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Short-term effects of tillage and residue management practices on dry matter yield and fate of ^{15}N-urea in a continuous maize cropping system under subtropical conditions

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ABSTRACT

In the Indo-Gangetic plains of south Asia, conventional tillage (CT) and removal of crop residues have been the major cause of declining soil fertility. While zero tillage (ZT) farming combined with retention of crop residues as surface mulch are well known to improve soil quality and crop productivity in different climatic zones, only limited knowledge exists on the performance ZT technology in the Indo-Gangetic plains. A field study was conducted under subtropical arid climate to elucidate short-term effects of different tillage, residue mulch and N fertilizer regimes on the productivity of irrigated maize grown for five cropping seasons. Treatments included CT and ZT; each with mulch (M^+) or without mulch (M^-), and with N (N^+) or without N (N^-). Fate of the fertilizer-N applied to the 5th maize crop was also investigated using ^{15}N tracer. After five cropping seasons, soil organic C (SOC) in the arable soil layer was higher under ZT compared to CT (29% increase), under M^+ compared to M^- (16% increase) and under N^+ compared to N^- (13% increase). Highest SOC was recorded under ZT-M^+-N^+ treatment (19.1 Mg ha^{-1}) and the lowest under CT-M^--N^- (10.7 Mg ha^{-1}). Nitrogen application increased the grain yield; the increase was higher under ZT than under CT in three cropping seasons. Mulch application reduced the grain yield in four cropping seasons. During all growing seasons, the grain as well as total biomass yields were highest under ZT-M^--N^+. Recovery of the fertilizer-N in soil (0–100 cm depth) ranged from 28 to 39% of the applied with lowest recorded under ZT-M^-. The fertilizer-N recovery in plant was highest (40%) under ZT-M^-, whereas the total fertilizer N recovery in the soil-plant system was not influenced by tillage or mulch regimes. Plant-N derived from soil (Ndfs) was higher under ZT compared to CT (47% increase), and under M^+ compared to M^- (15% increase); the highest Ndfs was recorded under ZT-M^- (31–68% increase). While mulch had no effect on the added-nitrogen-interaction, the latter was significantly higher under CT compared to ZT (65% increase). Results suggested that as compared to other tillage/mulch regimes, ZT without mulch produced similar or higher grain yield and showed highest fertilizer-N use efficiency in continuous maize cropping system under subtropical conditions prevailing in the Central Punjab, Pakistan.

1. Introduction

Agriculture has been traditionally relying on tillage for seedbed preparation and weed control. However, conventional tillage (CT) practices and removal/burning of crop residues not only affect the productivity of agricultural systems but also contribute to environmental degradation. Major negative effects associated with CT include stagnant or reduced crop yields, decline in the soil structure, losses of soil organic C and N pools (as CO_2, CH_4 and N_2O), and increased production costs and environmental pollution caused by fossil fuel combustion (Fischer et al., 2002; Intergovernmental Panel on Climate Change, 1996; Kahlon et al., 2013; Lal et al., 2007). Conservation tillage practices, *e.g.*, reduced or minimum tillage and zero-tillage (ZT) have been introduced as alternate technology for sustainable agricultural and to mitigate environmental problems associated with CT (Lal et al., 2007). Transition from CT to ZT began more than 50 years ago with the development of herbicides and since then ZT has been adopted by farmers worldwide on about 95 million ha (Derpsch, 2005). However, adoption of ZT farming has been mostly accomplished in mechanized medium- and large-sized farms, whereas it is practiced on a very limited scale on small land holdings (Derpsch, 2005). Leading countries practicing ZT farming include United States (20.3 m ha),

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Brazil (13.5 m ha), Argentina (9.25 m ha), Australia (8.64 m ha) and Canada (4.01 m ha) (Conservation Technology Information Center, 2005; Derpsch, 1998). While CT practices bury or remove up to 90% of crop residue, ZT farming relies on retention of more than 90% of the residue as surface mulch to control soil erosion, run-off, evaporation, and weed growth (Conservation Technology Information Center, 2005; Lal et al., 2007). However, ZT is generally defined as planting crops in unprepared soil with at least 30% mulch cover (Triplett and Dick et al., 2008); with this moderate residue application rate, ZT systems may perform better than higher application rates (Roldán et al., 2003).

The most visible effect of ZT is the protection of soil against erosion, a major factor in developing sustainable agricultural production systems (Harrold and Edwards, 1974; Triplett and Dick et al., 2008; van Doren et al., 1984). Impact of ZT on accumulation of soil organic carbon (SOC) is generally more noticeable in long-term than in short-term studies conducted under temperate and tropical climates. In most cases, however, SOC in ZT systems is concentrated in the soil surface rather than the whole soil profile as observed under CT. In a 9-year study under subtropical, hot and humid climate, a ZT system with high residue inputs accumulated more SOC in the 0–30 cm soil layer as compared to CT (Bayer et al., 2000). After 25 years of experiments under a temperate climate in Canada, SOC storage was higher under ZT than under CT though the effect was restricted to the upper 0–5 cm soil layer (Deen and Kataki, 2003). Another long-term study comparing ZT and CT on 11 sites in the eastern United States indicated higher SOC under ZT but only within 0–10 cm depth (Blanco-Canqui and Lal, 2008). After 5 years under minimum tillage in conjunction with residue mulch under subtropical conditions, soil quality improved in the surface layer as compared to other tillage regimes (Ghuman and Sur, 2001). In subtropical and tropical regions of Brazil, greater stabilization of SOC under ZT is largely attributed to storage in the 8–19 mm aggregate size class (Tivet et al., 2013). Besides, ZT compared to CT is well documented to increase the stratification ratio (SR) of SOC (SOC in the 0–5 cm divided by that in the 5–10, 10–20 and 20–40 cm). As compared to SOC per se, SR of SOC is regarded as a more reliable predictor of the soil quality independent of the soil type and climatic regimes (Franzluebbers, 2002; Franzluebbers et al., 2007; Moreno et al., 2006). Considering C accumulation under ZT farming, the latter has potential to mitigate greenhouse gas emissions. Conversion of all croplands to ZT may lead to C sequestration equivalent to 1 Pg C $year^{-1}$ (Pacala and Socola, 2004) or 0.1–1.0 Mg C ha^{-1} $year^{-1}$ (Lal, 2004). However, ZT compared to CT may lead to higher N_2O emission signifying the need of improved N management to realize the full benefit of C sequestration for mitigating global warming (Kong et al., 2009; Six et al., 2004).

Variable effects of tillage and crop residue management practices have been reported on crop yields both in short-term and long-term studies. In a short-term study comparing different tillage and mulch regimes under subtropical climate, reduced tillage combined with surface residue mulch produced higher maize forage yield than conventional cultivation without surface residues (Sharma, 1991). In a 2-year study, ZT combined with application of 4 t ha^{-1} of rice straw mulch (either removed after 20 days, or retained for the whole growing period) conserved soil moisture, suppressed weed growth and promoted root development thus improving wheat grain yield (Rahman et al., 2005). However, in another short-term study under subtropical climate, no significant effect of tillage or mulch regimes was observed on maize yield (Monneveux et al., 2006). In a long-term study comparing CT and ZT under semi-arid subtropical rain-fed conditions, ZT without residue mulch drastically reduced maize and wheat yields, whereas ZT with residue retention gave higher and more stable yields than alternate management practices (Govaerts et al., 2005). Although maize forage yield was not affected by tillage treatments in a sandy soil, it was reduced under ZT compared to CT in heavier textured soil due to restricted root development (Hughes et al., 1992). Corn and soybean yields in the US were typically higher under ZT than under CT on moderate- to well-drained soils (DeFelice et al., 2006). Increased crop yields under ZT compared to CT farming have also been reported in low rainfall areas (Peterson et al., 1993).

Although long-term ZT combined with crop residue mulch is well documented to improve soil quality and crop productivity, the magnitude and pattern of tillage-induced changes are soil- and site-specific. While ZT farming has been relatively well understood and employed on a large scale in temperate regions, relatively little knowledge exists on performance of ZT technology in the Indo-Gangetic Plains of South Asia. In this region, relatively fast turnover of SOC due to warm climate and the traditional practice of removing crop residues from fields have caused loss of the soil fertility leading to poor crop productivity. The present study was conducted to elucidate short-term effects of tillage regimes (ZT *versus* CT) and crop residue management practices (M^+ *versus* M^-) on crop yield and fate of ^{15}N-urea under a continuous maize cropping system in the Central Punjab, Pakistan.

2. Materials and methods

2.1. Study site

Field experiments were conducted at the Nuclear Institute for Agriculture and Biology, Faisalabad (31°23′ N, 73°2′ E; 184 m above mean sea level), Pakistan. The area has a subtropical arid climate characterized by large seasonal fluctuations in temperature and precipitation. Mean annual rainfall is about 360 mm of which about two third is received during July and August in the form of high intensity monsoon downpours. The annual excess of pan-evaporation over rainfall is around 1600 mm, the greatest rainfall deficit occurring during the months of May (203 mm) and June (314 mm). The soil (Typic Ustocrept, Hafizabad series) is a deep, well-drained loam developed in mixed calcareous medium-textured alluvium derived from Himalayas (Anonymous, 1967). Before starting experiments in Fall-2013, the selected field (50 m × 50 m) was exhausted by growing maize (Spring-2013) without application of any fertilizer. Soil samples were collected (core diameter, 5 cm) up to 1 m depth at 10 m × 10 m grid points (25 replicates). Standard methods were used for analyses of soil physicochemical properties *viz.* particle-size (Gee and Or, 2002), total organic carbon (Nelson and Sommers et al., 1996), total nitrogen (Bremner et al., 1996), bulk density (Grossman and Reinsch, 2002), electrical

Table 1
Physicochemical properties of the soil at the study site.

Soil depth	Clay	Silt	Total organic C	Total N	Bulk density	Saturation water	Electrical conductivity$_{(1:1)}$	$pH_{1:1}$	Field capacity	Permanent wilting point
cm	%	%	%	%	g cm^{-3}	%	dS m^{-1}		m^3 m^{-3}	m^3 m^{-3}
0–15	27 ± 0.3[1]	32 ± 0.8	0.48 ± 0.02	0.09 ± 0.02	1.48 ± 0.02	48.2 ± 1.91	0.48 ± 0.02	8.25 ± 0.06	0.29 ± 0.03	0.11 ± 0.02
15–35	24 ± 0.1	37 ± 0.7	0.30 ± 0.01	0.08 ± 0.01	1.40 ± 0.01	47.4 ± 2.10	0.35 ± 0.03	7.96 ± 0.03	0.28 ± 0.04	0.10 ± 0.03
35–55	20 ± 0.5	35 ± 0.6	0.21 ± 0.02	0.05 ± 0.01	1.39 ± 0.01	46.7 ± 1.00	0.41 ± 0.03	8.08 ± 0.02	0.28 ± 0.01	0.11 ± 0.01
55–75	20 ± 0.6	34 ± 0.5	0.15 ± 0.03	0.01 ± 0.00	1.43 ± 0.02	46.0 ± 1.50	0.46 ± 0.01	8.19 ± 0.03	0.27 ± 0.01	0.11 ± 0.02
75–100	20 ± 0.6	34 ± 0.6	0.01 ± 0.01	0.01 ± 0.00	1.55 ± 0.01	45.3 ± 2.00	0.50 ± 0.02	8.13 ± 0.14	0.27 ± 0.02	0.10 ± 0.01

[1] Values are means of 25 replicates ± SD.