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TILLAGE, CROP RESIDUE, AND NITROGEN LEVEL EFFECTS ON SOIL PROPERTIES AND CROP YIELDS UNDER RICE-WHEAT SYSTEM IN THE TERAI REGION OF NEPAL

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Abstract

In the Central Terai region of Nepal, most farmers utilize extensive tillage combined with the removal of most crop residues from the field for livestock fodder or burning the residues with unbalanced fertilizers applications. These traditional practices lead to soil fertility deterioration, heavy demand of water, and high energy usage. Very few farmers are applying reduced/zero tillage technologies, crop residues, and optimum soil nutrients for sustainable yields. With an aim to assess eco-friendly and energy effective conservation tillage, the field experiments were initiated in summer 2010 and continued for two rice-wheat cycles. The experiments, laid under strip-split-plot design, replicated thrice, consisted of three conservation tillage options, two residue levels, and three nitrogen doses. The results indicated that zero-tillage combined with residue retention lowered soil bulk density and pH, enhanced P and K availability to plants and improved productivity of the rice-wheat system. Therefore, zero-tillage associated with residues is suggested for mass-scale adoption.
Key words*:* Zero-tillage, bed-planting, crop-residue, nitrogen, bulk-density

Introduction

Rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) are used as staple crops in South Asia. The rice-wheat system (RWS) provides food for more than 400 million people and is a source of livelihood, employment, and income for hundreds of millions of rural and urban poor of South Asia (Ladha *et al.*, 2003). In Nepal, rice and wheat occupy 1.42 and 0.75 million ha, respectively (MoAD, 2012/13) and are grown in succession on more than 0.56 million ha which accounts 39 % of the rice and 74 % of the wheat area. The RWS provides food, income, and employment to 83 % of the Nepalese population.

Rice is traditionally grown in the wet (monsoon) season after intensive dry and wet tillage (*puddling*), followed by wheat in the dry (winter) season after excessive dry tillage (4 to 8 passes) and planking that further leads to late wheat planting (Giri, 1997; Hobbs *et al.*, 1997; Tripathi *et al.*, 2002; Rao *et al.*, 2007). Giri (1997) reported yield loss of 30 to 50 kg d^{-1} ha^{-1} due to delayed wheat planting at National Wheat Research Program (NWRP) in western Terai. Traditional tillage and crop establishment (TCE) methods create problems in maintenance of soil structure and management of irrigation, weeds and other pests, fertilizers, and crop residues (Rao *et al.*, 2007). Soil quality degradation has occurred because soils for both crops are managed differently. Soil puddling reduces weed competition and water losses but destroys soil structure and creates a hard pan at shallow depth and consumes a large quantity of water (Sharma *et al.*, 2002). Puddling causes poor tilth, restricts drainage, and creates inadequate soil aeration affecting wheat yield potentiality. Conventional tillage practice led to a decline in soil carbon from 30 to 50 % globally (Schlesinger, 1985) to as low as 20 % (Sharma *et al.*, 2002). Plant stover is a major source of C input into the soil system and plays a very vital role for the nourishment of the soil microbial population. The management of crop residues is of primary importance in maintaining soil fertility and productivity (Reicosky, 1997). Straw mulch, with the potential to ameliorate heat stress and increases infiltration rate (Lal, 1975), reduces surface evaporation (Lal, 1985), enhance soil organic carbon and N efficiency (Hobbs and Gupta, 2000). After rice harvest, significant crop residues (1.5-2.0 tons ha^{-1}) are left in the field, but, farmers resort them for good seedbed preparation (Regmi, 1997). Nitrogen (N), phosphorus (P), and potassium (K) are the main fertilizers used widely for cereals. Where, one-half of the N applied to the rice crop is lost by volatilization, denitrification, and leaching (Bhusal *et al.,* 2010). Inefficient N use contributes to greater loss of energy resources, increased production cost, and possible pollution of water by nitrates (Sharpe *et al.*, 1988). In Nepal, there has been a dramatic decrease in N and P fertilizers usage since early 2000 (Timisina *et al.*, 2011).

Considering the above facts, field experiments were conducted with the objectives to assess eco-friendly and energy-effective tillage methods, residue management and N application for soil fertility and productivity under rice-wheat cropping system.

Materials and methods

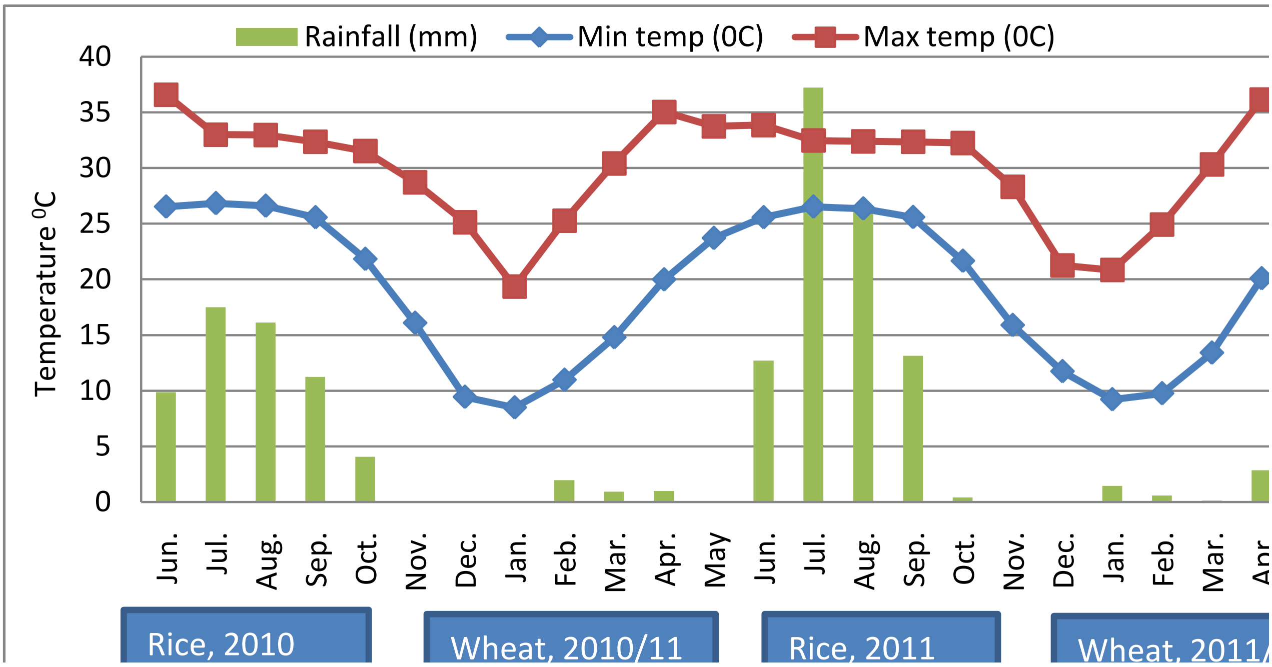
The field experiments were conducted on 37.8 m^2 (7 x 5.4 m) plots, under strip-split-plot design, replicated thrice, during summer and winter seasons, 2010/11 to 2011/12. The three factors were:

(a) Tillage and crop establishment (TCE) methods: (i) Conventional tillage (CT), (ii) Permanent bed planting (PB), and (iii) Zero-till planting (ZT)

(b) Residue management: (i) Residue retention (R_R) (ii) Residue removal (R_O)

(c) Nitrogen levels: (i) Zero N (N_O) (ii) Farmer's N dose (N_F) (iii) Abundant N dose (N_A).

Site/location: The experimental site, Pheta VDC, Bara, Nepal, has a sub-tropical climate with the mean max and min temperatures of 30.0 ^{0}C and 18.3 ^{0}C, respectively, and received an annual mean precipitation of 1735 mm, of which, 86 % occurred during May-Sept. (RARS, Parwanipur, 12 km). The mean monthly max and min temperatures and rainfall at the site during the experimentations are presented in Fig. 1. Soil of the experimental site was silty loam.



Rainfall recording: At the experimental site, a rain-gauge was installed. During the crop cycles, rainfall data were recorded daily at 8 a.m. Total rainfalls received at the site during the 1st to 4th crop cycles were 513.8, 33.6, 785.9, and 43.5 mm in 55, 3, 43, and 6 spells, respectively.

Conventional tillage: For rice, the plots were dry plowed by a tractor-drawn cultivator, double-pass, followed by soil puddling and wooden planking. Twenty five-day old, two to three rice seedlings per hill were transplanted manually on to the puddled fields. For wheat, the plots were plowed twice by the tractor-drawn cultivator, double-pass each time, 15- 20 cm deep, followed by wooden planking. Seed and basal fertilizers were separately broadcast manually on the tilled soil followed by shallow (5-7 cm) seed and soil manipulation, single pass, using the cultivator followed by light planking, in both the years.

Zero-till planting: At the first crop, the field was well plowed, four passes, followed by planking on which rice seeds were drilled, 3 cm deep, by a tractor- drawn inclined plate zero-till drill. For wheat crop establishment, without soil tilling, the seeds were drilled on the rice harvested plot by the same drill. In a pass, 9 rows were drilled, 20 cm apart, and 5 cm deep. After seed drilling, basal fertilizers were manually broadcast followed by light planking, with a tractor. In the second year, both the rice and wheat crops were drilled with the same drill, on untilled soil.

Permanent bed planting: Beds were initially formed, with a bed former attached to the tractor-drawn furrow irrigated raised bed (FIRB) seed drill, for the first rice experimentation and were reused as permanent beds with only superficial reshaping before planting the succeeding crops. Initially, the cross-section of the beds was 67.5 cm (bottom) X 30 cm (top) X 25 cm (depth). On the beds, rice as well as wheat seeds were drilled in two rows, 20 cm apart. Two beds were drilled in a pass of the drill. Seed drilling depths of 3- and 5 cm, for rice and wheat, respectively, were controlled with the depth control wheels provided on the drill machine. Basal fertilizers were manually broadcast on the bed tops.

Cultivars and seed rate: Four crops were grown in the rice-wheat sequence, for two years. Rice cultivar "Sonamasuli" and wheat variety "Gautam" were used as test crops. The seed rates were 30 kg ha^{-1} for rice and in case of wheat, 120 kg ha^{-1} for CT and ZT, and 80 kg ha^{-1} for PB. Foundation seeds of the crops were used for the experiments.

Planting date: Crop plantings were accomplished on Jun. 5, 2010, Dec.10, 2010, Jun.7, 2011, and Dec. 11, 2011 as first rice, second wheat, third rice, and fourth wheat crops, respectively.

Fertilizers application: Phosphorus (P_2O_5) @ 30 and 60 kg ha^{-1} and potassium (K_2O) @ 30 and 40 kg ha^{-1} were broadcast as basal doses for rice and wheat, respectively. In zero N, no nitrogen was applied to either crop. The farmers' N (N_F) and abundant N (N_A) doses for rice were 80 and 120 kg ha^{-1}, while, for wheat, they were 100 and 120 kg ha^{-1}, respectively. Half dose of N was applied at transplanting/planting and remaining half in two equal split doses as top dressings, in both the crops. Sources of fertilizers were Triple Super Phosphate (TSP), Urea, and Muriate of Potash.

Irrigation application: Pre-sowing irrigations for wheat crops were applied a week before seeding. The plots were irrigated from a shallow tube-well through an electric motor-pump/diesel pump-set. The lifted ground-water was conveyed to the individual plots through a 10 cm diameter poly-ethene pipe. The mean discharge rate of the pump was 5 lit. sec^{-1}. Two irrigations were applied to both the crops. While, irrigating in the furrows of the beds, water application was below 5 cm of bed-top. For wheat crops, first irrigation was applied at the crown root initiation (22 DAS) and second at maximum tillering stage (53 DAS).

Insecticide application: A mixture of Hexacorazole 5 % SC + Delfametharin 1 % @ 2 ml/lit of water i.e. 1 lit. ha^{-1} each was applied to rice crop in the second year.

Herbicide application: For the first rice crop, pre-emergence herbicide, Pendemethalin 30 EC, was sprayed @ 3.3 lit. ha^{-1}, two days after seed drilling, while, for the second year rice crop, Bispyribac (Nominee Gold) was applied @ 250 ml ha^{-1} with 750 liters water, at 40 DAS. Whereas, a mixture of 2, 4-D and Isoproturone, @ 900 g ha^{-1} each, was sprayed with a knap-sack sprayer to both the wheat crops.

Soil sampling: Before the experiment initiation, soil samples from the experimental field, 15 cm deep, were collected randomly with a soil auger. A composite soil sample was prepared and it was analyzed at the Soil Science Division (SSD), Nepal Agricultural Research Council (NARC) for bench mark soil physico-chemical properties (Table 1). After each crop harvest, two random samples, 15 cm deep, were collected from each plot, with a 5.08 cm internal diameter GI pipe, for soil bulk density (D_b). The samples were air dried in the individual plastic bowl till the constant weight appeared. Bulk density of individual sample was separately calculated and the mean value was computed and analyzed by Genestat 5. Likewise, after each crop harvest, three soil samples were randomly collected, 15 cm deep, from individual plot and were air dried, ground, and passed through 2 mm sieve. The samples were analyzed for total N, available P_2O_5, exchangeable K_2O, OM, pH, and textural class at the SSD, NARC. The data were analyzed by Genstat 5.

Table 1. Physico-chemical properties of the soil at Site, Pheta, Bara, Nepal, 2010

Soil texture	pH	OM (%)	Total N (%)	Available P_2O_5 (kg ha^{-1})	Exchangeable K_2O (kg ha^{-1})
Silty loam	5.7	4.98	0.241	379	118

Crop sampling: At crop maturity, samples (10 m^2 for ZT and CT, and 13.5 m^2 for PB) were manually harvested, threshed, grains were cleaned, and weighed. Grain moisture content of the samples were observed with the help of electronic moisture meter "Wiles 35" and recorded. Grain yields of rice (at 14 % m. c.) and wheat (at 12 % m. c.) were computed and recorded in both the years. Similarly, straw yields were recorded.

Results and discussion

Grain yields: During 2010/11, the rice-wheat system's grain yields obtained from tillage methods and residue management were at par. But, they were significant at 1% level of sinificance from applied nitrogen levels. While, during 2011/12, the system's grain and straw yields were significant at 1% level of significance for tillage, residues, and nitrogen levels (Table 2). During 2010/11 and 2011/12, under the rice-wheat system (RWS), zero-tillage (ZT) showed the highest grain yields (7989 and 7602 kg ha^{-1}, respectively), but, conventional tillage (CT) ranked second (7688 and 7302 kg ha^{-1}). Thus, during both the years, the system's grain productivity from ZT was higher by 300 kg ha^{-1} compared to CT. The reasons for higher grain yields from ZT may be due to prolonged soil moisture conservation, proper seed rate and seeding depth, uniform seed distribution, line seeding, less leaching of nutrients, free exchange of gases, and more plant photosynthesis. The results were in accordance with various researchers (Gupta *et al.*, 2002; Harrington, 2001; Hobbs, 2001). The lowest system's yields were obtained from permanent beds in both the years (Table 2). A yield penalty from raised beds (14-25%) irrespective of crop establishment methods for rice was also reported by Bhushan *et al.* (2007). The reasons for lower rice yields on beds could be due to moisture stress at panicle initiation and flowering stages (Bhushan *et al.*, 2007; Lu-Jun *et al.*, 2001; and Belder *et al.*, 2002), while, for wheat, it may be due to late planting.

The effect of residue retention (R_R) on the RWS's grain productivity, in 2011/12, was significant at 1% level. Compared to residue removal (R_O), residue retention (R_R) quantitatively enhanced the system's grain yield by 975 kg ha^{-1}, during 2011/12 (Table 2). The reasons for higher grain production from R_R may be due to soil moisture conservation, weed suppression and OM addition in the soil. The results were similar to the statement of Hobbs *et al.*, 1997. In contrast, R_R lowered the system's straw yield to about half, during both the years, because 40 cm stubbles were left in situ at harvests.

The application of higher doses of N showed positive effects on system's productivity during both the years (Table 2). Abundant N (N_A) application elevated the system's productivity by 11.5 % and 3.7 % compared to Zero N (N_O) and Farmer's N (N_F), respectively. In both the years, the system's grain yield was increased from higher N rates which were in agreement with Gill and Meelu (1982) that under rice-wheat rotation, increasing N level up to 120 kg ha^{-1} increased the yield of rice and yields of both rice and wheat (Singh and Sharma, 1979). Higher N application increased plant chlorophylls, growth and vigor, and higher tillers in both rice and wheat crops.

Table 2. Grain and straw yields of rice-wheat system as influenced by tillage, residues, and nitrogen levels at Pheta, Bara, Nepal, 2010/11 and 2011/12

Treatments	Yields (kg ha^{-1})					
	Grain			Straw		
	2010/11	2011/12	Mean	2010/11	2011/12	Mean
Tillage methods:						
Conventional tillage	7688	7302	7495	7545	8427	7986
Permanent bed planting	7554	6516	7035	7044	6558	6801
Zero tillage	7989	7602	7796	7693	7919	7806
LSD $_{(0.05)}$	379.6	451.1	-	1196.7	945.5	-
F-test $_{(0.05)}$	NS	**	**	NS	**	**
Residue management:						
Residue retention	7732	7628	7680	4857	5511	5184
Residue removal	7756	6653	7204	9998	9758	9878
LSD $_{(0.05)}$	309.9	368.3	-	977.1	772.0	-
F-test $_{(0.05)}$	NS	**	**	**	**	**
Nitrogen levels:						
Zero nitrogen	5795	5218	5506	5222	5650	5436
Farmers' nitrogen dose	8684	7830	8257	8478	8219	8348
Abundant nitrogen dose	8753	8373	8563	8582	9036	8809
LSD $_{(0.05)}$	379.6	451.1	-	1196.7	945.5	-
F-test $_{(0.05)}$	**	**	**	**	**	**
C. V. (%)	7.2	9.3	8.27	23.8	18.3	21.18

Note: NS= not significant, *= significant at 5% level of significance, **= significant at 1% level of significance

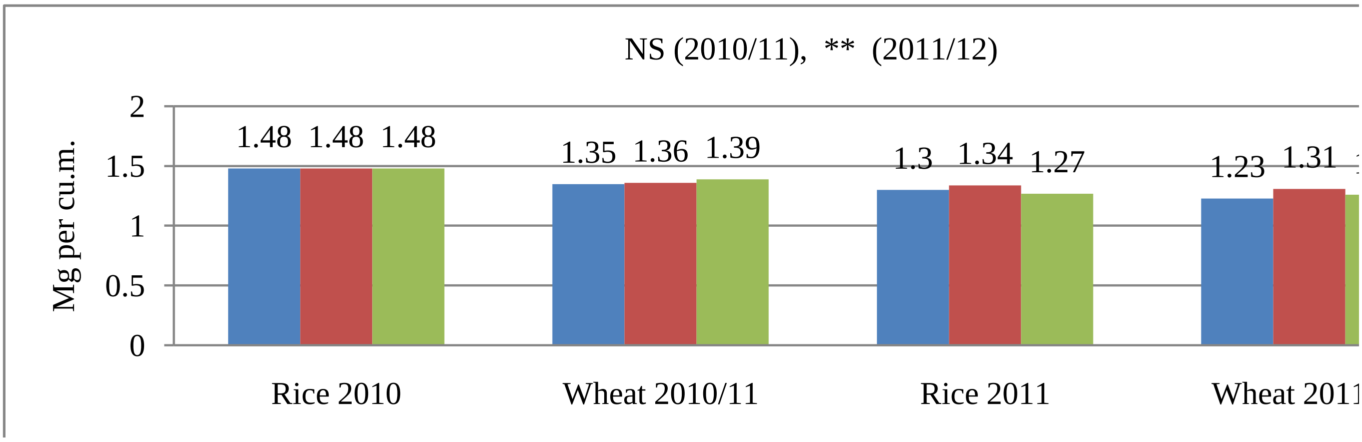
Straw yields: The effect of ZT on the mean straw yield was negative and it was slightly lower (7806 kg ha^{-1}) than CT (7986 kg ha^{-1}), over two years (Table 2). The mean straw yield, over the years, from CT was higher by 17.4 % and 2.3 % compared to PB and ZT, respectively. Over the years, residue retention showed lower straw yield by half compared to residue removal under the rice-wheat system. Abundant N application enhanced mean straw yields by 62 % and 5.5 % compared to N_O and N_F, respectively. These findings are in agreement with Phillips and Phillips (1984) and Sayre (2000) who narrated that conversion from conventional tillage to reduced-till systems with residue retention may require several crop cycles before potential advantages/ disadvantages begin to become apparent.

Nitrogen use efficiency: The N use efficiency (grain yield per unit N supply) was inversely proportional to increased N applied (Table 3). The findings of Sowers *et al.* (1994) also stated that the application of high N rates may result in poor N uptake and low N use efficiency due to excessive N losses. Nitrogen use efficiency was very low from both rice (21 %) and wheat (26 %) as was reported by Harrington and Hobbs (2009). The nitrogen use efficiency under the R-W system was higher from farmers' N dose, in both the years.

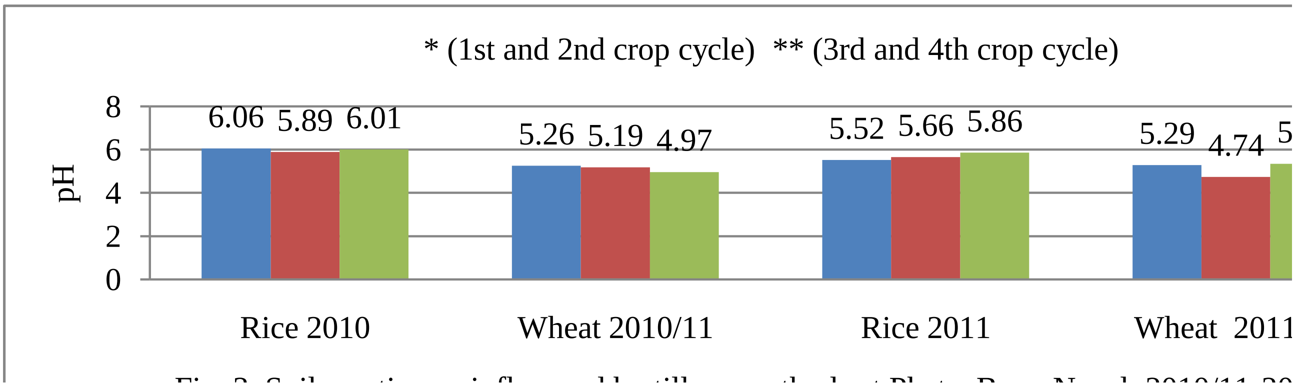
Table 3. Nitrogen use efficiency as influenced by applied N levels under rice-wheat system at Pheta, Bara, Nepal 2010/11 and 2011/12

Applied nitrogen level	N use efficiency (%)	
	2010/11	2011/12
Zero N dose	∞	∞
Farmers' N dose	48.24	43.50
Abundant N dose	36.47	34.89

Soil bulk density (D_b): The effects of tillage methods on D_b were not significant except at fourth crop harvest. Tillage caused a lower bulk density (0.2 Mg m^{-3}) in the surface soil layer (0-15 cm) at fourth crop harvest. At both the rice harvests, soil bulk densities from CT were higher (1.49 and 1.30 Mg m^{-3}) compared to nonpuddling in direct seeded rice (DSR) by ZT (1.48 and 1.27 Mg m^{-3}) (Fig. 2). The higher D_b from CT might be due to soil compaction because of more tractor movements during soil puddling. The results were in accordance with Tripathi *et al.* (2003) and Painuli (1993). Conversely, at the wheat harvests, D_b was lowered from 1.35 to 1.23 Mg m^{-3} in CT and from 1.39 to 1.26 Mg m^{-3} in ZT which was in accordance with Sharma *et al.* (2004). Also, the D_b was not significant for residue management and applied N doses. Compared to residue removal, the D_b by residue retention were lower (1.47 from 1.49 Mg m^{-3}) and (1.29 from 1.32 Mg m^{-3}) at the 1st and 2nd rice harvests, respectively, implying improvement in soil structure as reported by Surekha *et al.* (2004). As P_2O_5 was applied @ 30 and 60 kg ka^{-1} (for rice and wheat), N_F decreased soil D_b at 1st, 2nd, and 4th harvests. The results were similar to Bhattacharyya *et al.* (2004) who stated that soil D_b decreased from NP application under a rain-fed soybean-wheat rotation.



Soil reaction (pH): Soil pH values were varied significantly at 5% probability at the ends of first and second crop harvests, and at 1% level of significance at the third and fourth crop harvests, for the tillage options. The soil pH fluctuated during the four crop cycles and the soil turned into acidic, for the tillage options (Fig. 3). However, the decrease in pH was marginal from the treatments with and without tillage. Compared to R_O, the effects of R_R on soil pH were not significant, but, the pH values were lower 5.96, 5.09, 5.63, and 5.12 than 6.01, 5.18, 5.73, and 5.13 during the four crop cycles, respectively. The acidification was mostly due to removal of bases by the crops (Swain *et al.*, 2003). The N_A application, compared to N_O, lowered soil pH during all the crop cultivation (Fig. 4).



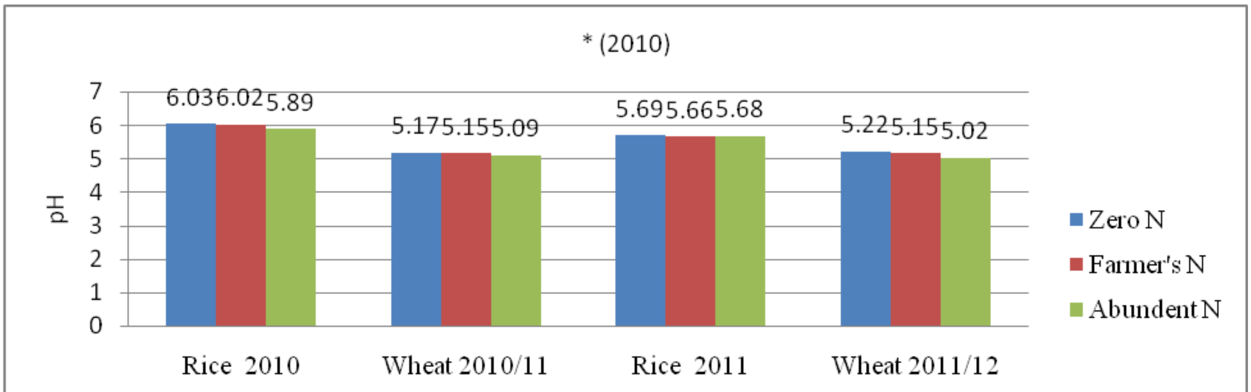
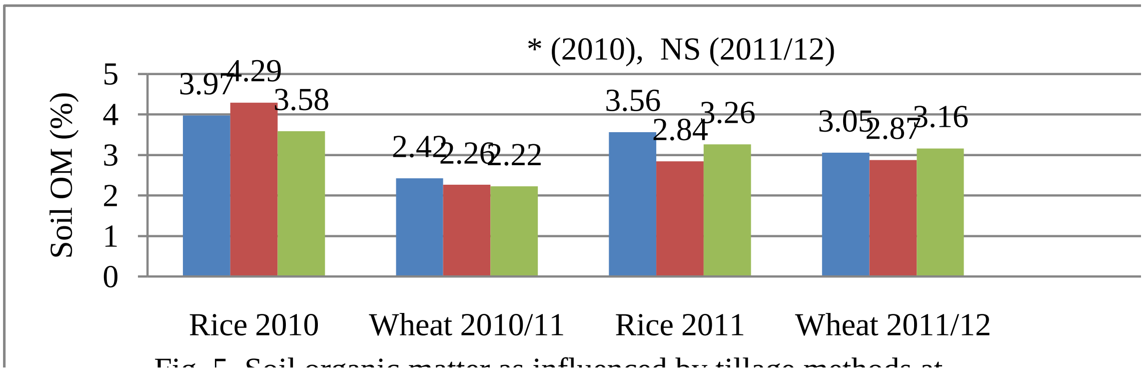


Fig. 5. Soil reaction as influenced by applied N at Pheta, Bara, Nepal, 2010/11-2011/12

Soil organic matter (OM): The effects of tillage, residues, and applied nitrogen levels on soil OM contents were similar at the ends of the crop cycles except in the first (rice) cycle. Soil OM values were fluctuated at the ends of crop harvests, for the tillage options (Fig. 5). The higher soil OM content at 1st rice harvest was most probably due to decomposition of wheat straw, added at rice planting, from high soil moisture during rice growing. At the second crop (wheat) harvest, the values were lower showing soil OM depletion. The reason for lower soil OM could be due to more OM mineralization during wheat growing period. The results were in accordance with Agustin *et al.* (2000) who stated that keeping crop residues on the soil surface and reducing tillage intensity reduced physical release of CO_2 and the greater cause of OM depletion in the soils. The results revealed that soil OM was enhanced at rice harvests which could be because of higher soil moisture at soil sampling and faster decomposition of mulch and rice plus wheat stubbles in abundant soil moisture during rice crop growth. Thus, soil OM was declined from the initial value (4.98 %) under the RWS as the crops were grown without compost and/or green manure application, which was in accordance with Swain *et al.* (2003). Long-term soil fertility experiments conducted in South Asia also revealed soil OM declines when only chemical fertilizers were used (Harrington and Hobbs, 2009). At fourth crop harvest, from the initial value, soil OM declined by 1.93, 2.11, and 1.82 % for CT, PB, and ZT, respectively. Compared to R_O, R_R showed higher soil OM by 0.18 and o.33 % in 2010 and 2011 at rice harvests, respectively, but, lower soil OM (0.16 %) at both the wheat harvests. The effects of N applications on OM were inconsistent.



Total soil nitrogen (N): The effects of tillage options on total N were not significant except at first crop harvest, among the four crop cycles. The initial N (0.24 %) was dropped during crop cycles. The total N at the second crop harvest was lower than at first crop harvest, but, it was increased at third crop harvest, which was further lowered at fourth crop harvest, for the tillage options (Table 4). The fluctuating soil moisture conditions and the intermittent drying and flash-flooding in rice triggered nitrification and denitrification causing large N loss (Pathak *et al.*, 2003). Similar results were also reported by Swain *et al.* (2003) while working with okra with bio-inoculants and fertilizer nitrogen. The trends were similar to the available N for R_R and R_O and for nitrogen applied. The drop in available N from first to fourth crop harvest from CT, PB, and ZT were (0.15 to 0.13 %), (0.16 to 0.12 %), and (0.14 to 0.13 %), respectively. Residue retention showed higher available N than R_O at both the rice harvests, while, in contrast, it was lower at both the wheat harvests. The effects of fertilizer applications were nonconsistent for the available N (Table 4).

Table 4. Soil primary nutrient elements at crop harvest as influenced by tillage, residue, and nitrogen level at Pheta, Bara, Nepal 2010/11 and 2011/12

Treatment	Total N (%)				Available P_2O_5 (kg ha^{-1})				Exchangeable K_2O (kg ha^{-1})			
	Rice 2010	Wheat 2010/11	Rice 2011	Wheat 2011/12	Rice 2010	Wheat 2010/11	Rice 2011	Wheat 2011/12	Rice 2010	Wheat 2010/11	Rice 2011	Wheat 2011/12
Tillage methods:												
CT	0.15	0.10	0.14	0.13	210	312	181	324	124	70	285	49
PB	0.16	0.11	0.12	0.12	219	276	116	348	159	68	262	50
ZT	0.14	0.11	0.13	0.13	224	276	179	326	131	72	302	34
LSD $_{(0.05)}$	0.01	0.02	0.02	0.01	20	34.9	40.3	37.0	26.6	11.8	46.9	11
F-test $_{(0.05)}$	*	NS	NS	NS	NS	NS	**	NS	*	NS	NS	**
Residue mgt.:												
R_R	0.16	0.10	0.14	0.12	220	299	154	352	142	78	286	49
R_O	0.15	0.12	0.13	0.13	216	277	163	312	133	62	280	40
LSD $_{(0.05)}$	0.01	0.014	0.01	0.01	16.3	28.5	32.9	30.2	21.7	9.6	38.3	9.0
F-test $_{(0.05)}$	NS	*	NS	NS	NS	NS	NS	*	NS	**	NS	NS
Nitrogen levels:												
N_O	0.15	0.12	0.13	0.12	219	284	158	325	136	69	290	44
N_F	0.14	0.11	0.14	0.13	218	292	168	327	135	71	282	45
N_A	0.16	0.10	0.12	0.12	217	288	149	345	142	70	277	45
LSD $_{(0.05)}$	0.01	0.02	0.02	0.01	20	34.9	40.3	37.0	26.6	11.8	46.9	11.0
F-test $_{(0.05)}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
C. V. (%)	14.1	24.0	17.0	17.9	13.6	17.9	37.5	16.4	28.5	24.9	24.5	36.7

Note: NS= not significant, *= significant at 5% level of significance, **= significant at 1% level of significance

Available phosphorus (P): For the tillage options, available P content was varied significantly at 1% level of significance at the third crop harvest. The available P content was lowered at first crop harvest compared to the initial value (379 kg ha^{-1}) which was further lowered at third crop harvest. While, the available P values were enhanced at second crop harvest compared to at first crop harvest and further increased at fourth crop harvest (Table 4). At the fourth crop harvest, available P contents were 324, 348 and 326 kg ha^{-1} by CT, PB, and ZT, respectively.

The P fixation capacity of the soil was increased with the increase in the levels of added P for the tillage, residue, and applied N (Table 4). The application of 30 kg P_2O_5 ha^{-1} to rice, the availability of P was lower than the 60 kg P_2O_5 ha^{-1} applied to wheat. The P availability was higher at wheat harvests compared to rice harvests for the tillage options. The increase in P fixation with increase in the amount of added P might be attributed to the increase in ionic strength generated by P addition (Mallik *et al.* 2003), resulting in lowered activity coefficient and raised concentration of reaction products in soil as per solubility product principle (Sanyal and De Datta, 1991). The available P values for PB were the lowest (116 kg ha^{-1}) for the third crop and the highest (348 kg ha^{-1}) from the fourth crop. The P values during 1st and 2nd crop harvests marginally enhanced, but, it was significantly higher by R_R (352 kg ha^{-1}) than R_O (312 kg ha^{-1}) at 4th crop harvest. Badanur *et al.* (1990) reported that available P content of soil increased significantly with crop residue and green manure incorporation over fertilizer application. At the fourth crop harvest, available P value for N_A was the highest (345 kg ha^{-1}) against N_F (327 kg ha^{-1}) and N_O (325 kg ha^{-1}).

Exchangeable potassium (K): For tillage, residue, and applied nitrogen, exchangeable soil K was fluctuated abruptly. Soil K values for tillage options were interestingly higher at rice harvests (more than double at second rice) and were meagerly lower at wheat harvests (lesser than half at second wheat), compared to bench mark value (118 kg ha^{-1}). Exchangeable soil K for tillage options, were significant at 5% level and 1% level at the first and fourth crop cycles, respectively (Table 4). Likewise, they were highly significant at the second crop harvest from residue retention. Residue retention indicated higher soil K values (142, 78, 286, 49 kg ha^{-1}) compared to residue removal (133, 62, 280, 40 kg ha^{-1}), during the crop cycles, respectively. The increase in soil available K due to straw application was also reported by Surekha *et al.* (2004). It was apparent that faster decomposition of bhusa/chaff mulch plus rice and wheat stubbles attributed to exchangeable K during the rice cycles, for the tillage options. In contrast, higher crop removal of soil K by wheat crops indicated lower soil K at the wheat harvests, irrespective of tillage methods, suggesting the possibility of K mining. The results were similar to the findings of Swain *et al.* (2003). Regmi *et al.* (2009) and Bhandari *et al.* (2002) who reported a highly negative K balance in the rice-wheat system.

Conclusion

Use of zero-tillage in combination with crop residues retention in soil increased the productivity of rice-wheat system with positive nutrient balance and improved soil quality in terms of decreased bulk density and soil pH, enhanced available P_2O_5 (5.8 %), exchangeable K_2O (7.8 %), and soil OM (1.5 %) under intensive rice-wheat cropping system. Therefore, zero-tillage with residues retention could be suggested for mass scale adoption in the Terai region of Nepal.

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