N. Rawal et al. (2017) Int. J. Appl. Sci. Biotechnol. Vol 5(1): 42-50
DOI: 10.3126/ijasbt.v5i1.17001

ISSN (Online): 2091-2609
DOI Prefix: 10.3126/ijasbt
International Journal of Applied Sciences and Biotechnology (IJASBT)

Research Article

Crop Yield and Soil Fertility Status of Long-Term Rice-Rice-Wheat Cropping Systems

Nabin Rawal[1*], Rajan Ghimire[2] and Devraj Chalise[1]
[1]Nepal Agricultural Research Council, Nepal.
[2]New Mexico State University Agricultural Science Center, Clovis, NM, USA.
[*]Corresponding author phone (+977)-9857065021, email: nabin_rawal@yahoo.com

Abstract
Balanced nutrient supply is important for the sustainable crop production. We evaluated the effects of nutrient management practices on soil properties and crop yields in rice (*Oryza sativa* L.) - rice - wheat (*Triticum aestivum* L.) system in a long-term experiment established at National Wheat Research Program (NWRP), Bhairahawa, Nepal. The experiment was designed as a randomized complete block experiment with nine treatments and three replications. Treatments were applied as: T1- no nutrients added, T2- N added; T3- N and P added; T4- N and K added; T5- NPK added at recommended rate for all crops. Similarly, T6- only N added in rice and NPK in wheat at recommended rate; T7- half N; T8- half NP of recommended rate for both crops; and T9- farmyard manure (FYM) @10 Mg ha^{-1} for all crops in rotation. Results of the study revealed that rice and wheat yields were significantly greater under FYM than all other treatments. Treatments that did not receive P (T2, T3, T7, T8) and K (T2, T4) had considerably low wheat yield than treatments that received NPK (T5) and FYM (T9). The FYM lowered soil pH and improved soil organic matter (SOM), total nitrogen (TN), available phosphorus (P), and exchangeable potassium (K) contents than other treatments. Management practices that ensure nutrient supply can increase crop yield and improve soil fertility status.

Keywords: Farmyard manure; long-term experiment; rice; soil organic matter; wheat

Introduction
Sustainable high yields of crops can support food security of the rapidly growing population (Palm *et al*., 2014). Need of increase in food production is more important in South Asia than other regions of the world because of the high population growth in the region (Yao *et al*., 2008). More than 90% of rice is produced and consumed in Asia. Continuous rice cropping, rice-wheat rotation, and rainfed mixed farming that includes upland rice production occupies approximately 56% of the cultivated land in South Asia and more than 13 million ha of Indogangatic plains of Nepal and India (Wassmann *et al*., 2004). In Nepal, rice and wheat supplies more than 75% of the country's total food demand (NARC, 2014). Terai region that stretches east to west in southern Nepal is the rice and wheat production pocket for Nepal. However, the main constraints in rice and wheat production include low soil fertility status and the lack of resources for improving the fertility status (Nambiar, 1994; Adhikari *et al*., 1999; Regmi *et al*., 2002; Ladha *et al*., 2003). Improved understanding for the soil-fertility management practices, their impacts on SOM, nutrients contents, and crop yield can help producers to increase food production and improve the sustainability of agriculture in South Asia (Majumder *et al*., 2008; Ghimire *et al*., 2012).

Studies revealed several alternative ways to improve SOM sequestration and increase crop yields. Balanced nutrient supply through chemical and organic sources can improve SOM accumulation and increase crop yield in low fertility environments of South Asia (Yadav *et al*., 2000; Regmi *et al*., 2002). A study in a rice-wheat system in Parwanipur, Nepal revealed that treatments receiving organic sources of nutrients increased SOM by 18% to 62% compared with the NPK treatment (Gami *et al*., 2000). From a 19-year rice-wheat cropping systems study in India, Majumder *et al.* (2008) indicated that application of NPK and organic amendments (FYM, straw, and green manure) could increase SOC by 24%. However, there is no consistent trend in yields of major crops with reference to increase in SOC accumulation and other nutrients (Regmi *et al*., 2002).

Improved fertility status could support sustainable crop production. Long-term experiments have significantly contributed to our understanding of soil fertility management and sustainable crop production in different agroecosystems (Gami *et al*., 2000; Ghimire *et al*., 2015; Tang *et al*., 2008). Such a long-term studies are extremely important in South Asia including Terai regions of Nepal for determining yield trend and nutrient balance in soil, predicting carrying capacity of soils and accessing the sustainability of agricultural systems across the region (Majumder *et al*. 2008; Ghimire *et al*., 2012). Studies suggest that improved fertilizer management practices can increase crop production and improve SOC sequestration (Ladha *et al*., 2003). Good quality FYM helped in improving physicochemical properties of soil and making soil nutrients gradually available for plant uptake (Singh *et al*., 2014). The long-term application of organics fertilizers can increase productivity and boost better energy and environmental balance (Singh *et al*., 2014). Data from the long-term experiments established in early 1970s could provide information on yield trend of rice and wheat in South Asia, but the information on soil fertility status is lacking for several of these experiments (Palm *et al*., 2014).

The main objective of this study was to evaluate the effects of mineral fertilizer and organic manure on soil properties and grain yield in long-term rice-rice-wheat system experiment established in 1978 at NWRP, Bhairahawa, Nepal. The study also evaluated and explained yield trends of rice and wheat and analyzed the relationship between crop yields and soil properties.

Materials and Methods

Study Site and Treatments

A long-term study was established in 1978 at Regional Agricultural Research Station, NWRP, Bhairahawa, Nepal. The experimental site is located at 27°32′ N, 83º28′ E and 120 m elevation. This area has a humid subtropical climate influenced by south-western monsoon. Average air temperature ranges from a minimum of about 7°C in winter to the maximum of about 45ºC in summer. The experimental site receives approximately 1700 mm rainfall, more than 85% of which occurs during June to September. November and December are the driest months. A few light precipitations are expected in January and February. The Soil at the study site is classified as TypicHeplaquepts formed on the Himalayan residuum and has a slightly alkaline pH (8.0). The soil has a silty loam texture with sand, silt, and clay contents of 120 g kg^{-1}, 670 g kg^{-1} and 210 g kg^{-1} at 0-20 cm depth.

Table 1. Treatments and management history of rice – rice – wheat long-term experiment at National Wheat Research Program, Bhairahawa, Nepal (1978-2014).

Treatment†	**Spring rice**			**Summer rice**			**Wheat**		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
	kg ha^{-1}								
T1	0	0	0	0	0	0	0	0	0
T2	100	0	0	100	0	0	100	0	0
T3	100	30	0	100	30	0	100	40	0
T4	100	0	30	100	0	30	100	0	30
T5	100	30	30	100	30	30	100	40	30
T6	100	0	0	100	0	0	100	40	30
T7‡	50	0	0	50	0	0	50	0	0
T8‡	50	20	0	50	20	0	50	20	0
T9	FYM			FYM			FYM		

†T1 = no added nutrients; T2 = N only application; T3 = N and P application; T4 = N and K application; T5 = NPK (recommended rate); T6 = N only in rice and NPK in wheat (recommended practice); T7 = 1/2 N of recommended practice; T8 = half NP; T9 = farmyard manure (10 Mg ha^{-1} for each crop). N, P and K stand for nitrogen, phosphorus, and potassium.

‡30 cm stubble incorporation from each crop.

The experiment has a randomized complete block design with nine treatments and three replications. All treatments (T1-T9) comprised, T1- Control without added nutrients. T2- Only N added at the recommended rate. T3- N and P additions at the recommended rate (NP). T4- N and K additions (NK) at the recommended rate. T5- NPK additions at the recommended rate. T6- only N in rice and NPK in wheat in recommended rates. T7- half of N added at recommended rate. T8- half of NP added at recommended rate. T9- FYM additions at 10 Mg ha^{-1}. Plot size for the individual treatment is of 4 m × 3 m. Three crops, spring rice, summer rice, and wheat are grown in a year. All fertilizers are applied as per the recommendations set by Nepal Agriculture Research Council at the beginning of the experiment (Table 1). All the P fertilizer as $[NH_4]_2HPO_4$ and K fertilizer as KCl are applied on the day of planting wheat and a week after transplanting of rice. Nitrogen fertilizer is applied in two splits, 50% as $[NH_4]_2HPO_4$ and NH_2CONH_2 at the time of planting, and 50% as NH_2CONH_2 after 25-30 days of planting wheat/transplanting rice. Farmyard manure (20 g kg^{-1} N, 4.5 g kg^{-1} P, and 10 g kg^{-1} K, dry weight equivalent) is applied a week before planting wheat and transplanting rice.

Spring rice was planted in the second week of April, which was harvested in July, summer rice was planted in the last week of July and harvested in the first week of November, and Wheat is plated in the third week of November and harvested in March of the following year. Rice seedlings were grown in a nursery for three weeks, and two seedlings were transplanted at 20 cm × 20 cm spacing. Wheat was sown by hand in rows at 25 cm with the seed rate of 120 kg ha^{-1} in 2-3 cm depth. Farmyard manure was applied at 7-10 days before rice planting or wheat showing. Cultivars of rice and wheat, as well as crop and irrigation management detail, has been reported previously (Regmi, 1994; Regmi *et al*., 2002). Continuous submergence of rice seedling with 3-5 cm water height was maintained throughout the growing season. Plots were drained 2-3 weeks before rice harvest. In wheat, three irrigations were given at crown root initiation (21 DAS), maximum tillering (55 DAS), and flowering (85 DAS) stages. Weeds were controlled by hand weeding, and other plant protection measures were applied as needed.

Crop Yield Measurement, Soil Sampling and Laboratory Analysis

Grain yield was estimated by harvesting 6 m^2 areas in each plot using rice knives. Crop grain and straw was separated using plot thresher, grains were cleaned, and dried to approximately 12-13% moisture, and weighed for yield estimation. Grain yield was also measured from the whole plot in both crops at maturity and was adjusted to 14% and 12% for rice and wheat, respectively. Straw was removed from the field after threshing.

Soil samples were collected from 0-15 cm depth of three sampling spots at each treatment using a 7-cm diameter soil auger. Samples were collected after harvesting wheat on April 2014. Soils collected from different sampling spots within a plot were mixed thoroughly, and brought to the laboratory for analyses. In the laboratory, soil samples were air dried for a week and sieved through a 2 mm sieve. Soil pH was determined by the method of Dewis and Freitos (1970) by electrodes in 1:2 (soil-water) solution. Soil organic matter content was determined by the method of Walkley and Black (Nelson and Sommers, 1982). Total N was estimated by Kjeldhal's digestion method of Bremner and Mulvaney (1982). Available P was determined by modified Olsen method (Olsen and Sommers, 1982). Exchangeable K was determined in a 1M ammonium acetate extracts by using a flame photometer (Knudsen *et al*., 1982).

Statistical Analysis

Data for SOM, nutrients, as well as crop yield in 2014, were tested for normality and homogeneity of variance. All the data were analyzed using a Randomized Complete Block Design procedure in MSTATC (Steel and Torrie, 1980). Treatment means differing in F test were separated using Duncan's multiple range test (DMRT). Long-term averages for crop yield are presented; however, they are not statistically analyzed. Relationships between soil properties in 2014 and average crop yield for 2001–2014 were compared using multiple correlation tests in Minitab 17.0 (Minitab Inc. State College, PA). Statistical significance for all analyses was evaluated at P<0.05 unless otherwise stated.

Results and discussion

Crop Yield

Grain yields of rice and wheat in rice-rice-wheat system were influenced by soil fertility treatments (Table 2). The highest spring rice grain yield of 2191 kg ha^{-1} was obtained in NPK followed by 1534 kg ha^{-1} in FYM treatment. Use of FYM produced 3243 kg ha^{-1} summer rice and 2091 kg ha^{-1} wheat, which were significantly greater than rice and wheat yields in other treatments. The control plot with an indigenous nutrient supply only supported summer rice, wheat, and spring rice yields of 563, 447 and 267 kg ha^{-1} respectively after 36 years under the rice-rice-wheat system. This result corroborates with many other studies that suggested low productivity of the rice-wheat system attributable to decline in nutrient availability or nutrient imbalances because of the inappropriate fertilization practice (Timsina and Connor, 2001; Bhandari *et al*., 2002). Low SOM content and crop yield in rice-wheat systems with the long-term use of recommended dose of NPK was also observed in some field studies potentially due to unavailability of other essential nutrients (Nambiar 1994; Abroal *et al*., 2000; Yadav *et al*., 2000).

Table 2: Grain yield of rice and wheat in rice-rice-wheat long-term experiment at National Wheat Research Program, Bhairahawa, Nepal, 2014

Treatments†	Spring rice	Summer rice	Wheat
	(kg ha^{-1})		
T_1	267^{c}	563^{e}	447^{cd}
T_2	158^{c}	573^{e}	339^{cd}
T_3	1265^{b}	3012^{ab}	271^{d}
T_4	82^{b}	1194^{d}	365^{cd}
T_5	2191^{a}	2899^{ab}	1311^{b}
T_6	1136^{a}	2388^{c}	1327^{b}
T_7‡	248^{c}	608^{e}	290^{cd}
T_8‡	1137^{b}	2704^{bc}	707^{c}
T_9	1534^{b}	3243^{a}	2091^{a}
F test	***	***	***
CV %	30.3	12.7	26.8
LSD(0.05)	582.1	419.4	384.5

†T1 = no added nutrients; T2 = N only application; T3 = N and P application; T4 = N and K application; T5 = NPK (recommended rate); T6 = N only in rice and NPK in wheat (recommended practice); T7 = 1/2 N of recommended practice; T8 = half NP; T9 = farmyard manure (10 Mg ha^{-1} for each crop). Different letters within a row indicate significant difference between treatments at P = 0.05.

‡30 cm stubble incorporation from each crop.

Analysis of yield trend revealed a severe decline in yield of all crops in treatments T2 and T4. Grain yield was nearly zero in spring rice, indicating severe P deficiency in T2 (Fig. 1). Yield trend of NK treatment (T4) was similar to the trend in control treatment. In both treatments in which P was included (T3 and T5) and FYM applied (T9), grain yield declined until 2008/09 and slightly increased after. This trend was possibly due to changes in P dynamics (sorption and desorption of P) in soils. Fertilizer treatments had less distinct influence in the yields of summer rice than the yields of spring rice. Yield trend of summer rice in NK treatment (T4) was also similar to the yield trend in control treatment (Fig. 2) suggesting an important role of P nutrition both for spring and summer rice. We also noted significant differences in yields of NPK and NP treatments. Although the largest yield was produced in the recommended dose of NPK and FYM application, neither the recommended dose of NPK nor FYM could sustain long-term production of rice crops in this system. Nambiar and Abrol (1989) reported a declining trend of rice and wheat yield with an inadequate amount of nutrients, mainly NPK. The importance of N to maintain yield has been reported in many studies (Regmi, 1994; Bhandari *et al.*, 2002)). Studies also reveal the important role of soil P and K for maintaining rice and wheat yields (Hobbs and Morris, 1996; Regmi *et al.*, 2002). Wheat yield was significantly greater in T9 and T5 than in other treatments. There was fluctuation in grain yield of wheat, which could be due to a year to year variation in rainfall and other climatic variables during crop growing period. The data revealed that the grain yield of wheat was significantly higher from the application of FYM (T9) followed by recommended fertilizer dose (T5). Grain yield of wheat in T5 (recommended dose in both rice and wheat) was higher than in T6 (recommended dose in wheat only). This suggests the need for applying recommended dose of NPK in rice and wheat for obtaining higher yield in a rice – rice – wheat system. Similarly, significant differences in grain yield were observed between NPK and NP treatments, which suggest importance of K for rice and wheat production in this area. Yield trends of wheat for N treatment (T2), NK treatment (T4) and NP treatment (T3) were similar to the control (no-fertilizer) treatment (Fig. 3). In fact, there was very low grain yield in all no P treatments (T1, T2, T4, and T7), which signifies the importance of P for rice and wheat production in this area.

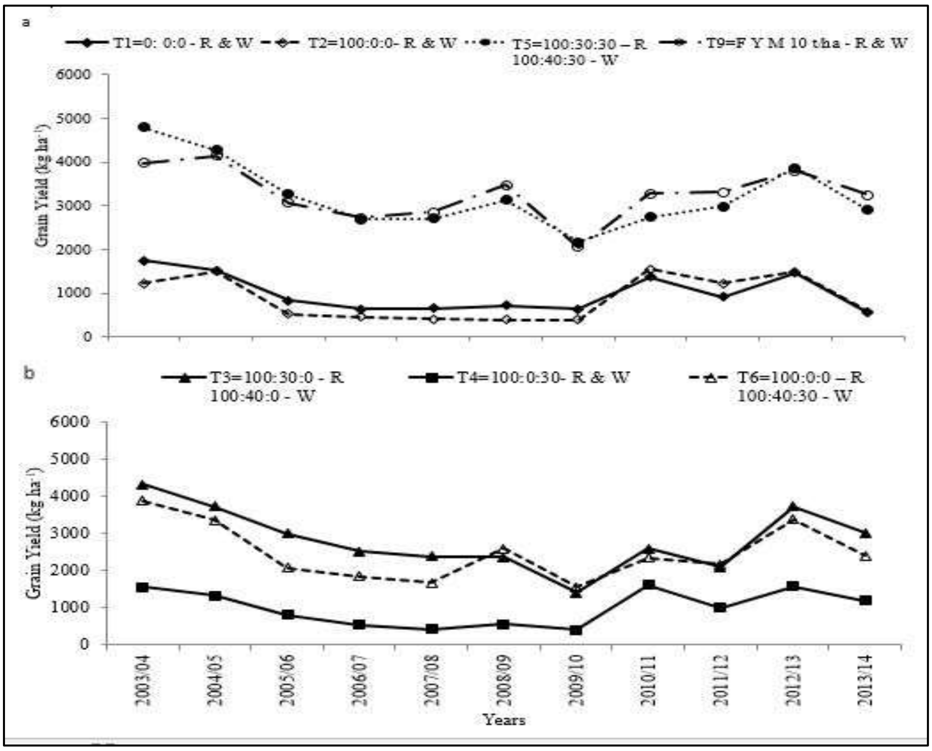

Fig. 1: Effect of long-term application of soil fertility treatments (a) T1, T2, T5 and T9 and (b) T3, T4, T6 on spring rice yield. T1 = no added nutrients; T2 = N only application; T3 = N and P application; T4 = N and K application; T5 = NPK (recommended rate); T6 = N only in rice and NPK in wheat (recommended practice); T9 = farmyard manure @10 Mg ha^{-1} for each crop.

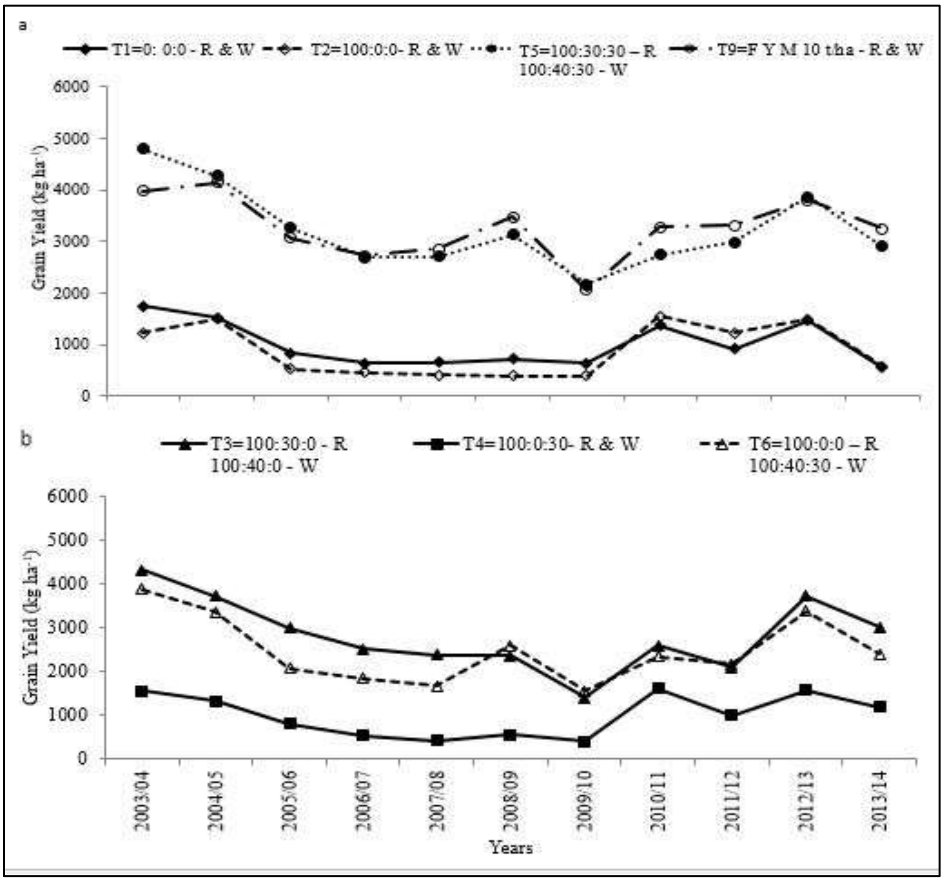

Fig. 2: Effect of long-term application of soil fertility treatments (a) T1, T2, T5 and T9 and (b) T3, T4, T6 on summer rice yield. T1 = no added nutrients; T2 = N only application; T3 = N and P application; T4 = N and K application; T5 = NPK (recommended rate); T6 = N only in rice and NPK in wheat (recommended practice); T9 = farmyard manure (10 Mg ha^{-1} for each crop).

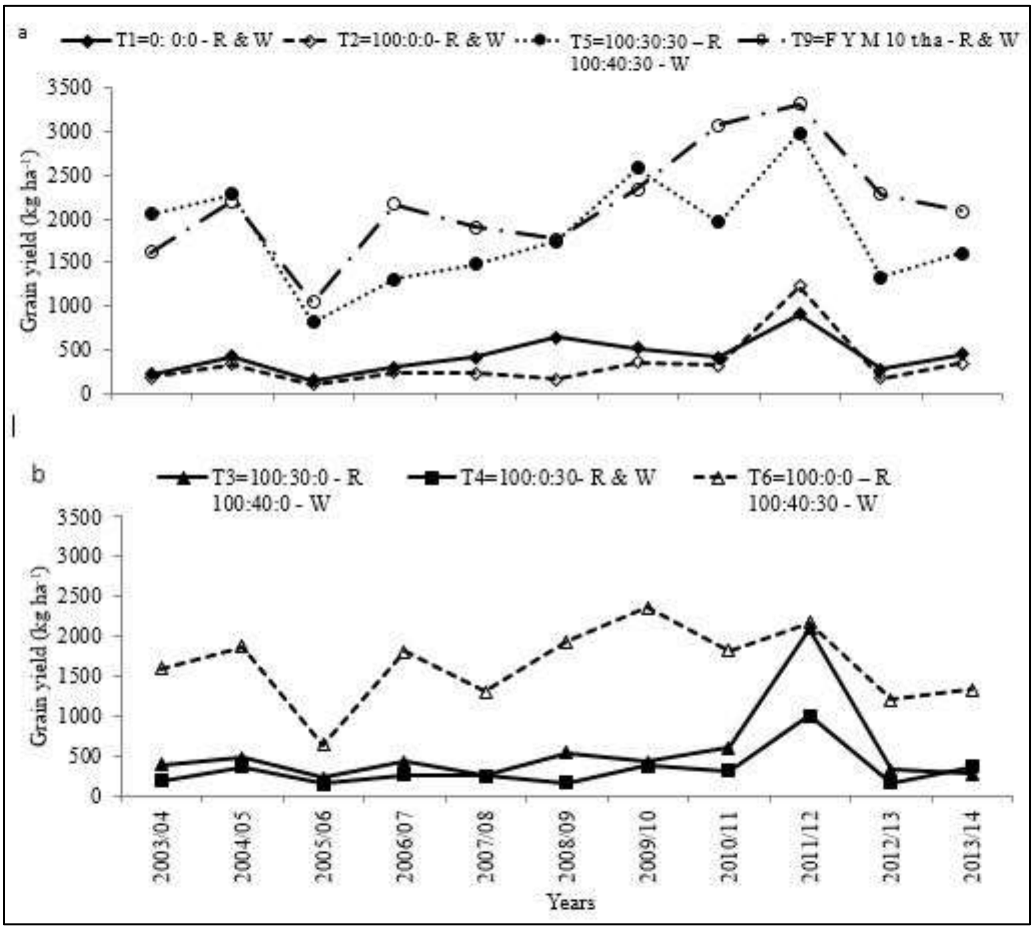

Fig. 3: Effect of long-term application of soil fertility treatments (a) T1, T2, T5 and T9 and (b) T3, T4, T6 on wheat yield. T1 = no added nutrients; T2 = N only application; T3 = N and P application; T4 = N and K application; T5 = NPK (recommended rate); T6 = N only in rice and NPK in wheat (recommended practice); T9 = farmyard manure (10 Mg ha^{-1} for each crop).

Overall, the yields of all three crops in this experiment showed declining trends. Decline in rice and wheat yields in plots that do not receive balanced nutrition is expected because these plots gradually deplete soil nutrient reservoir and influence the nutrient balance in the soils. A decline in crop yield in the plots that received full doses of inorganic (NPK) nutrients or FYM may suggest the need for revisiting the national nutrient recommendation to meet high yield potential of emerging crop varieties. This also warrants need of additional research to find factors controlling crop production in rice-rice-wheat system of Nepal. Declining trend of yields even with adequate NPK or FYM are potentially because of the declining indigenous supply of nutrients under intensive cropping system and inadequate nutrient supply to meet the crop requirement (Nambier and Abrol, 1989; Ghimire *et al*., 2012; Paudel *et al*., 2014).

Crop yield data in the treatment without P and K clearly suggested that soil P and K supply were limiting crop yields. Yields of both rice crops dropped when P was omitted, but two rice crops responded differently with P deficiency, indicating differences in P availability during spring and summer. It appears that insufficient application of K primarily limited yield in both NPK and FYM treatments. Potassium adsorption isotherm study demonstrated that soil from the FYM treatment had significantly higher K sorption capacity than the soil from NPK treatment (Regmi, 1994).

Soil Fertility Status

There was a significant effect of FYM and fertilizer NPK on soil pH, SOM, soil N, available P, and exchangeable K contents. Soil pH was lower in T9 (7.87) from the application of FYM as compared to other treatments. Application of FYM also maintained significantly higher SOM (91.9 Mg ha^{-1}) in T9 than other treatments. This SOM content was at least four times more than SOM at the time the experiment was established. The lowest SOM content was observed in control treatment (28.5 Mg ha^{-1}) (Table 3). Similarly, the highest soil N content was observed in T9 (3.54 Mg ha^{-1}) and the lowest in control treatment (1.70 Mg ha^{-1}). This finding corroborates with observations of Bhattacharyya *et al*. (2013) from a rice-rice cropping systems experiment in which application of FYM resulted in higher nutrients pools than other treatments in a long-term study in India. Huang *et al*. (2009) reported greater soil N content under organic manure than under inorganic fertilizers application.

Table 3: Effects of manures and fertilizer on soil pH, soil organic matter, nitrogen, phosphorus, and potassium contents of soil after 36 years of rice – rice – wheat experiment, National Wheat Research Program, Bhairahawa, Nepal, 2014.

Treatments†	Soil pH	SOM (Mg ha^{-1})	N (Mg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1	8.25^{a}	28.5^{c}	1.70^{c}	11.5^{c}	94.3^{b}
T_2	8.25^{a}	37.4^{bc}	1.96^{bc}	11.7^{c}	76.0^{bc}
T_3	8.16^{a}	48.1^{bc}	2.27^{bc}	94.0^{b}	35.0^{c}
T_4	8.23^{a}	37.3^{bc}	1.96^{bc}	14.7^{c}	103.3^{ab}
T_5	8.21^{a}	51.6^{b}	2.37^{b}	44.3^{c}	71.3^{bc}
T_6	8.20^{a}	48.2^{bc}	2.27^{bc}	10.7^{c}	62.3^{bc}
T_7‡	8.23^{a}	45.2^{bc}	2.18^{bc}	12.7^{c}	76.0^{bc}
T_8‡	8.18^{a}	46.2^{bc}	2.21^{bc}	38.0^{c}	71.7^{bc}
T_9‡	7.87^{b}	91.9^{a}	3.54^{a}	503.7^{a}	137.7^{a}
F test	***	***	***	***	* **
LSD(0.05)	0.16	19.98	0.58	45.50	40.0
CV %	1.1	23.9	14.7	31.9	28.6
Initial (1978)	8.0	23.0	1.97	9.8	126

†T1 = no added nutrients; T2 = N only application; T3 = N and P application; T4 = N and K application; T5 = NPK (recommended rate); T6 = N only in rice and NPK in wheat (recommended practice); T7 = 1/2 N of recommended practice; T8 = half NP; T9 = farmyard manure (10 Mg ha^{-1} for each crop). SOM, N, P and K stand for soil organic matter, nitrogen, phosphorus, and potassium. Different letters within a row indicate significant difference between treatments at P = 0.05.

‡30 cm stubble incorporation from each crop.

At the end of 36 years, the highest soil available phosphorus (503.7 kgha^{-1}) was observed in T9 and the lowest available soil phosphorus (11.5 kgha^{-1}) in the control plot. Soil exchangeable K was also significantly higher in T9 (137.7 kgha^{-1}) with the application of FYM. Soil fertility is not sustained from the NPK fertilizer application alone while application of FYM boosted the crop yield and improved the soil quality (Kumar and Tripathi, 1990). Declining yield trend at lower N level over the years may indicate the diminishing reservoir of nutrients in the soil (Regmi *et al*., 2002). Imbalanced fertilizer application can lead to nutrient deficiency of macro and micronutrients. Even balanced application of macronutrients devoid of micronutrients or organic materials can deteriorate soil physical, chemical and biological environment and micronutrient deficiency leading to low crop yields (Singh *et al*., 2014). In rice-wheat experiments, the SOM is reported to declines over time when conservation practices are not adopted (Regmi *et al*., 2002; Majumder *et al*., 2008). Studies also suggest changes in the chemical composition of SOM that influences N supply to the plants (Olk *et al*., 1996; Bronson and Hobbs, 1998).

Correlation analysis of yield data with soil properties revealed strong relationship among soil properties and crop yield (Table 4). Crop yields increased with a decrease in soil pH and increased with increase in SOM, N and P contents. There was no significant relationship between soil K and crop yields of rice and wheat.

Table 4: Pearson correlation coefficients of soil properties in 2014 with fourteen-year average (2001-2014) spring rice, summer rice, and wheat yield in rice-rice-wheat long-term experiment.

Soil properties	Crop yield†		
	Spring rice	**Summer rice**	**Wheat**
pH	-0.57(0.10)	-0.62(0.07)	-0.67(0.05)
SOM	0.69(0.04)	0.70(0.04)	0.77(0.02)
N	0.69(0.04)	0.70(0.04)	0.77(0.02)
P	0.49(0.18)	0.55(0.13)	0.61(0.08)
K	-0.01(0.99)	-0.07(0.86)	0.29(0.45)

†Values in parenthesis indicate significant probability of correlation coefficients for soil properties and crop yield. SOM, N, P, and K stand for soil organic matter, nitrogen, phosphorus, and potassium.

Conclusion

We studied the yields of rice and wheat during 2001-2014 and soil properties in 2014 in a long-term rice-rice-wheat system experiment. The control plot with an indigenous nutrient supply only supported the grain yield of 563 kg ha^{-1}, 267 kg ha^{-1}, and 447 kg ha^{-1} in summer rice, spring rice, and wheat respectively after 36-years of the rice-rice-wheat system and suggested depletion indigenous supply of essential nutrients. Depletion in soil fertility and inadequate fertilization, specifically P and K, caused low rice and wheat yield. Long-term FYM application can improve SOM, TN, available P, and exchangeable K contents compared to the nutrient status of other treatments. A fertilizer management strategy that ensures sufficient nutrient supply for high and stable overall productivity of rice–rice-wheat system is needed.

Acknowledgments

We acknowledge the Wheat Coordinator and all the past and present staffs of NWRP, Bhairahawa, Nepal for maintaining the long-term experiment and providing facilities and support to complete the present study. Without their assistance, the experiment would not have reached this stage.

References

Abroal IP, Bronson KF, Duxbury JM and Gupta RK (2000) Long-term soil fertility experiments in rice–wheat cropping systems. In: Rice–wheat Consortium Paper Series No. 6. Rice–wheat Consortium for the Indo-Gangetic Plains. New Delhi, India.

Adhikari C, Bronson KF, Panuallah GM, Regmi AP, Saha PK, Dobermann A, Olk DC, Hobbs PR and Pasuquin E (1999) On-farm soil N supply and N nutrition in the rice-wheat system of Nepal and Bangladesh. *Field Crops Res*. **64**: 273–286. DOI: 10.1016/S0378-4290(99)00063-5

Bhandari AL, Ladha JK, Pathak H, Padre AT, Dawe D and Gupta RK (2002)Yield and soil nutrient changes in a long-term rice-wheat rotation in India. *Soil Sci Soc Am J* **66**: 162-170. DOI: 10.2136/sssaj2002.0162

Bhattacharyya P, Nayak AK, Mohanty S, Tripathi R, Shahid M, Kumar A, Raja R, Panda BB, Roy KS, Neogi S, Dash PK, Shukla AK and Rao KS (2013) Greenhouse gas emission in relation to labile soil C, N pools and functional microbial diversity as influenced by 39 years long-term fertilizer management in tropical rice. *Soil Tillage Res* **129**: 93–105. DOI: 10.1016/j.still.2013.01.014

Bremner JM and Mulvaney CS (1982) Nitrogen Total. In: Page AL, Miller RH, Keeney DR. Method of soil analysis. Chemical and microbiological properties. Agronomy no.9. Part 2, 2nd eds. ASA & SSSA, Madison, WI. pp. 595–622.

Bronson KF and Hobbs PR (1998) The role of soil management in improving yields in the rice-wheat systems of South Asia. In: Lal R, editor. Soil quality and agricultural sustainability. Chelsea, Mich. (USA): Ann Arbor Press. pp. 129-139.

Chalk PM, Heng LK and Moutonnet P (2003) Nitrogen fertilization and its environmental impact. In 'Proceeding of 12th International World Fertilizer Congress, Beijing, China.pp.1-15.

Dewis J and Freitos (1970) F Physical and chemical methods of soil and water analysis. Soils Bulletin No. FAO. Rome.

Gami SK, Ladha JK, Pathak H, Shah M, Pasuquin E, Pandey SP, Hobbs PR, Joshi D and Mishra R (2000) Long-term changes in yield and soil fertility in a twenty-year rice-wheat experiment in Nepal. *Biol Fertil Soils* **34**: 73–78.

Ghimire R, Adhikari KR, Chen ZS, Shah SC and Dahal KR (2012) Soil organic carbon sequestration as affected by tillage, crop residue, and nitrogen application in rice–wheat rotation system. *Paddy Water Environ* **10**: 95-102. DOI: 10.1007/s10333-011-0268-0

Ghimire R, Machado S and Rhinhart K (2015) Long-term crop residue and nitrogen management effects on soil profile carbon and nitrogen in wheat-fallow systems. *Agron J* **107**(6): 2230-2240. DOI: https://doi.org/10.2134/agronj14.0601

Hobbs P and Morris M (1996) Meeting South Asia's future food requirements from rice-wheat cropping systems: priority issues facing researchers in the post-green revolution era. Natural Resources Group (NRG) Paper 96-01, CIMMYT, Mexico.

Huang QR, Hu F, Huang S, Li HX, Yuan YH, Pan GX and Zhang WJ (2009) Effect of long-term fertilization on organic carbon and nitrogen in a subtropical paddy soil. *Pedosphere* **19**: 727–734. DOI: 10.1016/S1002-0160(09)60168-5

Knudsen D, Peterson GA and Pratt PF (1982) Lithium, sodium and potassium. In: Page AL, Miller RH, Keeney DR (eds.) Method of soil analysis, chemical and microbiological properties. ASA & SSSA, Madison. pp. 228–238.

Kumar A and Tripathi RP (1990) Effect of continuous use of manure and fertilizer on physical properties of soil under paddy-wheat-cowpea cropping system. *Crop Res* **3**: 7-13.

Ladha JK, Hill JE, Duxbury JM, Gupta RK and Buresh RJ (2003) Improving the Productivity and Sustainability of Rice–wheat System: Issues and Impacts. ASA Spl. Publ. 65.p. 231.

Majumder B, Mandal B, Bandyopadhyay PK, Gangopadhyay A, Mani PK, Kundu AL and Mazumdar D (2008) Organic amendments influence soil organic carbon pools and rice–wheat productivity. *Soil Sci Soc Am J* **72(3)**: 775-785. DOI: 10.2136/sssaj2006.0378

Nambiar KKM (1994) Soil fertility and crop productivity under long-term fertilizer use in India. Indian Council for Agricultural Re-search, New Delhi, India.

Nambiar KKM and Abrol IP (1989) Long-term fertilizer experiments in India: An overview. *Fertilizer News*. **34**: 11-20.

Nelson DW and Sommers LE (1982) Total carbon, and organic carbon, and organic matter. In: Page AL (eds.) Method of soil analysis, chemical and microbiological properties. ASA & SSSA, Madison. pp. 539–579.

Nepal Agricultural Research Council (2014) Agricultural Statistics of Nepal 2013/14.NARC, Khumaltar, Nepal.

Olk DC, Cassman KG, Randall EW, Kinchesh P, Sanger L and Anderson JM (1996) Changes in chemical properties of soil organic matter with intensified rice cropping in tropical lowland soils. *Eur J Soil Sci* **47**: 293-303. DOI: 10.1111/j.1365-2389.1996.tb01403.x

Olsen SR andSommers LE (1982) Phosphorus. In: Page AL, Miller, R.H., Keeney, D.R. (Eds.) Method of soil analysis.

Chemical and microbiological properties.ASA & SSSA, Madison. pp. 403–430.

Palm C,Blanco-Canqui H,DeClerck F,Gatere L and Grace P (2014)Conservation agriculture and ecosystem services: An overview. *Agric Ecosyst Environ* **187**: 87-105. DOI: 10.1016/j.agee.2013.10.010

Paudel B,Acharya BS, Ghimire R, Dahal KR andBista P (2014)Adapting Agriculture to Climate Change and Variability in Chitwan: Long-Term Trends and Farmers' Perceptions. *Agric Res* **3**:165-174. DOI: 10.1007/s40003-014-0103-0

Rai SK andKhadka YG (2009) Wheat Production under long-term Application of Inorganic and Organic Fertilizers in Rice-Wheat system under Rainfed Conditions. *Nepal Agric Res J* **9**: 123-131.

Regmi AP (1994)Long-term effects of organic amendments and mineral fertilizers on soil fertility in a rice-wheat cropping system in Nepal.MS Thesis, University of the Philippines Los Banos, Phillipines.

Regmi AP,Ladha JK,Pathak H,Pashuquine E,Dawani D, Hobbs PR, Joshi D,MaskeySL andPandey SP (2002)Yield and soil fertility trends in a 20 years rice wheat experiment in Nepal. *Soil Sci Soc Am J* **66**: 857–867. DOI: 10.2136/sssaj2002.8570

Singh DK, PandeyPC and Gupta S (2014)Long-term addition of organics to sustain the system productivity of Rice (Oryza sativa L.) –Wheat (Triticumaestivum L.) under Indo-Gangetic Plains of India. *Int J Sci Res Innov Techn* **1**: 1-10.

Singh R andAgarwal SK (2004)Effect of organic manuring and nitrogen fertilization on productivity, nutrient use efficiency and economics of wheat (Triticumaestivum). Indian *J Agron* 49: 49-52.

Steel GD andTorrie TH (1980)Principles and Procedures of Statistics McGraw Hill Book Co. Inc., New York.

Tang X, Li JM, Ma YB,HaoX andLi XY (2008) Phosphorus efficiency in long-term (15years) wheat-maize cropping systems with various soil and climate conditions. *Field Crops Res* **108**: 231-237. DOI: 10.1016/j.fcr.2008.05.007

Timsina J and Connor DJ (2001) The productivity and management of rice-wheat cropping system: issues and challenges. *Field Crop Res* 69: 93-132. DOI: 10.1016/S0378-4290(00)00143-X

UN-FAO (2001)Farming Systems and Poverty, improving farmers' livelihoods in a changing world. Food and Agriculture Organization of the United Nations, FAO data repository.

Wang KR, Liu X, Zhou WJ,Xie XL and Buresh RJ (2004)Effects of nutrient recycling on soil fertility and sustainable rice production. *J Agro-Environ Sci* **23**: 1041-1045.

Wassmann R,Neue HU,Ladha JK andAulakh MS (2004)Mitigating greenhouse gas emissions from rice-wheat cropping systems in Asia. *Environ Dev Sustain* **6**: 65–90. DOI: 10.1023/B:ENVI.0000003630.54494.a7

Yadav RL,Dwivedi BS,Pandey PS (2000)Rice-wheat cropping system: Assessment of sustainability under green manuring and chemical fertilizer inputs. *Field Crops Res* **65**:15–30. DOI: 101016/S0378-4290(99)00066-0

Yao C, Yang S,Qian W, Lin Z and Wen M (2008)Regional summer precipitation events in Asia and their changes in the past decades. *J Geophys Res* **113**: 1-17. DOI: 101029/2007jd009603