Nepal Journal of Science and Technology 9 (2008) 7-13

Long Term Effects of Organic and Inorganic Fertilizers on Rice under Rice-Wheat Cropping Sequence

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Abstract

A long term field experiment was started in 1989 on alluvial soil of Inceptisol at Agronomy Research Farm, Khumaltar, Lalitpur to evaluate the effects of organic and inorganic fertilizers on soil properties and yields of rice under rice-wheat cropping sequence. Rice yield was monitored from 1998 to 2003. Chianung-242 rice variety was used as a test crop for all of the five years of experimentation. All the treatments manifested significant increase in rice yield over control. Results showed highest significant grain yield of 7.9 tons ha^{-1} from the sole application of farmyard manure (FYM) @ 10 tons ha^{-1}. The long-term experiment exhibited that the balanced application of chemical fertilizers alone did not sustain soil productivity under continuous cropping system. Application of 100 kg N ha^{-1} alone produced the yield up to 7.2 tons ha^{-1} whereas phosphorus and potassium did not affect the yields in most of the years. None of the soil properties, soil pH, organic carbon, total nitrogen, available phosphorus and potassium were affected by application of balanced fertilizers while with the application of 10 tons FYM ha^{-1}, the total nitrogen, available phosphorus and organic carbon contents in the soil were improved as compared to other treatments. The efficiency of fertilizers and manure was influenced by the amount of rainfall received as reflected by the higher grain yield during the higher rainfall years.

Key words: rice**,** alluvial soil, organic manure, inorganic fertilizers, rice-wheat system

Introduction

Long-term experiment plays an important role in understanding the complex interaction of plants, soils, climate and management practices and their effects on crop productivity. Rice and wheat are the major crops in Nepal. The area and production of both of the crops are increasing while the productivity is still not satisfactory to the level of their potential and scope. Soil fertility and plant nutrient management are key issues to be addressed to understand the reasons for declining crop yields. Proper use of chemical fertilizers and organic manures supports increased agricultural productivity and at the same time, helps maintain soil fertility (Gami & Sah 1988). Imbalanced use of synthetic fertilizers contribute to deterioration of soil quality as well as environment. For recommending appropriate technologies to maintain soil fertility as well the environment, it is necessary to evaluate long-term effects of inorganic and organic manures on soil properties. It is also necessary to meet the food requirement for growing population by producing more crop yields through maintaining soil fertility. Increment in the production of rice and wheat is not only due to the increment of area, but also due to the introduction of improved technologies including the use of chemical fertilizers. The effect of continuous application of chemical fertilizers on crop production and soil health has not yet been taken seriously. Imbalanced use of chemical fertilizers disturbs soil health. Recommendation of chemical fertilizers should be based upon soil analysis and crop response. Practice of using imbalanced chemical fertilizers by farmers has been posing a serious problem not only to agriculturists but also to policy makers, ecologists and environmentalists (Yadav *et al*. 1988).

The long-term soil fertility experiments, started sometimes between 1843 to 1856 by J. B. Lawes and J. H. Gilbert at Rothamsted (Johnston & Powlson 1994) are valuable repositories of information regarding the sustainability of intensive agriculture. It is valuable for understanding the relationships in the context of changing soil and crop management practices and productivity. It is also important for the reason that the data collected from constantly monitoring long-term experiment could be useful for improving statistical and simulation tools (IRRI 2000). Population is increasing globally by about 80 million people per year. By 2050, the world is likely to be inhabited by between 8 and 11 billion people (Fischer & Heilig 1998). The food grain production have stagnated for both rice and wheat crops for few years (Dawe & Dobermann 1999, Hobbs & Morris 1996). It may include either the changes in biochemical and physical composition of soil organic matter (SOM), gradual decline in the supply of soil nutrients due to inappropriate fertilizer applications causing nutrient imbalances (macro and micro), scarcity of surface and groundwater as well as poor water quality or the infestation of weeds (Paroda *et al.* 1994).

Generally farmers use to cultivate rice sequentially under rice-wheat cropping system in the same field. The productivity of rough rice under this system is only 2 t ha^{-1} (Pandey *et al.* 1998). A rice-wheat cropping system is widely cultivated in most parts of mid-hills and especially in the Indo-Gangetic alluvial plain area of Nepal. The rice-wheat systems of Kathmandu valley and surrounding areas are probably the most hunted by the modern agricultural technologies including the use of fertilizers. Although fertilizer use has been a prime contributing factor for the increased agricultural productivity in these areas, there are situations when they are not available in right time and in adequate quantity despite high price. Therefore, the use of fertilizers alone may not be a viable solution to sustain the rice-wheat cropping system, particularly for a resource poor country like Nepal. The information regarding the effects of long-term rice-based cultivation in this region is meager. Considering all these situations, this study on the long-term effect of organic and inorganic fertilizer use on the yield of rice and available soil nutrient was carried out.

Material and Methods

A long-term fertilizer trial was start in 1993 at the Agronomy Research Farm, Khumaltar, Lalitpur by Soil Science Division to study the long-term effect of inorganic and organic fertilizers on soil fertility and crop productivity under rice-wheat cropping system. The experiment was laid out in a randomized complete block design as described by Gomez and Gomez (1984) with eleven treatments replicated four times. The detail of the treatments has been presented in Table 1. The size of each plot was 4 x 3 m (12 m^2). Chemical sources of N, P and K were diammonium phosphate, urea and muriate of potash respectively. Full dose of organic manure was applied at the time of land preparation. Similarly, full dose of phosphorus and potash and half dose of nitrogen were applied at the time of rice transplanting. The 24-day-old seedlings were transplanted at 25 x 25 row-to-rows and plant-to-plant distance. The remaining N was top dressed at maximum tillering stage. Soybean was grown up to 15 days and incorporated into the same plot. Yield and yield components, grain yield, straw weight, number of tiller (1m^{-2}) panicle length (10 plants), plant height (10 plants) and 1000-grain weight were recorded at respective crop growth stages. Composite soil samples were taken after each crop harvest for chemical analysis. Plant samples were also taken for nutrients content analysis. Statistical analysis was done with the help of IRRISTAT (2005).

Table 1. Treatment details of the experiment

Treatment		Treatment	
No.	Details	No.	Details
1	0:0:0 N: P_2O_5: K_2O kg ha^{-1} Control	7	100:0:30 N: P_2O_5: K_2O kg ha^{-1*}
2	100:0:0 N: P_2O_5: K_2O kg ha^{-1}	8	50:0:0 N: P_2O_5: K_2O kg ha^{-1} + 15 cmwheat straw
3	100:30:0 N: P_2O_5: K_2O kg ha^{-1}	9	50:20:0 N: P_2O_5: K_2O kg ha^{-1}
4	100:0:30 N: P_2O_5: K_2O kg ha^{-1}	10	FYM 10 tons ha^{-1}
5	100:30:30 N: P_2O_5: K_2O kg ha^{-1}	11	Green Manure Incorporation (Soybean)
6	0:30:30 N: P_2O_5: K_2O kg ha^{-1}		

* Treatment 7 received phosphorus in successive wheat crop.

Results and Discussion

Yield and yield components

The yield and yield component data of rice have been presented in Table 2, 3, and 4. The inconsistency in the yields of rice in different experimental years is mainly due to rainfalls, which were erratic in the testing years. Grain (5.2 t ha^{-1}) and straw (4.4 t. ha^{-1}) yields were much lower in the control treatment (without fertilizer) than in the other treatments in most of the years. Analyses of the mean yield of the five years data showed the highest significant grain yield (7.9 t ha^{-1}) from the treatment number 10 (10 ton FYM ha^{-1}) and was significantly higher in all the years. Same treatment also produced the highest straw yield of 7.1 t ha^{-1}. In the longer run, soil fertility is not sustained from the balanced fertilizer application alone while application of FYM helps to boost up crop yield (Lal & Mathur, 1989a, Kabeerthumma *et al.* 1993) and improve physical soil status (Lal & Mathur, 1989b, Kumar & Tripathi 1990). Declining yield trend at lower N level over the years may indicate the diminishing supply capacity of soil. In most of the years, analytical data of grain and straw indicated no specific response of phosphorus and potassium (Table 2 and 3) in the alluvial soil of Khumaltar. However, application of 40 kg P_2O_5 ha^{-1} in treatment 5 in successive wheat crop might have its response on rice yield, which produced second highest yield of 7.35 t ha^{-1} (treatment- 5) as compared to 7.14 t ha^{-1} (treatment- 3).

Table 2. Mean grain yield of rice (t/ha), Khumaltar, 1998-2003

Treatment	1998/1099	1999/00	2000/01	2001/02	2002/03	Average
0:0:0 N: P_2O_5: K_2O kg ha^{-1}	6.07 e	5.47b	3.89 c	5.03 d	5.36 d	5.17 e
100:0:0 N: P_2O_5: K_2O kg ha^{-1}	7.77 bcd	7.13 a	6.55 ab	6.38 abc	8.03 ab	7.17 bc
100:30:0 N: P_2O_5: K_2O kg ha^{-1}	7.87 bcd	7.18 a	5.92 ab	6.31 abc	7.46 bc	6.95 bcd
100:0:30 N: P_2O_5: K_2O kg ha^{-1}	8.56 ab	7.58 a	6.28 ab	6.19 a-d	7.10 bc	7.14 bc
100:30:30 N: P_2O_5: K_2O kg ha^{-1}	8.50 abc	7.79 a	6.43 ab	6.36 abc	7.47 bc	7.31 b
0:30:30 N: P_2O_5: K_2O kg ha^{-1}	7.78 bcd	7.02 a	5.83 ab	5.74 bcd	6.52 c	6.58 d
100:0:30 N: P_2O_5: K_2O kg ha^{-1}	8.44 abc	7.15 a	6.94 a	6.61 ab	7.63 bc	7.35 b
50:0:0 N: P_2O_5: K_2O kg ha^{-1} + 15 cm	7.32 cd	6.89 a	5.68 b	5.49 bcd	6.75 c	6.43 d
50:20:0 N: P_2O_5: K_2O kg ha^{-1}	7.51 bcd	7.49 a	5.97 ab	5.33 cd	7.23 bc	6.71 cd
FYM 10 tons ha^{-1}	9.17 a	7.53 a	6.45 ab	7.71 a	9.05 a	7.86 a
Green manure incorporation (Soybean)	7.06 de	7.27 a	5.55 b	6.12 a-d	6.70 c	6.54 d
Mean	7.82	7.14	5.96	6.06	7.21	6.84
CV (%)						11.1
LSD (5 %)						1.06
S.E.D. (DF 40)						0.54

Means followed by a common letter are not significantly different at the 5 % level by DMRT.

Table 3. Mean straw yield of rice (t/ha), Khumaltar, 1998-2003

Treatment Combination	1998/099	1999/00	2000/01	2001/02	2002/03	Average
0:0:0 N: P_2O_5: K_2O kg ha^{-1}	2.82 a	5.39 d	2.99 bc	5.07 bc	5.81 d	4.42
100:0:0 N: P_2O_5: K_2O kg ha^{-1}	3.38 a	9.78a b	5.31 a	5.98 abc	10.37 ab	6.97
100:30:0 N: P_2O_5: K_2O kg ha^{-1}	3.95 a	8.69 bc	4.70 ab	7.15 ab	8.79 bc	6.66
100:0:30 N: P_2O_5: K_2O kg ha^{-1}	4.03 a	9.00 bc	4.68 ab	7.39 a	8.52 bc	6.72
100:30:30 N: P_2O_5: K_2O kg ha^{-1}	3.39 a	11.15 a	5.05 ab	6.29 abc	9.01 bc	6.98
0:30:30 N: P_2O_5: K_2O kg ha^{-1}	3.83 a	7.36 c	4.05 abc	6.07 abc	7.48 cd	5.76
100:0:30 N: P_2O_5: K_2O kg ha^{-1}	3.62 a	7.43 c	5.00 ab	6.65 abc	8.29 bc	6.19
50:0:0 N: P_2O_5: K_2O kg ha^{-1} + 15 cm	2.58 a	7.68 c	2.16 c	4.63 c	5.78 d	4.57
50:20:0 N: P_2O_5: K_2O kg ha^{-1}	3.45 a	7.38 c	3.50 abc	5.39 abc	9.64 ab	5.88
FYM 10 tons ha^{-1}	4.49 a	7.89 bc	4.73 ab	6.82 ab	11.51 a	7.086
Green manure incorporation (Soybean)	3.68 a	7.81 bc	4.50 ab	6.03 abc	7.48 c d	5.89
Mean	3.57	8.14	4.24	6.13	8.43	6.10
CV (%)						21.7
LSD (5 %)						1.85
S.E.D. (DF 40)						0.94

Regarding the tiller number per square meter, the highest number of 254 was observed in treatment 11 which were at par with treatment 10 and 4 (254 and 235 respectively) (Table 4). Other yield components like plant height, panicle length and 1000 grains weight were not likely to be distinguished from each other (Table 4).

Table 4. Combined mean over 5 years of plant height, panicle length, and tiller number of rice, Khumaltar, 1998-2003

Treatment	Plant Height (cm)	Panicle Length (cm)	Tiller (No. m^{-2})	1000 grain wt.
0:0:0 N: P_2O_5: K_2O kg ha^{-1} (Control)	112.6 a	21.8 b	220 c	34.7ab
100:0:0 N: P_2O_5: K_2O kg ha^{-1}	113.1 a	22.2 ab	218 c	35.1a
100:30:0 N: P_2O_5: K_2O kg ha^{-1}	105.9 a	22.2 ab	227 bc	34.1abc
100:0:30 N: P_2O_5: K_2O kg ha^{-1}	106.6 a	22.3 ab	235 abc	33.0bc
100:30:30 N: P_2O_5: K_2O kg ha^{-1}	106.9 a	22.3 ab	226 bc	34.1abc
0:30:30 N: P_2O_5: K_2O kg ha^{-1}	104.5 a	22.1 ab	226 bc	33.4abc
100:0:30 N: P_2O_5: K_2O kg ha^{-1}	104.8 a	22.3 ab	220 c	34.0abc
50:0:0 N: P_2O_5: K_2O kg ha^{-1} + 15 cm stubbles	109.4 a	22.6 a	214 c	32.6c
50:20:0 N: P_2O_5: K_2O kg ha^{-1}	105.2 a	22.3 ab	221 c	34.8ab
FYM 10 tons ha^{-1}	108.7 a	22.2 ab	245 ab	32.9bc
Green manure incorporation (Soybean)	108.3 a	21.9 b	254 a	34.8b
Mean	107.8	22.2	227	33.9
CV (%):	13.0	3.9	14.6	7.8
LSD (5 %):	19.5	1.2	46.3	3.7
S.E.D.: (df 40)	9.9	0.6	23.4	1.9

Nutrients Balance and Soil Fertility Status

As described by Nambiar and Ghosh (1984) and Biswas and Bendi (1989), nutrient uptake by rice was estimated by analyzing nutrient contents in grain and straw. Nutrient balance was calculated from the particular annual nutrient addition and removal in grain and straw (Table 5) for each of the treatment. Nutrient balance for N, P and K were negative in all the treatments. The highest negative balance of N (-84.74 kg ha^{-1}) was obtained in treatment 1 where no nutrients were added. This study however, does not account the losses from soil as ammonium and nitrate volatilization (Freney *et al.* 1981), denitrification (Patrik & Tusneen 1972), and leaching (Harada & Kutsuna 1955).

As compared to phosphorus, crop removal was higher in K ranging from 90.13 to 133.67 kg ha^{-1} (Table 5). Phosphorus was added annually at the rate 30 and 20 kg ha^{-1} while potash was applied at the rate of 30 kg ha^{-1} annually. Despite such a high negative balance of K over the years, rice was not showing response of K application. It appears that K is released adequately from minerals i.e. non-exchangeable forms in the soil. Ganeshmurty *et al.* (1985) have also reported similar observation.

Table 5. Mean annual nutrient balance in rice field

Treatment	Annual N Addition (kg ha^{-1})	Nitrogen N Uptake (kg ha^{-1})			Balance(kg ha^{-1})
		Grain	Straw	Total	
1. N_0	0	57.71	27.03	84.74	-84.75
2. N_{100}	100	81.80	46.39	128.19	-28.19
3. N_{100}	100	75.26	46.65	121.91	-21.91
4. N_{100}	100	82.38	49.11	131.49	-31.19
5. N_{100}	100	85.38	48.66	134.04	-34.04
6. N_{100}	100	86.25	44.14	130.39	-30.39
7. N_{50}	50	76.85	33.90	110.75	-60.75
8. N_{50}	50	78.59	35.55	114.14	-64.14

Treatments	Annual P_2O_5 addition (kg ha^{-1})	P uptake (kg ha^{-1})			Balance(kg ha^{-1})
		Grain	Straw	Total	
1. P_0	0	24.82	21.46	46.27	-46.27
2. P_{30}	30	35.88	30.45	66.33	-36.33
3. P_{30}	30	42.85	41.38	84.23	-54.23
4. P_{30}	30	33.47.	37.43	70.89	-40.89
5. P_{20}	20	36.84	24.27	61.11	-41.11

Potassium

Treatment	Annual K_2O addition (kg ha^{-1})	K uptake (kg ha^{-1})			Balance (kg ha^{-1})
		Grain	Straw	Total	
1. K_0	0	33.39	56.75	90.13	-90.13
2. K_{30}	30	45.42	83.18	128.6	-98.6
3. K_{30}	30	52.36	81.30	133.66	-103.66
4. K_{30}	30	45.83	86.71	132.54	-102.54
5. K_{30}	30	46.06	83.78	129.84	-99.84

Note: Among the 11 treatments 8, 5, and 5 which were treated with N, P, and K were selected respectively for the balance sheet

For pH and soil nutrient status, surface soil (0-20 cm) was analyzed each year after the harvest of rice. Soil pH was strongly acidic and no change was observed even with the fertilizer application at various doses. The organic carbon content of soil was very low to low, whereas total N content was medium to low in range (Table 6). Some increment in available phosphorus was observed in the plots treated by phosphorus and FYM. Phosphorus and potassium ranged from medium to very high categories. From Table 6 it is noticeable that the regular application of FYM might significantly increase the available phosphorus, total nitrogen and carbon contents in the soil but not the potassium level.

Table 6. Soil analysis combined mean of five years under different treatments

Treatments	Soil pH	Available P(kg ha^{-1})	Available K	Total N(%)	Organic Carbon
0:0:0 N: P_2O_5: K_2O kg ha^{-1}	4.9	193.4	162.1	0.12	1.55
100:0:0 N: P_2O_5: K_2O kg ha^{-1}	4.7	256.35	191.6	0.16	1.79
100:30:0 N: P_2O_5: K_2O kg ha^{-1}	4.9	282.1	223.2	0.15	1.89
100:0:30 N: P_2O_5: K_2O kg ha^{-1}	4.7	274.7	241.0	0.16	2.02
100:30:30 N: P_2O_5: K_2O kg ha^{-1}	4.8	292.4	260.5	0.15	1.85
0:30:30 N: P_2O_5: K_2O kg ha^{-1}	4.7	284.4	279.9	0.16	1.89
100:0:30 N: P_2O_5: K_2O kg ha^{-1}	4.7	279.2	237.9	0.16	1.92
50:0:0 N: P_2O_5: K_2O kg ha^{-1} + 15 cm wheat straw	4.8	251.9	220.4	0.17	2.09
50:20:0 N: P_2O_5: K_2O kg ha^{-1}	4.8	272.1	210.3	0.15	1.96
FYM 10 tons ha^{-1}	4.8	315.2	243.5	0.19	2.22
Green manure incorporation ((Soybean)	4.8	248.7	200.1	0.16	1.96
Mean	4.8	268.2	224.7	0.15	1.92
CV (%)	4.7	17.6	15.9	14.7	14.5
LSD (5 %)	0.31	65.97	49.96	0.03	0.67
S.E.D.	0.16	33.41	25.3	0.02	0.19

From the results of the five-year long-term experiment, it is clear that the recommended chemical fertilizer dose of 100:30:30 N: P_2O_5: K_2O kg ha^{-1} for rice crop seems to be inadequate for boosting its yield and soil productivity. Long-term application of FYM @ 10-tons ha^{-1} was found to enhance its yield and increased the soil nutrients content in the soil.

In conclusion, the combine use of inorganic and organic sources of plant nutrients or integrated plant nutrient system (IPNS) could be beneficial to improve crop productivity and soil-physico-chemical properties in a sustainable manner without any environmental damage. While considering the soil acidity during the experiment period, it is now essential to apply lime for correcting existing soil acidity, which would, in other way, help plants nutrients to be available from their fixed form.

Acknowledgement

Authors are highly grateful to Dr. S. L. Maskey, former Chief of Soil Science Division, Dr. D. P. Sherchan and Dr. K. B. Karki; present Chief of Soil Science Division Khumaltar for providing supports to carry out the field experiment and laboratory analyses of soil and plant samples as well as valuable suggestions during the research period. All the staff who were directly and indirectly involved in the experiment are duly acknowledged for their precious support without which this experiment would not have been accomplished. Last but not least, the authors feel privileged to thank Nepal Agricultural Research Council (NARC) for endorsing the proposed research proposal in the NARC system and financial support to carry out this work by way of sponsoring "Long term fertilizer experiment under rice-wheat system" at the Agronomy Research Farm, Khumaltar, Lalitpur.

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