FYM-10 + UN-60	0.48	0.62 cd	0.79 de	0.98 de	6.70	4.86 c	6.13 c	7.31 c
T8 FYM-20 + UN-30	0.48	0.66 bc	0.83 cd	1.03 cd	6.68	5.14 bc	6.61 bc	7.76 bc
T9 FYM-20 + UN-60	0.47	0.67 b	0.86 c	1.08 c	6.58	5.00 bc	6.44 bc	7.67 bc
T10 SR-10	0.47	0.82 a	1.08 b	1.42 b	6.52	4.89 c	6.57 bc	7.73 bc
T11 SR-10 + UN-30	0.47	0.82 a	1.10 ab	1.46 ab	6.50	5.23 bc	6.66 abc	7.97 abc
T12 SR-10 + UN-60	0.48	0.84 a	1.13 a	1.49 a	6.84	5.25 abc	6.72 abc	8.02 abc
$LSD_{0.05}$	NS	0.052	0.052	0.052	NS	0.89	0.94	0.96

† UN, urea nitrogen; FYM, farmyard manure; SR, soybean residue; 30, 60 or 120 represents kg N ha^{-1} mineral fertilizer; and 10 or 20 represents Mg ha^{-1} combined FYM/SR added.

‡ Lowercase letters indicate differences at $p \leq 0.05$.

§ NS, not significant at $p \leq 0.05$.

the plants, to control soil moisture, aeration, temperature, to destroy weeds and/or pests, and to incorporate manure into the soil (Khan et al., 2008; Wolff et al., 2018). However, tillage has become a controversial practice over the last few decades. For example, better plant growth/performance and improved soil physicochemical properties were achieved with DT (Patil and Sheelavantar, 2006; Somerville et al., 2018) or CT (Yagioka et al., 2015) or MT (Muhammad et al., 2018; Wolff et al., 2018). Beside tillage operations, fertilization is considered as one of major agronomic practices in the farming system of the studied areas. Majority of the farming community uses commercial fertilizers for crop productivity due to impaired nutritional status of the soil. This continuous synthetic fertilization had further decreased the organic matter contents of the soil and rendered the soil as non-sustainable. Beside commercial fertilization, the other various fertilization approaches (i.e., the use of manure, crop residue, on-farm compost or commercial compost) can be used both as sole source or combined with synthetic fertilizers for sustainable production in the study area (Ibrahim and Khan, 2017; Khan et al., 2017). In this article we are addressing one of the approach i.e., integrated use of nutrients effects on soil bulk density, C and N stocks and allied C sequestration in a very poor soil in the north-western Pakistan.

Soil Bulk Density

The soil bulk density decreased with decreasing the depth of tillage operations. It suggested that MT had lower soil bulk density than DT. This improvement in BD with less disturbed soil could be based on two mechanisms, first the enhancement of microbial activities and second due to improvement in microbial biomass. The overall improvement of microbial activity had improved the soil porosity and aggregate stability. It is well documented that less plowed plots had improved aggregate stability and particle size (Shahbaz et al., 2017), soil macro-pores and SOC (Zuber et al., 2015), and soil microbial mobility (Mangalassery et al., 2015) which could account for lower soil bulk density in MT than DT. Zuber et al. (2015) also documented improvement in soil bulk density in less disturbed soil. Minimum plowing causes less soil compaction and therefore lower the soil bulk density. On the other hand, continuous deep plowing resulted in soil compaction (Gangwar et al., 2006) and thus increased the soil bulk density. The addition of FYM either alone or combined with N resulted in lower bulk density than SR or control plots. This lowering of bulk density due to FYM addition is due to the low bulk density of FYM (0.41 g cm^3) than soil (1.36 g cm^2), and thus on mixing a sizeable amount of FYM (10 or 20 Mg ha^{-1}) might have decreased the soil bulk density. The interaction of soil particles with the FYM, which improve the microbial activities (Cai et al., 2016), or soil porosity in FYM incorporated plots (Rusinamhodzi et al., 2013) might be another reason for lowered bulk density in the MT plot over DT. These results further indicated that soil bulk density decreased with easily decomposable sources of organic fertilizer than soybean residue. The easily decomposable source might have acted as readily available source of energy for microorganism, and thus might have increased the microbial activity and hence porosity (Yang et al., 2017), and thus ultimately decreased the soil bulk density.

Soil Carbon Dynamics

The SOC concentration was greater in MT than DT over the whole studies. Increases in C concentration is only possible with addition of external input (Akhtar et al., 2018a) or improving soil microbial activity (Cai et al., 2016). In MT plots, the higher C concentration might be related to greater amount of crop's roots in the surface layer of MT in the semiarid region (Guan et al., 2015) which might have contributed a substantial amount of C in top 0- to 20-cm soil depth. The FYM/SR had showed increasing trend for C concentration over the experimental

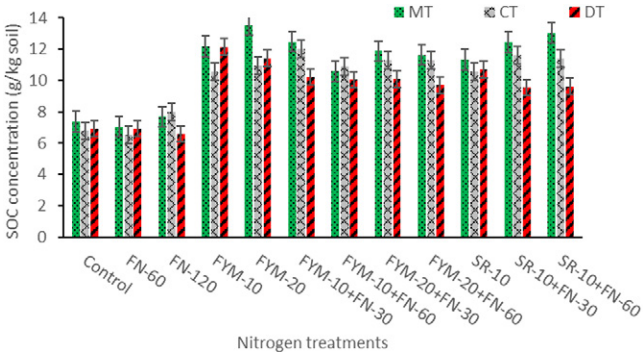


Fig. 4. Soil organic carbon (SOC) concentration (g/kg) as affected by nitrogen treatments and tillage practices averaged over all sampling intervals. Vertical bars show standard errors of mean.

period unlike control or mineral fertilizer application. The addition of synthetic fertilizer to the FYM/SR acted as energy source for microbes and thus enhanced the decomposition via stimulating the microbial activities and thus had released more SOC as CO_2 (Mganga and Kuzyakov, 2014; Serrano-Silva et al., 2011). The reduced plant residue returned to the soil by plant or from external supply had reduced the SOC concentration in plots with urea/control across the tillage practices (Guan et al., 2015; Khan et al., 2015). The increased SOC with organic N fertilization confirm the findings of earlier researcher like Dolan et al. (2006). The application of 20 Mg FYM ha^{-1} can supply a total of 3.24 Mg C ha^{-1} yr^{-1}. Hence, a part of C supplied from FYM was likely converted into SOC (Akhtar et al., 2018a). Our results support the findings of earlier researchers (Dolan et al., 2006) who founded greater SOC concentration with manure addition.

Of course, an increase in C stock of 0.12 to 1.12 Mg ha^{-1} for 2 yr either with mixed or sole use of FYM/SR has not been documented. However, in semiarid regions, having very poor soil (<1% organic matter), such results are not astonishing. In C deficient soil in Xuzhou, China, it has been reported that the above ground C biomass was increased (Zhang et al., 2010), such increases in C biomass could perhaps be related to increases soil TN and subsequently greater low molecular weight substance in the rhizosphere due to increased external supplies of organic sources. In our finding the C inputs from external sources, i.e., FYM/SR was greater than C losses (which occurred possibly by decomposition), and thus had increased the C stock. The sizeable C input through manure or residue had resulted in greater C sequestration. The C sequestration is a homeostasis of SOC decomposition and C inputs. It was further observed that C sequestration was greater with SR than FYM. As, the microbes can easily decompose a labile material than recalcitrant (Mganga and Kuzyakov, 2014). Therefore, the labile manure was assumed to be easily degraded by microorganism as compared to recalcitrant soybean residue. This relative decomposition was also based on stoichiometry of the both sources rather than simple CN ratios. Though, the narrow CN ratio of the SR did not enhance the mineralization. However, the greater phosphorous and other nutrients might have made the manure more labile than SR. This supposition was further proved, when synesthetic fertilizer was added, which caused greater C sequestration rate in SR plots than FYM incorporated plots. This mean that in addition to stoichiometry, the CN ratio also played a vital role (Kuzyakov et al., 2007). It was advent

Table 3. Changes in soil organic carbon (SOC) stock in 0- to 20-cm depth over three growing seasons in response to tillage and N sources.

Treatment†	SOC stock		Change	Sequestration rate
	Sept. 2005	May 2007		
	—— Mg ha^{-1} ——		Mg SOC ha^{-1}	Mg SOC ha^{-1} yr^{-1}
Minimum tillage	9.015	9.603	0.59	0.35
Conventional tillage	8.865	9.120	0.26	0.15
Deep tillage	8.806	8.748	–0.06	–0.04
$LSD_{0.05}$	NS‡	NS		
T1 Control	8.505	5.989 e§	–2.52	–1.51
T2 UN-60	8.555	6.570 e	–1.98	–1.19
T3 UN-120	8.363	6.329 e	–2.03	–1.22
T4 FYM-10	9.463	10.146 a–d	0.68	0.41
T5 FYM-20	9.183	10.355 a–d	1.17	0.70
T6 FYM-10 + UN-30	9.397	10.983 a	1.59	0.95
T7 FYM-10 + UN-60	8.926	9.118 d	0.19	0.12
T8 FYM-20 + UN-30	9.024	9.539 b–d	0.52	0.31
T9 FYM-20 + UN-60	8.885	9.352 cd	0.47	0.28
T10 SR-10	8.694	10.218 a–d	1.52	0.91
T11 SR-10 + UN-30	8.616	10.484 a–c	1.87	1.12
T12 SR-10 + UN-60	9.066	10.815 ab	1.75	1.05
$LSD_{0.05}$	NS	1.59	–	–

† UN, urea nitrogen; FYM, farmyard manure; SR, soybean residue; 30, 60 or 120 represents kg N ha−1 mineral fertilizer; and 10 or 20 represents Mg ha^{-1} combined FYM/SR added.

‡ NS, not significant at $p \leq 0.05$.

§ Lowercase letters indicate differences at $p \leq 0.05$.

from these studies, that min-N addition to these sources had increased the microbial activities, and hence increased the CO_2 efflux, and thereby increased the C sequestration. In current studies in 0- to 20-cm soil depth, an addition of 10 Mg ha^{-1} soybean residue sequestered 0.91 Mg C ha^{-1} y^{-1}, which can be increased to 1.12 Mg C ha^{-1} y^{-1} (with +30 kg urea N ha^{-1}) or 1.05 Mg C ha^{-1} y^{-1} (with + 60 kg urea N ha^{-1}) along with additional benefits of wheat grain yield (Khan et al., 2015). So, it was assured from this current studies that in C deficient soil, the SR has greater potential for C sequestration than manure.

Soil Nitrogen Concentration and Stocks

The TN concentration of soil were in the order of MT > CT > DT at the end of the experiment. The potentials for soil erosion and N leaching reduced by conservation tillage (Sainju et al., 2006) indirectly decrease losses of N due to runoff or erosion in MT plots, which might have increased the TN relative to the other tillage practices. Furthermore, higher return of root residue and exudates in shallow rhizosphere soil might have also contributed to higher TN in MT than CT or DT. The higher the plant available nitrogen in the soil, the lesser would be the mineralization from the soil total N (Moscatelli et al., 2008), and this might have more TN in MT than CT. The TN stocks for FYM was double and for SR was 4-fold higher relative to urea and/or control treatments. This suggests that N supplied by urea was either taken up by crops (Khan et al., 2019) or lost through leaching or volatilization (Shahbaz et al., 2017) in contrast to organic sources. The enough organic material supplied via FYM and SR might have increased the soil TN stock. The addition of sizable amount of FYM and SR had increased the TN as a result of direct addition from external sources. Beside

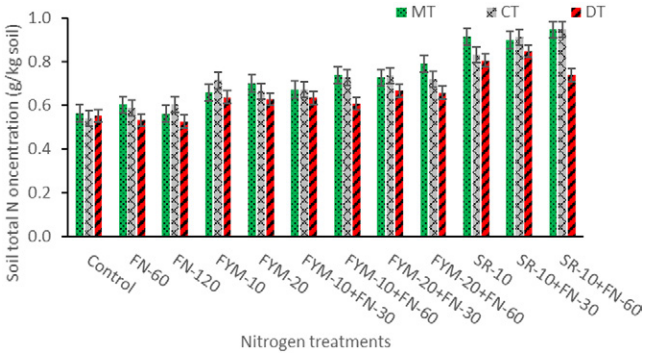


Fig. 5. Total nitrogen concentration (g/kg) of soil as affected by nitrogen treatments and tillage practices averaged over all sampling intervals. Vertical bars show standard errors of mean.

these direct additions of TN from these sources, it is widely documented that such management practices also improve both soil physical and biological properties, and hence improve the plant productivity. Such improvement in plant productivity improved plants roots (Khan et al., 2019) and thus the greater root number and size had more contribution to the total nitrogen.

CONCLUSIONS

The MT had improved soil bulk density, SOC and TN than CT or DT. The manure and SR inputs increased SOC and TN since 2005 to 2007. Carbon stock was increased with SR and decreased with FYM when synthetic fertilizers was added. This hold true for greater decomposition of SOC in FYM than SR and caused greater C sequestration with SR than FYM. The sequestration rate of SOC was 3–4 time with FYM and SR than control. Increasing the synthetic N fertilization from 30 to 60 kg N ha^{-1} added to FYM had increased the sequestration of SOC, suggesting a decreased in CN ratio and enhanced decomposition. The integration of urea with SR had built more N stock than the sole inorganic sources principally in MT plots. Thus, the organic matter deficiency can be restored with addition of SR along with low quantity of urea nitrogen particularly in minimum plowed plots.

Table 4. Effects of tillage and N sources on soil total nitrogen (TN) stocks over three growing seasons in cereal based cropping system.

Treatment†	TN stock				Change
	Sept. 2005		May 2007		
	Mg ha^{-1}				g TN ha^{-1}
Minimum tillage	0.26		0.59	a‡	0.34
Conventional tillage	0.25		0.55	a	0.30
Deep tillage	0.21		0.41	b	0.20
$LSD_{0.05}$	NS§		0.041		
T1 Control	0.14	de	0.18	e	0.04
T2 UN-60	0.15	de	0.21	e	0.06
T3 UN-120	0.16	e	0.23	e	0.07
T4 FYM-10	0.21	cd	0.41	cd	0.20
T5 FYM-20	0.22	bc	0.44	d	0.22
T6 FYM-10 + UN-30	0.22	cde	0.44	d	0.22
T7 FYM-10 + UN-60	0.24	cd	0.48	cd	0.25
T8 FYM-20 + UN-30	0.25	ab	0.53	c	0.28
T9 FYM-20 + UN-60	0.25	ab	0.58	c	0.33
T10 SR-10	0.31	a	0.94	b	0.63
T11 SR-10 + UN-30	0.31	a	0.96	ab	0.65
T12 SR-10 + UN-60	0.32	a	1.00	a	0.68
$LSD_{0.05}$	0.021		0.12		

† UN, urea nitrogen; FYM, farmyard manure; SR, soybean residue; 30, 60 or 120 represents kg N ha^{-1} mineral fertilizer; and 10 or 20 represents Mg ha^{-1} combined FYM/SR added.

‡ Lowercase letters indicate differences at $p \leq 0.05$.

§ NS, not significant at $p \leq 0.05$.

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DECLARATION OF INTEREST

The authors declare no conflict of interest.

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