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Conservation agriculture and its impact on soil quality and wheat yield: A Western Uttar Pradesh perspective

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Abstract
Conservation tillage and nitrogen may improve soil fertility, yield on sustainable basis. The aim of this study was to evaluate the impact of three tillage systems viz. zero (ZT), reduced (RT), and conventional tillage (CT) with or without residue retention/incorporation and five N rates (0, 80, 120, 160, and 200 kg·N·ha^{-1}) on yield and soil health i.e. soil organic matter (SOC), particulate organic carbon and labile carbon fraction of wheat (*Triticum aestivum* L.). Nitrogen rates significantly affected yield and soil quality with highest values recorded at 200 kg·N·ha^{-1}. Mean maximum grain yield (46.13 and 47.18 q ha^{-1}) could be achieved at 160 kg·N·ha^{-1}. The use of ZT with residue retention and RT with residue retention for two crop cycle increased soil organic carbon by 54.68% and 54.22% more than that of conventional tillage (CT), respectively. The SOC, POC and LFC were highest in ZT compared to other tillage systems. Though tillage × N interactions were not significant for most of the parameters under study, the overall effect of ZT with 160 kg·N·ha^{-1} appeared to be most favorable compared to RT and CT. The results suggest that ZT with 160 kg·N·ha^{-1} was optimum and sustainable strategy to achieve higher yield and also to improve SOC and LFC on sandy loam soil of western Uttar Pradesh.

Keywords: Conservation agriculture, nutritional security, productivity, soil health

1. Introduction

Land quality and land degradation affect agricultural productivity, but quantifying these relationships has been difficult (Wiebe 2003) [31]. However, it is clear that the necessary increase in food production will have to come from increase in productivity of the existing land rather than agricultural expansion and the restoration of degraded soils and improvement in soil quality will be extremely important to achieve this goal. The effects of soil degradation or regeneration, and therefore increased or reduced soil quality, on agricultural productivity will vary with the type of soil, cropping system and initial soil conditions, and may not be linear (Scherr 1999) [27]. Wheat is one of the prehistoric crops which provides major energy requirement of the human diet across the world. Recent past has witnessed increased demand of wheat due to availability of wide range of end products at lower prices over other cereal crops.

According to FAO estimate, world would require around 840 million tonnes of wheat by 2050 from its current production level of 642 million tons. This demand excludes the requirement of animal feed and adverse impacts of climate change on wheat production. To meet this demand, developing countries should increase their wheat production by 77 percent and more than 80 percent of demand should come
from vertical expansion (FAO 2009) [7]. The production target is not very high, however, it has to be achieved when productivity growth in wheat is either stagnating or has slowed down across the globe. Besides, there is an urgent need for enhancing productivity through agronomic (water, nutrients, weed management etc.), genetic and physiological interventions along with resource conservation technologies. To cope with emerging challenges of natural resource degradation, escalating input costs and declining farm profits while improving the productivity, the new agronomic management practices based on the elements of conservation agriculture and precision farming have shown promise under different production systems in diverse ecologies and farming situations.

Conservation agriculture (CA) is recommended as a practice for sustainable crop production that simultaneously preserves soil and water resources (Hobbs, 2007 and Hobbs *et al*, 2008) [13, 14]. The positive effects of CA on soil and water conservation, environmental health, and economic viability, it has been regarded as an environment-friendly technology and has been applied worldwide (Gupta and Sayre, 2007; Thomas *et al*., 2007 and Lahmar 2010) [11, 29, 19]. However, given the increasingly serious situation of food security worldwide, concerns are arising about the impacts of CA practices on crop yield, especially in the western Uttar Pradesh (Gupta and Sayre, 2007) [11]. The effects of CA on crop yield can be variable (Farooq *et al*., 2011) [8]. For example, CA may increase crop yield through improving soil fertility by conserving soil and water and sequestering organic carbon in farmland soils Holland 2004 [12]. Govaerts *et al*., 2007 [10] Liu *et al*., 2010 [20] and Naresh *et al*., 2015 [21, 22]. On the other hand, CA may also have detrimental impacts on crop yield by altering soil physiochemical and biological conditions, such as decreasing soil temperatures in areas of high latitude and seasons with low temperature, and aggravating weed and disease incidence (Boomsma *et al*., 2010; Kaschuk *et al*., 2010; Deubel *et al*., 2011 and Naresh *et al*., 2016) [3, 16, 6, 23,]. The realistic effects of CA on crop yield may depend largely on specific CA practices, regional climate characteristics, and cropping systems Hobbs *et al*., 2008; [14] Giller *et al*., 2009 [9]; Putte *et al*., 2010 [24] and Naresh *et al*., 2016 [23]. In the present study, an experiment was conducted to compare tillage, nitrogen and residue effects on soil quality and wheat yield in light textured soil of western Uttar Pradesh.

2. Materials and Methods

2.1 Experimental site

The field experiment was established in 2014 at Sardar Vallabhbhai Patel University of Agriculture &Technology, Meerut research farm (29^0 04', N latitude and77^0 42' 'E longitude a height of 237m above mean sea level) U.P., India. The region has a semi-arid sub-tropical climate with an average annual temperature of 16.8^0C. The highest mean monthly temperature (38.9 ^{0}C) is recorded in May, and the lowest mean monthly temperature (4.5^0C) is recorded in January. The average annual rainfall is about 665 to 726 mm (constituting 44% of pan evaporation) of which about 80% is received during the monsoon period. The predominant soil at the experimental site is classified as Typic Ustochrept. Soil samples for 0–20 cm depth at the site were collected and tested prior to applying treatments and the basic properties were non-saline (EC 0.42 dS m^{-1}) but mild alkaline in reaction (pH 7.98). The soil initially had 4.1 g kg^{-1} of SOC and 1.29 g kg^{-1} of total N (TN), 1.23 g kg^{-1} of total phosphorus, 17.63 g kg^{-1} of total potassium, 224 mg kg^{-1} of available N, 4.0 mg kg^{-1} of available phosphorus, and 97 mg kg^{-1} of available potassium.

2.2 Experimental design and management

A detailed description of different tillage systems is necessary to compare the influence of tillage practices on environmental performance.Six tillage crop establishment methods T_1- ZTR; T_2-, ZTWR; T_3- RTR; T_4- RTWR, T_5- CTR; T_6- Conventional tillage (CT) in main plots and five nitrogen management practices were F_0-Control; F_1- 80 kg Nha^{-1}; F_2-120 kg Nha^{-1}; F_3-160 kg Nha^{-1}*;* F_5-200 kg Nha^{-1} allotted to sub-plots in a split-plot design and replicated thrice. The gross and net plot sizes were 10 m×2.8 m and 8.0 m×2.1 m, respectively and treatments were superimposed in the same plot every year to study the cumulative effect of treatments.

2.3 Soil sampling and processing

Soil samples from each replicated plot were collected randomly from three spots with the help of a core sampler (10 cm internal diameter and 15 cm height) after the harvest of wheat crop in the year 2015 & 16. The soil cores were collected from 0 to 15, 15 to 30, 30 to 45 and 45 to 60 cm soil depth. One composite sample representing each replication was prepared by mixing two cores of respective soil depth. Immediately after collection, the soil samples were brought to the laboratory and stored in a refrigerator for measurement of microbial biomass carbon (MBC). A subset of soil samples was air dried and passed through a 2 mm sieve for determination of pH, SOC and particulate organic carbon (POC).

2.4 Soil organic carbon

Soil organic carbon was determined by wet digestion with potassium dichromate along with 3:2 H_2SO_4: 85% H_3PO_4 digestion mixture in a digestion block set at 120°C for 2h (Snyder and Trofymow, 1984).A pre-treatment with 3 ml of 1 NHCl g^{-1} of soil was used for removal of carbonate and bicarbonate. By using the bulk density value the SOC for each soil layer was calculated and expressed as Mg ha^{-1}.

2.5 Particulate organic carbon

For the POM fraction, 50 g of air-dried soil sample was submerged in deionized water for 30 min to promote slaking of aggregates. Then, the mixture was poured onto a 250-µm sieve inside a cylinder and reciprocally shaken at 120rpm with 50glass beads of 10-mm diameter. The micro-aggregates that passed through the 250-µm sieve were collected in a bottom sieve of 25-µm. The fraction retained on the 250-µm sieve consisted of coarse material (POM and sand from 250 to 2,000-µm) and was labeled as coarse POM. The aggregates retained on the 25-µm sieve (having size from 25 to 250-lm) were dispersed by shaking for 18 h with 25 ml of 0.5g ml^{-1} sodium hexametaphosphate and 12 glass beads of 4-mm diameter in a 50-ml centrifuge tube to isolate the fine POM (Cambardella and Elliott 1992) [4].

2.6 Light Fraction Organic C and N

PMN in soil was determined by the method described by Keeney (1982) [17], where 10 g air-dry soil was taken in a test tube with distilled water (1:2) and incubated for 7 days under waterlogged conditions at 40 °C. The mineralized NH_4^+ N was determined by the Kjeldahl's distillation method. The amount of PMN (mg NH_4^+ N kg^{-1} d^{-1}) was determined by subtracting the concentration of NH_4^+ N at the beginning of incubation.

2.7 Statistical Analysis

Statistical analysis of data of various soil health parameters was carried out by ANOVA in split-split plot design Cochran and Cox, (1950) [5]. The effects of different treatments were evaluated using the least significant difference (LSD) test at the 0.05 level of probability. The data presented in figures are means ± standard deviation (SD) of three replications.

3. Results and Discussion

3.1 Yield and yield attributes

The grain, straw and biological yield was slightly higher in 2015-16 than 2014-15 was may be because of comparatively better weather conditions like rainfall, temperature and sunshine hours prevailed during the crop season (Fig.1a & b). The significant increase in grain, straw and biological yield increased with tillage practices. Zero till with residue retention fulfilled the timely crop water requirement, which resulted into better growth in term of dry matter accumulation. The higher growth finally resulted into significant increase in grain yield through yield attributes namely number of effective tillers, number of grains per spike and test weight. Zero till residue retention increased the grain yield of wheat by about 12.5 and 19.4% during 2014-15 and 14.2 and 22.6% during 2015-16, respectively (Fig1b). This increase was because of increased the number of grains per spike to the tune of 8.5 and 15.6% during first year and 17.2 and 30.2% during second year respectively (Fig 1a). Similarly, the increase in test weight was also recorded in the range of 5.3 and 9.3% during 2014-15 and 7.3 and 10.2% during 2015-16, respectively. However inorganic sources of nitrogen may also have increased the nutrient availability for better growth and development (Fig. 1a). The significantly higher grain (65.0 and 62.7%) straw (33.2 and 38.7%) and biological yield (45.5 and 48.0%) along with harvest index (5.1 and 3.9%) in 160 kg Nha^{-1} over control was because of more availability of nutrients for their growth and development of better yield attributes and yield (Fig. 1a& b). The poor nutrition in control affected the grain yield more than biological yield which ultimately resulted in significant reduction in harvest index. Similar results have been reported by Ali *et al.*, 2012 [1]. Rahman *et al.*, 2010 [25]. Naresh *et al.*, 2014a and Kumar *et al.*, 2015 [18].

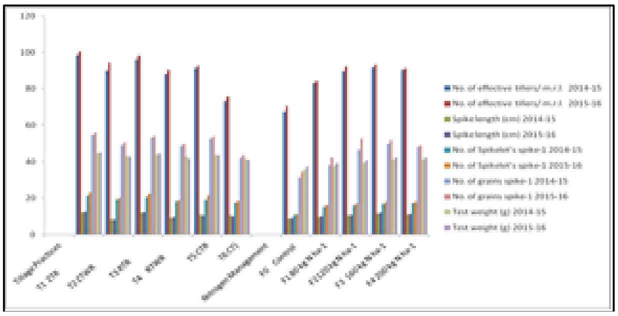


Fig 1: (a): Effect of tillage practices and N management on yield attributes of wheat crop

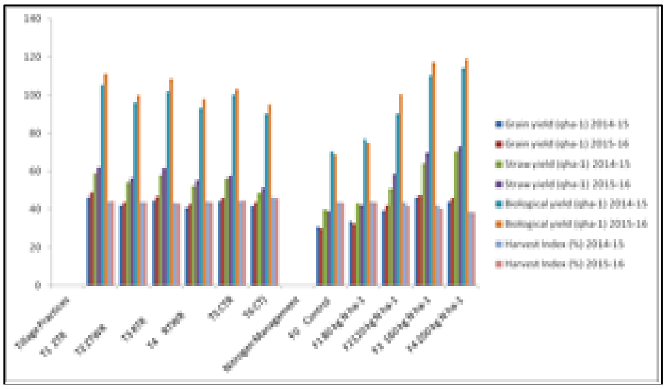
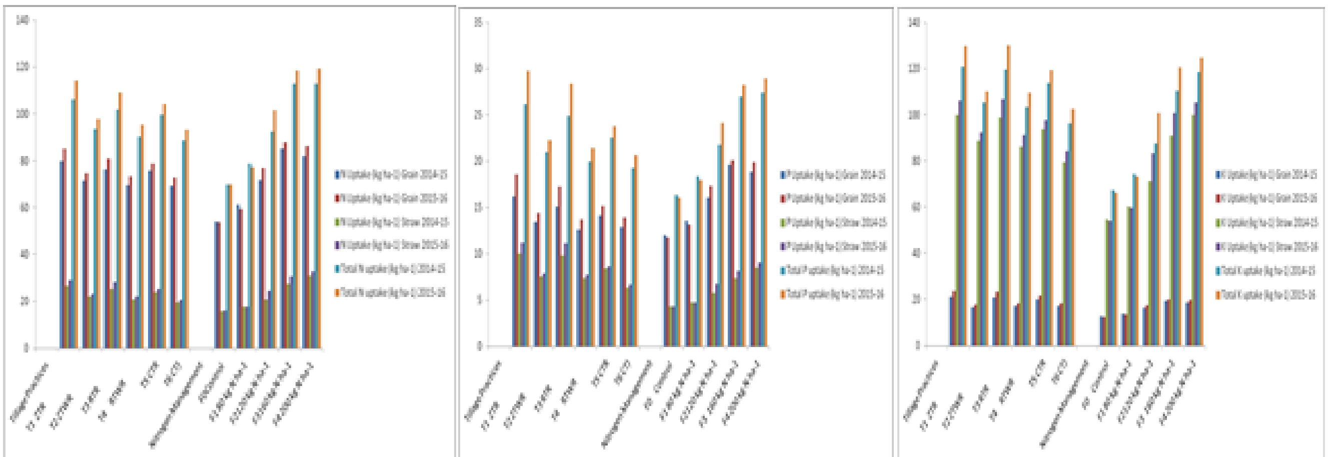


Fig 1(b): Yield and harvest index of wheat on yield attributes of wheat crop crop as affected by various tillage and N management

3.2 NPK content and uptake

The tillage crop residue practices increased the NPK uptake by the crop with increase in moisture availability during both the years of study. The nitrogen and phosphorous uptake was more through the grain (75% of total N and 72% of total P) and potassium was more through the straw (82% of total) than grain (Fig. 2 a, b &c). The higher N and P uptake in grain because of its chemical composition due to higher amino acid and protein content in grain require more N and P, whereas, higher K content in straw is because of its higher content is required for providing strength to stem by forming cellulose, lignin and pectin. The higher NPK uptake was mainly because of higher grain and straw yield in T_1 followed by T_3 compared to T_6 during experimentation. Similar trend have been observed by Ingle *et al.*; 2007 [15].

The effect of plant nitrogen treatment increased NPK uptake with increasing level of nitrogen dose applied through different chemical fertilizers during both the years of study. The increased level of nitrogen dose increased the NPK uptake in grain and straw both but the uptake of N and P was increased with increase in nitrogen content in grain and straw significantly over control during both the years. The higher uptake of NPK in grain under higher dose of N (160 kg Nha^{-1}) and straw dose of N (200 kg Nha^{-1}) was because of more availability of these nutrients, which encouraged the crop growth and finally higher grain and biomass yield. Similar result has been reported by Rani *et al.*, 2009 [26]. Wang *et al.*, 2012 and Bhattacharya *et al.*, 2013.

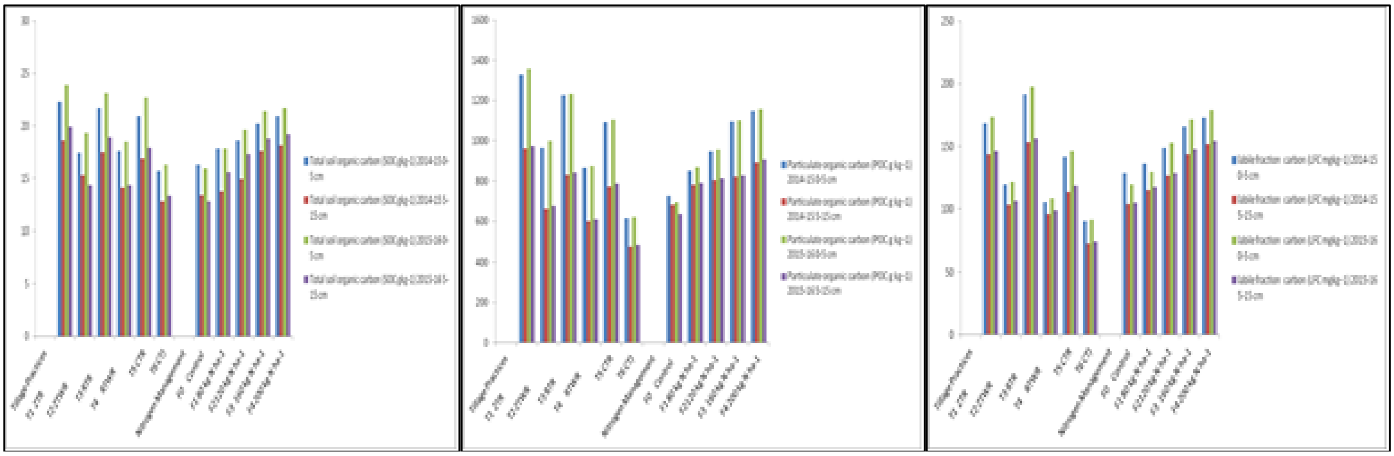


(A) (B) (C)

Fig 2: Effect of tillage crop residue and nitrogen management on (a) nitrogen, (b) Phosphorus and potassium uptake under grain and straw and its total uptake of wheat crop

3.3 Soil properties

Total soil organic carbon (SOC), particulate organic carbon (POC), and labile fraction carbon (LFC) were significantly higher under (T_1) zero till and (T_3) reduced till with residue retention plots over rest of the tillage practices (Fig 3 a, b & c). Higher SOC content in residue retention could be attributed to more annual nutrient recycling in respective treatments and decreased intensity of mineralization. SOC content improved in fertilized plots as compared to the unfertilized plots due to C addition through the roots and crop residues, higher humification rate constant, and lower decay rate. Similarly the increase of POC to the priming effect of the application of fertilizers or fresh organic material to the soil, which stimulated the mineralization of organic matter through increased microbial activity. The LFC showed higher sensitivity to crop management practices as compared to SOC. Because of the dynamic nature of LFC, it can be promoted as an indicator of early changes in soil organic matter status due to management practices. The time required for organisms to the level for optimum mineralization depend on many factors including climate, application rate and microbial activity Similar result has been reported by Wang *et al*., 2012; Bhattacharya *et al*., 2013 and Naresh *et al*., 2016 [30, 23].



(A) (B) (C)

Fig 3: Effect of tillage crop residue and nitrogen management on (a) total soil organic carbon (b) particulate organic carbon and (c) labile fraction organic carbon

4. Conclusion

Soil conservation management improved the quality of the soil by enhancing the SOC and POC and biological status, especially in 0-5cm upper layer. Results of this 02-year field study with wheat crop indicate that the content of SOC, POC and LFC decreased with soil depth, and thin surface layer (0 – 5 cm) contained much higher concentration of these pools than 5 - 15 cm subsurface layer. The surface soil layer had substantially higher levels of all soil health parameters than subsurface layer, presumably due to higher retention of crop stubbles, fallen leaves and root biomass. The enhanced proportions of POC LFC in SOC with the supply of optimum nitrogen and retention of crop residues indicate that the improvement in labile forms of Carbon and N was relatively rapid than control suggesting that active C and N pools reflect changes due to nitrogen management. The N, P, K, uptake increased in ZT plots compared with CT plots. Decrease in N, P, K, uptake in Ct plots as compared to ZT plots might have enhanced soil aggregation processes and compared to conventional tillage (CT), zero-tillage and reduced tillage could significantly improve the SOC content in cropland and the POC, and LFC concentrations were greatly influenced by ZT in the surface (0 - 5 cm) and subsurface (5 - 15 cm) soil layer after 02 cycles of the experiment.

Our results have very significant implications for yield and yield attributes during experimentation and soil C sequestration potential in semiarid subtropical soils inherently low in organic matter and nutrients of Northern India. SOC concentration in surface soil (0– 15 cm) was sharply increased by the tillage practices and nitrogen management. Thus, returning crop residue to the soil is crucial to improving the SOC level. The large scale implementation of the straw plus inorganic fertilizer amendments will help to enhance the capacity of carbon sequestration and promote food security in the region.

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