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EFFECT OF LONG TERM INTEGRATED NUTRIENT MANAGEMENT ON SOIL N, P AND K FRACTIONATIONS IN TERRACED LAND

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ABSTRACT

An experiment with twelve treatments involving NPK, FYM, poultry litter, forest litter, Azospirillum and Zn either alone or in combinations applied continuously for eleven years was conducted to evaluate the influence of long term integrated nutrient management practices on various forms of soil nitrogen, phosphorous and potassium in terraced land at Medziphema (Nagaland). The results revealed that the highest NH_4-N content was recorded in NPK+ FYM followed by NPK+ FYM+ Zn, whereas the highest NO_3-N content was in NPK treatment. After eleven years, the rate of buildup of available N in various nutrient management practices was 0.6 to 12.7 kg N ha^{-1} yr^{-1} with an average of 6.7 kg N ha^{-1} yr^{-1}, whereas, the rate of buildup of organic N in various nutrient management practices was 12.2 to 48.9 kg N ha^{-1} yr^{-1} with an average of 34.9 kg N ha^{-1} yr^{-1}. The accumulation of available N in different treatments after eleven years brought about a change in soil fertility status from low to medium in all the treatments except in control, ½N+ PK, ½N+ PK+ Azospirillum and forest litter burned+ ½ FYM treatments. On an average, NH_4-N, NO_3-N, available N and organic N represented 2.8, 0.7, 7.4 and 86.7% of total N. Among treatments, NPK+ poultry litter favoured significantly highest build up in solution P, available P, inorganic P, organic P and total P. The accumulation of available P in different treatments caused a change in P fertility status from low to medium in all the treatments except in ½N+ PK and forest litter burned+ ½ FYM treatments after eleven years of integrated nutrient management. The rate of buildup of organic P in various nutrient management practices was 0.4 to 7.5 kg P ha^{-1} yr^{-1} with an average of 5.0 kg P ha^{-1} yr^{-1}, whereas, rate of buildup of total P was 0.9 to 14.1 kg ha^{-1} yr^{-1} with an average of 10.2 kg ha^{-1} yr^{-1}. On an average, solution P, inorganic P, available P and organic P represented 0.2, 40.3, 2.8 and 59.6% of total P. All the forms of soil potassium were highest in ½N+ PK+ ½N forest litter treatment. Both water soluble K and exchangeable K content in various nutrient management practices exhibited similar trends. The rate of buildup of available K in various integrated nutrient management practices was 0.7 to 8.2 kg K ha^{-1} yr^{-1} with an average of 4.7 kg K ha^{-1} yr^{-1}. After eleven years of integrated nutrient management, K fertility status changed from low to medium only NPK+ FYM, NPK+ forest litter, NPK+ FYM+ Zn, ½N+ PK+ ½N FYM and ½N+ PK+ ½N forest litter treatments. On an average, water soluble K, exchangeable K, available K and non-exchangeable K represented 0.2, 0.6, 0.7 and 3.9% of total K.

Key words: Terraced land, integrated nutrient management, N, P and K forms

INTRODUCTION

Bench terracing is one of the reliable conservation measure frequently employed to manipulate surface topography of hill slopes to convert them to suit intensive agriculture. Bench terracing usually expose infertile and biologically inert subsoil of less desirable properties for growth than those of the top soil. The initial production potential of terraced land is generally low. To increase immediate as well as long term productivity of terraced land, sound fertility management practices are obviously needed. It improves the nutrient status of the exposed subsoil and also ensures a steady build up of soil fertility together with other physico-chemical properties of the soil suitable for plant growth. Organic residue influences a number of physical, chemical and biological properties of the soil and their combined effect together ensure favorable plant growth conditions in soil. The effect of long term integrated nutrient management practices on various forms of soil nitrogen, phosphorous and potassium on terraced land in acid soils of Nagaland has not been studied. The present investigation was carried out to study the effect of integrated nutrient management practices on various forms of soil N, P and K on terraced land under upland rice cultivation in Nagaland.

MATERIALS AND METHODS

A hill slope of 22% was bench terraced in 2001 at the experimental farm of the School of Agricultural Sciences and Rural Development, Nagaland University, Medziphema, Nagaland. A field experiment on these terraces was

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established in 2001 and has been maintained since then. The soil samples collected in *Kharif* 2011 after eleven years of nutrient management and continuous cultivation of upland rice forms the basis of this investigation.

The experiment was laid out in randomized block design with twelve treatments and replicated thrice. During each year of experimentation, the plots were manually dug with spade and prepared to ensure good seedbed. The recommended dose of 60 kg N, 60 kg P_2O_5 and 40 kg K_2O ha^{-1} for rice was applied. The farmyard manure, poultry litter and forest litter were applied @ 10.0 t ha^{-1}, 3.3 t ha^{-1} and 5.0 t ha^{-1}, respectively. For ½ N (30 kg ha^{-1}) through FYM, poultry litter and forest litter, calculated amounts of these organic sources containing 0.5, 1.5 and 0.1% N, respectively were applied (6.0, 2.0 and 30.0 t ha^{-1}, respectively) to the soil. Zinc (Zn) was applied @ 10 kg ha^{-1} in the form of $ZnSO_4.7\ H_2O$ as basal dose. Azospirillum was used as seed treatment before sowing @ 20 g kg^{-1} of seed. For Forest litter burned+ ½ FYM treatments which resembles farmers' practice in Nagaland, the required amount of forest litter @ 5.0 t ha^{-1} was evenly spread on the soil surface and burned there. The ash was incorporated thoroughly in the soil. Thereafter, 5 t FYM ha^{-1} (½ FYM) was applied 30 days before sowing and mixed in the soil. The FYM, poultry litter and forest litter were applied one month before sowing and mixed well in the soil. Upland rice variety Teke (landrace) was sown with a spacing of 20 cm row to row using a seed rate of 75 kg ha^{-1}. Soil samples from individual plots were collected after the harvest of rice crop and air dried at room temperature.

The NH_4-N and NO_3-N was determined using procedure of Chopra and Kanwar (1991). The available N was determined by alkaline permanganate method of Subbiah and Asija (1956). Organic N was determined by using sodium carbonate and concentrated sulphuric acid as described by Chopra and Kanwar (1991). The total N in soil was determined by modified Kjeldahl digestion and distillation method (Jackson, 1973). The inorganic P was extracted over night with 100 ml 2N H_2SO_4 as suggested by Anderson (1960). The available P in soil was extracted by Bray's method No. 1 (Bray and Kurtz, 1945). The P content in different extracts and triacid digested material was measured using ascorbic acid method (Watanabe and Olsen, 1965). The difference between total and inorganic P was taken as organic P. Water soluble K was extracted with distilled water and estimated flame photometrically. The available K was extracted from the soil with neutral normal ammonium acetate (Jackson, 1973) and estimated flame photometrically. The difference between available K and water soluble K was considered as exchangeable K. The non-exchangeable K was determined by extracting the soil with 1N HNO_3 according to the procedure as described by Black (1965). The total K in the soil was measured flame photometrically in the triacid digest of the soil.

RESULTS AND DISCUSSION

Forms of Nitrogen

NH_4-N and NO_3-N

The NH_4-N and NO_3-N content in the soil ranged from 24.3 to 64.8 mg kg^{-1} with an average of 48.9 mg kg^{-1}, and 5.8 to 15.8 mg kg^{-1} with an average of 11.6 mg kg^{-1}, respectively (Table 1). After eleven years of integrated nutrient management, the highest NH_4-N was recorded in NPK+ FYM and the lowest in control. The NH_4-N in NPK+ FYM, NPK+ poultry litter, NPK+ forest litter and NPK+ FYM+ Zn showed a significant increase over NPK. The NH_4-N in ½N+ PK+ ½N FYM, ½N+ PK+ ½N poultry litter and ½N+ PK+ ½N forest litter was also significantly higher as compared to NPK. The increase in NH_4-N over control in different treatments varied from 9.3 to 62.5% with an average of 49.0%. The significant increase in NH_4-N in NPK+ FYM, NPK+ FYM+ Zn, NPK+ poultry litter and NPK+ forest litter over NPK was 36.3, 35.4, 34.1 and 32.3%, respectively. Integrated use of NPK fertilizers with organic sources might have resulted accumulation of organic matter of lower C: N ratio and its subsequent decomposition and mineralization could have contribute towards higher NH_4-N accumulation. Low levels of NH_4-N in control, ½N+ PK, NPK, ½N+ PK+ *Azospirillum* and forest litter burned+ ½ FYM treatments might be either due to low rate of ammonification of organic N as affected by its input or due to NH_4-N use by rice or its transformation to other forms of N. Gupta *et al.* (2005) also observed more accumulation of NH_4-N in soil profile with the application of FYM as compared with biogas slurry.

Table 1: Effect of integrated nutrient management practices on forms of soil nitrogen (mg kg^{-1})

Treatment	NH_4-N	NO_3-N	Available N	Organic N	Total N
T_1-Control	24.3	5.8	101.2	1378.4	1712.6
T_2-½N+ PK	38.6	10.1	106.4	1466.3	1737.5
T_3-NPK	41.3	15.8	126.7	1540.7	1768.3
T_4-NPK+ FYM	64.8	15.2	159.8	1611.9	1798.4
T_5-½N+ PK+ ½N FYM	55.0	11.9	136.3	1567.8	1786.2
T_6-NPK+ poultry litter	62.7	14.9	157.3	1618.3	1808.4
T_7-½N+ PK+ ½N poultry litter	56.3	11.5	135.8	1570.2	1784.3
T_8-NPK+ forest litter	61.0	13.8	138.5	1577.3	1789.1
T_9-½N+ PK+ ½N forest litter	51.4	9.2	130.3	1571.4	1786.3
T_{10}-½N+ PK+ *Azospirillum*	40.5	10.8	116.4	1475.2	1740.5
T_{11}-NPK+ FYM+ Zn	63.9	14.6	163.5	1609.7	1802.7
T_{12}-Forest litter burned+ ½ FYM	26.8	6.1	104.1	1438.5	1728.8
SEm $\pm$	2.51	0.75	3.01	9.21	5.07
CD (p=0.05)	7.36	2.20	8.83	27.07	14.87

The NO_3-N content in the soil increased significantly in all the treatments except forest litter burned+ ½ FYM over control. The highest NO_3-N was observed in NPK. The NO_3-N in NPK+ FYM, NPK+ poultry litter and NPK+ FYM+ Zn was significantly higher than ½N+ PK, ½N+ PK+ ½N poultry litter, ½N+ PK+ ½N FYM and ½N+ PK+ ½N forest litter. The increase in NO_3-N over control in different treatments ranged from 4.9 to 63.3% with an average of 48.3%. The significant decrease in NO_3-N in ½N+ PK+ ½N FYM, ½N+ PK+ ½N poultry litter and ½N+ PK+ ½N forest litter over NPK was 24.7, 27.2 and 41.8%, respectively. This might be either due to higher NO_3-N uptake or higher NO_3 immobilization during decomposition of added organic residues. Bharadwaj *et al.* (1994) reported that application of FYM along with NPK decreased NO_3-N content in soil as compared to application of NPK fertilizer alone. The highest NO_3-N content in NPK treatment might be due to higher nitrification of urea fertilizer. Duraisami *et al.* (2001) also reported that NO_3-N content in the soil increased with the application of increasing doses of fertilizer N. The fact that NH_4-N accumulated on addition of NPK and organic sources as compared to NO_3-N suggested that the process of ammonification dominated the nitrification in treatments where integrated application of fertilizer N and organic residues was made. This may be because of the fact that *Nitrosomonas* and *Nitrobacter* are slow growers (Russell, 1973) and their population in resultant surface soil after terracing might also be low as compared to ammonifiers.

Available N

Available N content in the soil varied from 101.2 to 163.5 mg kg^{-1} with an average of 131.4 mg kg^{-1} (Table 1). Available N content in the soil increased significantly in all the treatments except ½N+ PK and forest litter burned+ ½ FYM over control. Among the treatments, highest available N was recorded in NPK+ FYM+ Zn treatment, whereas, lowest available N was recorded in control. The available N in NPK+ FYM, NPK+ FYM+ Zn, NPK+ poultry litter and NPK+ forest litter was significantly higher than NPK. Substituting half N through FYM or poultry litter also showed a significant increase in available N as compared to NPK. The significant increase in available N on addition of NPK fertilizers, FYM, poultry litter, forest litter and other amendments in different combinations to upland rice are in agreement with those reported by other workers (Bajpai *et al*., 2006; Duraisami *et al*., 2001). The increase in available N in soil ranged from 6.5 to 139.6 kg ha^{-1} with an average of 73.7 kg ha^{-1} over control. After eleven years, the rate of build up of available N in various nutrient management practices was estimated to be 0.6 to 12.7 kg N ha^{-1} yr^{-1} with an average of 6.7 kg N ha^{-1} yr^{-1}. Similar results were also reported by Humtsoe and Chauhan (2005). Lowest build up of available N (0.6 kg N ha^{-1} yr^{-1}) observed in forest litter burned+ ½ FYM was in agreement with Humtsoe and Chauhan (2005) who reported that Alder litter burned and resultant ash mixed in surface soil brought about minimum build up of available N. Fire induced changes in the nature of soil humus perhaps rendering it more mineralizable may be partly responsible for the increase in available N content in forest litter burned+ ½ FYM. Laxminarayana (2006) also observed a significant increase in available N content in NPK+ poultry litter and NPK+ FYM over NPK treatment after three years of continuous cropping. The combined effect of the processes of transformation of N added through fertilizers and organic sources, mineralization of native organic N compound and loss of N from soil including crop removal may be responsible for the increase in available N pool in these treatments. The accumulation of available N in different treatments after eleven years brought about a change in soil fertility status from low to medium in all the treatments except in control, ½N+ PK, ½N+ PK+ *Azospirillum* and forest litter burned+ ½ FYM treatments. This suggested that addition of NPK in combination with FYM, poultry litter and forest litter favoured comparatively higher build up of available N.

Organic N and total N

The organic N and total N content in the soil ranged from 1378.4 to 1618.3 mg kg^{-1} with an average of 1535.5 mg kg^{-1}, and 1712.6 to 1808.4 mg kg^{-1} with an average of 1770.3 mg kg^{-1}, respectively (Table 1). The organic N and total N content in the soil increased significantly in all the treatments over control. After eleven years of continuous integrated nutrient management, highest organic N and total N was found in NPK+ poultry litter treatment. Both organic N and total N in NPK+ FYM, NPK+ FYM+ Zn, NPK+ poultry litter and NPK+ forest litter showed a significant increase over NPK. The treatments receiving half N from fertilizer and other half from organic sources also recorded significantly higher organic N and total N content as compared to NPK. After eleven years, the rate of build up of organic N and total N in various nutrient management practices was estimated to be 12.2 to 48.9 kg N ha^{-1} yr^{-1} with an average of 34.9 kg N ha^{-1} yr^{-1}, and 3.3 to 19.5 kg N ha^{-1} yr^{-1} with an average of 12.8 kg N ha^{-1} yr^{-1}, respectively. The significant increase in organic N content in integrated treatments over NPK might be due to the variation in N content in these organic residues and its influence on the rate of decomposition and synthesis of microbial metabolites and their C: N ratio, combine effect of which would result variation in the cumulative build up of organic N in these treatments. Sihag *et al.* (2005) also found positive effect on the build up of organic N with the application of FYM along with inorganic fertilizers. The lowest rate of build up of total N in forest litter burned+ ½ FYM treatment (3.3 kg N ha^{-1} yr^{-1}) perhaps is because of combine effect of comparatively low input of N in this treatment and fire induced loss of soil N and N in forest litter. These results corroborate the findings of other workers (Laxminarayana and Patiram, 2006). An analysis of data established that on an average, NH_4-N, NO_3-N, available N and organic N represented 2.8, 0.7, 7.4 and 86.7% of total N.

Table 2: Effect of integrated nutrient management practices on forms of soil phosphorus (mg kg^{-1})

Treatment	Solution P	Inorganic P	Available P	Organic P	Total P
T_1-Control	0.2	74.6	2.0	123.6	198.2
T_2-½N+ PK	0.3	98.8	3.7	139.7	238.5
T_3-NPK	0.5	100.1	6.0	144.7	244.8
T_4-NPK+ FYM	0.8	101.6	8.9	158.8	260.4
T_5-½N+ PK+ ½N FYM	0.7	104.3	7.9	150.8	255.1
T_6-NPK+ poultry litter	0.9	107.2	10.2	160.2	267.4
T_7-½N+ PK+ ½N poultry litter	0.7	103.7	9.6	156.0	259.7
T_8-NPK+ forest litter	0.5	102.5	7.0	148.1	250.6
T_9-½N+ PK+ ½N forest litter	0.4	101.1	7.3	147.9	249.0
T_{10}-½N+ PK+ *Azospirillum*	0.4	101.4	6.5	140.8	242.2
T_{11}-NPK+ FYM+ Zn	0.8	106.0	9.8	156.3	262.3
T_{12}-Forest litter burned+ ½ FYM	0.2	80.1	2.1	125.6	205.7
SEm $\pm$	0.07	1.26	0.41	3.11	3.74
CD (p=0.05)	0.19	3.70	1.20	9.13	10.98

Forms of Phosphorus

Solution P and inorganic P

The solution P and inorganic P content in the soil ranged from 0.2 to 0.9 mg kg^{-1} with an average of 0.5 mg kg^{-1}, and 74.6 to 107.2 mg kg^{-1} with an average of 98.5 mg kg^{-1} (Table 2). Solution P showed a significant increase in all the treatments except in ½N+ PK, ½N+ PK+ ½N forest litter, ½N+ PK+ *Azospirillum* and forest litter burned+ ½ FYM over control. The solution P in NPK+ poultry litter, NPK+ FYM and NPK+ FYM+ Zn showed a significant increase over

NPK and NPK+ forest litter treatments. The solution P in ½N+ PK+ ½N poultry litter and ½N+ PK+ ½N FYM was significantly higher as compared to NPK and ½N+ PK+ ½N forest litter. The inorganic P content in ½N+ PK+ ½N FYM, NPK+ poultry litter, and NPK+ FYM+ Zn showed a significant increase over NPK. Sihag *et al.* (2005) reported that the amount of inorganic P recovered as saloid-P, Al-P and Ca-P forms increased significantly with the application of inorganic fertilizers and their combined use with organic materials over control and the highest amount of all the forms of P was recorded under FYM followed by green manuring and press mud treatments. The highest inorganic P recorded in NPK+ poultry litter was 7.1, 5.5 and 4.6% higher as compared to inorganic P in NPK, NPK+ FYM and NPK+ forest litter, respectively. This may be attributed to the higher input of P as in NPK+ poultry litter as compared to other treatments and also mineralization of native organic P as well as that added to the soil.

Available P

The available P content in the soil varied from 2.0 to 10.2 mg kg^{-1} with an average of 6.8 mg kg^{-1} (Table 2). After eleven years of integrated nutrient management, available P showed a significant increase in all the treatments except in forest litter burned+ ½ FYM over control. The highest available P was recorded in NPK+ poultry litter followed by NPK+ FYM+ Zn and the lowest was in control. The available P in NPK+ poultry litter, NPK+ FYM and NPK+ FYM+ Zn was significantly higher than NPK and NPK+ forest litter. The available P content in ½N+ PK+ ½N FYM, ½N+ PK+ ½N poultry litter and ½N+ PK+ ½N forest litter also showed a significant increase over NPK. The data revealed that relatively higher available P levels accumulated in treatments where NPK fertilizers were applied in combinations with poultry litter and FYM. Higher available P content in these integrated treatments might be due to relatively higher input of P through fertilizer and poultry litter or FYM. Laxminarayana (2006) observed highest available P (12.15 kg ha^{-1}) with the application of 100% NPK+ poultry manure. Singh *et al.* (2008) also reported that available P content of surface soil increased appreciably with the application of manures along with fertilizers as compared to sole application of NPK fertilizers. The rate of buildup of available P in various integrated nutrient management practices was estimated to be 0.02 to 1.67 kg P ha^{-1} yr^{-1} with an average of 1.06 kg P ha^{-1} yr^{-1}. Similar results were also reported by Dutta and Chauhan (2011). The accumulation of available P in different treatments caused a change in P fertility status from low to medium in all the treatments except in ½N+ PK and forest litter burned+ ½ FYM treatments after eleven years of integrated nutrient management. The fact that highest amount of available P accumulated in NPK+ poultry litter followed by NPK+ FYM+ Zn, ½N+ PK+ ½N poultry litter, NPK+ FYM and ½N+ PK+ ½N FYM treatments suggested that besides the source and amount of P added, the available P levels in soil may be the result of the combined effect of the processes of transformation of added P through fertilizers and organic sources, mineralization of native and added organic P and loss of P from soil including crop removal. Part of added fertilizer P that is not used by the crop would accumulate in soil in various forms to contribute with varying degree towards different forms of P including available P pool in soil.

Organic P and total P

The organic P and total P content in the soil ranged from 123.6 to 160.2 mg kg^{-1} with an average of 146.0 mg kg^{-1}, and 198.2 to 267.4 mg kg^{-1} with an average of 244.5 mg kg^{-1}, respectively (Table 2). Both organic P and total P in the soil increased significantly in all the treatments except forest litter burned+ ½ FYM over control. The higher of these two P fractions was recorded in NPK+ poultry litter and the lowest in control. The organic P content in NPK+ FYM, NPK+ poultry litter, NPK+ FYM+ Zn and ½N+ PK+ ½N poultry litter showed a significant increase over NPK. After eleven years of integrated nutrient management, the rate of buildup of organic P in various treatments was estimated to be 0.4 to 7.5 kg P ha^{-1} yr^{-1} with an average of 5.0 kg P ha^{-1} yr^{-1}. These results suggested that addition of NPK in combination with FYM and poultry litter favoured higher buildup of organic P as compared to application of NPK alone or with forest litter. Higher build up of organic P in these treatments could be due to higher levels of P added through poultry litter as well as variation in microbial activity and nature of microbial metabolites. The total P content in NPK+ poultry litter, NPK+ FYM, NPK+ FYM+ Zn, ½N+ PK+ ½N poultry litter and ½N+ PK+ ½N FYM was significantly higher as compared to

NPK treatment. The significant increase in total P in NPK+ poultry litter and ½N+ PK+ ½N poultry litter over NPK was 9.2 and 6.1%, respectively. The buildup of total P in different nutrient management practices varied from 0.9 to 14.1 kg ha^{-1} yr^{-1} with an average of 10.2 kg ha^{-1} yr^{-1}. Similar results were also reported by Dutta and Chauhan (2011). An analysis of data established that on an average, solution P, inorganic P, available P and organic P represented 0.2, 40.3, 2.8 and 59.6% of total P.

Table 3: Effect of integrated nutrient management practices on forms of soil potassium (mg kg^{-1})

Treatment	Water Soluble K	Exchangeable K	Available K	Non Exchangeable K	Total K
T_1-Control	5.2	18.3	23.5	208.4	5800
T_2-½N+ PK	8.2	24.6	30.8	217.3	6000
T_3-NPK	8.9	31.9	40.8	228.5	6100
T_4-NPK+ FYM	13.5	41.5	55.0	260.5	6400
T_5-½N+ PK+ ½N FYM	12.6	39.2	51.8	255.1	6300
T_6-NPK+ poultry litter	10.4	37.7	48.1	248.3	6200
T_7-½N+ PK+ ½N poultry litter	10.2	37.2	47.4	242.7	6100
T_8-NPK+ forest litter	13.1	40.2	53.3	258.4	6300
T_9-½N+ PK+ ½N forest litter	15.3	48.6	63.9	266.8	6500
T_{10}-½N+ PK+ *Azospirillum*	8.4	27.3	35.7	229.0	6100
T_{11}-NPK+ FYM+ Zn	13.9	42.7	56.6	263.4	6300
T_{12}-Forest litter burned+ ½ FYM	6.4	20.3	26.7	210.3	5900
SEm $\pm$	0.91	2.01	2.24	3.91	55.00
CD (p=0.05)	2.67	6.08	6.58	11.47	161.49

Forms of Potassium

Water soluble K and exchangeable K

The water soluble K and exchangeable K content in the soil varied from 5.2 to 15.3 mg kg^{-1} with an average of 10.5 mg kg^{-1}, and 18.3 to 48.6 mg kg^{-1} with an average of 34.1 mg kg^{-1}, respectively (Table 3). Both water soluble and exchangeable K content in various nutrient management practices exhibited similar trends and increased significantly in all the treatments except forest litter burned+ ½ FYM. This might be due to the fact that addition of potassic fertilizer has increased the concentration of K in soil solution, thereby water soluble K content in the soil increased. To maintain dynamic equilibrium, K in solution phase proportionately saturated the exchange site of the clay minerals leading to increase in exchangeable K in soil. Both water soluble K and exchangeable K content in NPK+ FYM, NPK+ forest litter, NPK+ FYM+ Zn, ½N+ PK+ ½N FYM and ½N+ PK+ ½N forest litter treatments recorded significant increase over NPK. The highest water soluble and exchangeable K observed in ½N+ PK+ ½N forest litter might be due to higher input of K through forest litter in this treatment. Yaduvanshi and Swarup (2006) also reported that the distribution of water soluble and exchangeable K content of the top soil in the treatments receiving K fertilizer (150% NPK, 100% NPK and 100% NPK+ FYM or GM) was higher as compared with 100% N or 100% NP treatments.

Available K

The available K content in the soil ranged from 23.5 to 63.9 mg kg^{-1} with an average of 44.5 mg kg^{-1} (Table 3). After eleven years of integrated nutrient management, available K content in the soil increased significantly in all the treatments except in forest litter burned+ ½ FYM over control. Available K content was highest in ½N+ PK+ ½N forest litter treatment and the lowest in control. Addition of FYM, poultry litter or forest litter with NPK or substituting half nitrogen through FYM, poultry litter or forest litter caused a significant increase in available K in soil as compared to addition of NPK alone. Available K in NPK+ FYM, NPK+ poultry litter, NPK+ forest litter and NPK+ FYM+ Zn treatments were 34.8, 17.9, 30.6 and 38.7% higher as compared to NPK, respectively. The increase in available K was perhaps related to the input and uptake of K in these treatments. These results corroborate the findings of other workers (Humtsoe and Chauhan, 2005; Singh *et al.*, 2006). The rate of buildup of available K in various integrated nutrient management practices was 0.7 to 8.2 kg K ha^{-1} yr^{-1} with an average of 4.7 kg K ha^{-1} yr^{-1}. Similar trend of available K build up was also reported by Humtsoe and Chauhan (2005). This increase in available K might be due to combined effect of addition of K through fertilizers and organic sources, weathering of K minerals and loss of K from soil including crop removal. After eleven years of integrated nutrient management, K fertility status changed from low to medium only NPK+ FYM, NPK+ forest litter, NPK+ FYM+ Zn, ½N+ PK+ ½N FYM and ½N+ PK+ ½N forest litter treatments. K fertility status in other treatments did not change and remained low perhaps because basal dose of 40 kg K_2O ha^{-1} appears to be insufficient to meet the crop requirement and its residual effect towards available K pool may not be appreciable.

Non-exchangeable K and total K

The non-exchangeable K and total K content in the soil varied from 208.4 to 266.8 mg kg^{-1} with an average of 240.7 mg kg^{-1}, and 5800 to 6500 mg kg^{-1} with an average of 6166.7 mg kg^{-1}, respectively (Table 3). The non-exchangeable K content in soil showed a significant increase in all the treatments except ½N+ PK and forest litter burned+ ½ FYM treatments over control. Addition of FYM, poultry litter or forest litter with NPK or substituting half nitrogen through FYM, poultry litter or forest litter caused a significant increase in non-exchangeable K in soil as compared to addition of NPK. This might be due to fixation of applied K as well as residual K balance through addition of organic residues. After eleven years of integrated nutrient management, the total K in showed significant increase in all the treatments except in forest litter burned+ ½ FYM over control. Total K in NPK+ FYM, NPK+ FYM+ Zn, NPK+ poultry litter, NPK+ forest litter, ½N+ PK+ ½N FYM and ½N+ PK+ ½N forest litter was significantly higher than NPK. A significant build up in total K in ½N+ PK+ ½N forest litter over ½N+ PK, NPK, ½N+ PK+ ½N poultry litter, ½N+ PK +*Azospirillum* and forest litter burned+ ½ FYM might be due to lower uptake and removal of K by crop as compared to the amount added in ½N+ PK+ ½N forest litter treatment. Yaduvanshi and Swarup (2006) from a long term experiment, reported that in all the fertilizer and manure treatments removal of K in the crop exceeded K addition and the total soil K balance was negative. On an average, water soluble K, exchangeable K, available K and non-exchangeable K represented 0.2, 0.6, 0.7 and 3.9% of total K.

The above results led to conclude that combined application of inorganic fertilizers with organic sources had pronounced influence in improving the soil fertility status as compared to control and inorganic alone. These result established that NPK+ FYM, NPK+ poultry litter and NPK+ FYM+ Zn are the best nutrient management practices that can be adopted for rice cultivation under terrace land.

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