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Direct and Residual Effect of Fly Ash, Organic Materials and Mineral Fertilisers on Performance of Rice-based Cropping System under Acid Lateritic Soil Conditions

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Abstract: Direct effect of integrated fertilisation with fly ash, organic materials and mineral fertilisers to soil improved or sustained rice grain yield compared with the mineral fertilisers alone. Yields of potato, groundnut and mustard were increased under the residual effect of the integrated fertilisation sources vis-à-vis mineral fertilizers. The combined direct and residual effect of fertilisation sources on cropping sequences revealed that equivalent rice grain yield was higher under the integrated sources as compared to the mineral fertilisers alone. This difference was up to 10% for rice-groundnut sequence while 15% for rice-potato, 19% for rice-mustard, and 27% for rice-sweet potato sequence. Besides crop yield, beneficial residual soil properties in terms of pH, bulk density, organic carbon and available nutrients were noted. An increase in nutrient use efficiency and a save in mineral fertilisers were also feasible under the integrated sources. Residual fertility alone could not produce enough yields. Direct fertilisation in addition to residual fertility increased yields of groundnut pod and mustard seed. Accumulation of heavy metals and radioactive elements in soil and plant remained within safe limits even after application of fly ash at 10 t ha^{-1} for all the four seasons.

Key words: Fly ash, organic materials, mineral fertilizers, lateritic soil.

Introduction

Under intensive cropping, continuous use of mineral fertilisers (MF) often leads to nutritional imbalance in soil and decline in crop productivity (Nambiar, 1994). The problem is more acute in acid lateritic soils because these are characteristically low in organic matter content (Mahapatra et al., 1985) and deficient in available N, P, K, Ca, Mg, and S as well as some micronutrients such as Zn, Cu, B, and Mo (Samui and Mandal, 2003). Fundamental chemical properties such as cation exchange capacity and pH buffer capacity in acid soils are largely governed by the organic matter content (Moody et al., 1997). When soils with low organic matter, cation exchange and buffer capacity are under continuous cultivation, organic matter declines quite rapidly followed by extensive leaching of basic cations and rapid development of acidity. Growing of crops with MF alone cannot mitigate the loss of C, N, and P while combined application of organic manure and MF was effective in this respect (Agbenin and Goladi, 1997). High availability of Fe, Al and Mn, and deficiency of available plant nutrients in such soils can be overcome by liming and chemical fertilisation. These inputs being costly, use of some cheap soil ameliorant and nutrient source is desirable. Recycling of alkaline fly ash (FA) can be considered for pH adjustment and partial nutrient supplementation (McCarty et al., 1994). Some work has been done to integrate FA along with the organic materials and MF for improving crop yield and nutritional status in acid lateritic soils. An attempt has been made in this paper to review the work done on effects of FA on crop yield and soil productivity of acid lateritic soils under rice-based cropping sequences, particularly, when used in combination with organic materials and mineral fertilisers.

Characteristics of Fly Ash

Past studies reveal that there is beneficial effect of FA as soil amendment and nutrient source for better crop growth and yield (Adriano et al., 1980). The essential macronutrients present in it are P, K, Ca, Mg and S, besides micronutrients like Zn, B, Mo, Si, Na and Al (Carlson and Adriano, 1993). It has alkaline pH and when mixed in soil, it tends to neutralize acid soil (Moliner and Street, 1982). FA consists mainly of silt-sized particles; so, addition of ash to either sandy or clayey soil can improve its texture (Chang et al., 1977). For most soils, FA amendment would reduce bulk density of the soil mixture (Chang et al., 1977; Kalra et al., 1998). This property has important bearing with the crops like potato, sweet potato and groundnut, as the economic plant parts of these crops grow underground. Nutritional condition of FA varies with the source of coal, combustion process and storage and handling of ash. It can be observed from Table 1 that available P and K is more in FA by 10.3 and 1.6 times than in acid lateritic soil. Available Ca, Mg, Zn and Cu were also higher in FA than in the soil.

Table 1: Physical and chemical properties of acid lateritic soil and FA

Particulars	*Acid lateritic soil*	*FA*
i) Sand (% w/w)	62.5	42.5
ii) Silt (% w/w)	22.8	47.3
iii) Clay (% w/w)	14.7	10.2
Bulk density (g cc^{-1})	1.67	0.93
Maximum water holding capacity (% w/w)	33.1	59.3
pH (1:2.5 w/v water)	5.29	8.28
Cation Exchange Capacity (cmol kg^{-1})	3.21	2.31
Organic Carbon (g kg^{-1})	2.90	2.90
Total N (%)	0.40	0.04
Available N (mg kg^{-1})	75.6	16.9
Total P (%)	0.21	0.29
Available P (mg kg^{-1})	4.46	45.8
Total K (%)	0.54	0.43
Available K (mg kg^{-1})	40.0	63.0
Available Ca (mg kg^{-1})	246.0	396.0
Available Mg (mg kg^{-1})	55.0	233.0
Available Fe (mg kg^{-1})	56.0	6.9
Available Mn (mg kg^{-1})	10.0	1.9
Available Zn (mg kg^{-1})	0.88	2.48
Available Cu (mg kg^{-1})	1.26	1.31

Results and Discussion

Effect of Integrated Fertilisation Sources on Cropping Systems and Soil

Rice-potato System

Direct effect of fertilisation sources on rice was studied at equivalent nutrient level of 90:26 kg N:P ha^{-1}. The nutrient requirement was met through organic material and MF (Rautaray et al., 2003a). The addition of nutrients through FA was not taken into account while calculating the equivalent nutrient level. The five organic materials (paddy straw, farmyard manure, *Azolla*, water hyacinth and *Sesbania*) in combination with complimentary dose of MF, and FA uniformly @ 10 t ha^{-1} (FA_{10}) as supplement formed five different integrated nutrient treatments.

Rice grain yields under integrated fertilization sources and mineral fertilizers alone were similar (Table 2). After harvest of rice, the effect of residual fertility on potato crop (variety Kufri Chandramukhi) was studied in the same layout. The effect of residual fertility was studied in presence of mineral fertilisers. Because of low inherent fertility in acid lateritic soil, it was not possible to grow a successful potato crop in absence of direct application of MF. Hence, potato crop received a standard fertiliser dose of 100:26:83 and 150:65:125 kg N:P:K ha^{-1} through MF in all the plots during first and second year, respectively. Higher tuber yield was recorded under the residual effect of integrated fertilisation sources as compared to MF. Maximum tuber yield (24.1 t ha^{-1}) was recorded under FA_{10}+PS_5+MF, which was higher by 28% as compared to the MF. Yield of potato tuber was converted to equivalent rice grain yield for comparing the effect of fertilisation sources in rice-potato cropping sequence. Integrated fertilisation sources were superior to MF in producing higher rice equivalent yield in rice potato cropping sequence. This benefit was to the extent of 15% for the treatment FA_{10}+PS_5+ MF. Tubers were divided into three grades viz., large, medium, and small based on respective diameter of >7.5, 2.5-7.5 and <2.5 cm. The percentage of yield under each grade on weight basis is depicted through Figure 1. The treatment FA_{10}+PS_5+MF resulted in maximum yield of large tubers and minimum under the MF.

Coal ash is a source for supplying a large number of nutrients including K and Zn, which is especially preferred for potato (Sekhon and Singh, 1982; Tisdale et al., 1985). Higher availability of P, K, Zn and Cu under integrated fertilization sources as compared to MF can

Table 2: Direct effect of fertilisation sources on yield of rice grain, their residual effect on yield of potato tuber, and equivalent* yield (total yield as rice grain) of the rice-potato cropping sequence

Fertilisation sources	*Yield (t ha^{-1})*		
	Rice grain (Mean of 1996 and 1997)	*Potato tuber (Mean of 1996-97 and 1997-98)*	*Total as rice grain (equivalent yield)*
FA_{10}+PS_5+MF	4.65	24.1	12.6
FA_{10}+$WH_{2.5}$+MF	4.59	22.7	12.1
FA_{10}+FYM_5+MF	4.60	22.1	11.9
FA_{10}+$AZ_{0.75}$+MF	4.47	22.2	11.8
FA_{10}+$GM_{2.5}$+MF	4.71	20.7	11.5
MF	4.80	18.8	11.0
LSD (0.05)	NS	1.20	0.38

*1 kg of potato tuber = 0.33 kg rice grain considering the monetary value of rice grain and potato tuber as Rs 3.95 and Rs 1.30 kg^{-1}, respectively.

FA_{10}+PS_5+MF = FA 10 t + Paddy straw 5 t + 57.5 kg N and 18.5 kg P ha^{-1} through mineral fertiliser, FA_{10}+$WH_{2.5}$+MF = FA 10 t + Water hyacinth compost 2.5 t+ 58.7 kg N and 16.5 kg P ha^{-1} through mineral fertiliser, FA_{10}+FYM_5+MF = FA 10 t + Farmyard manure 5 t + 45.0 kg N and 10.5 kg P ha^{-1} through mineral fertiliser, FA_{10}+$AZ_{0.75}$+MF = FA 10 t +*Azolla* 0.75 t + 57.0 kg N, 20.7 kg P and 10.9 kg K ha^{-1} through mineral fertiliser, FA_{10}+$GM_{2.5}$+MF = FA 10 t + Green manure 2.5 t + 35.5 kg N, 22.0 kg P and 17.2 kg K ha^{-1} through mineral fertiliser.

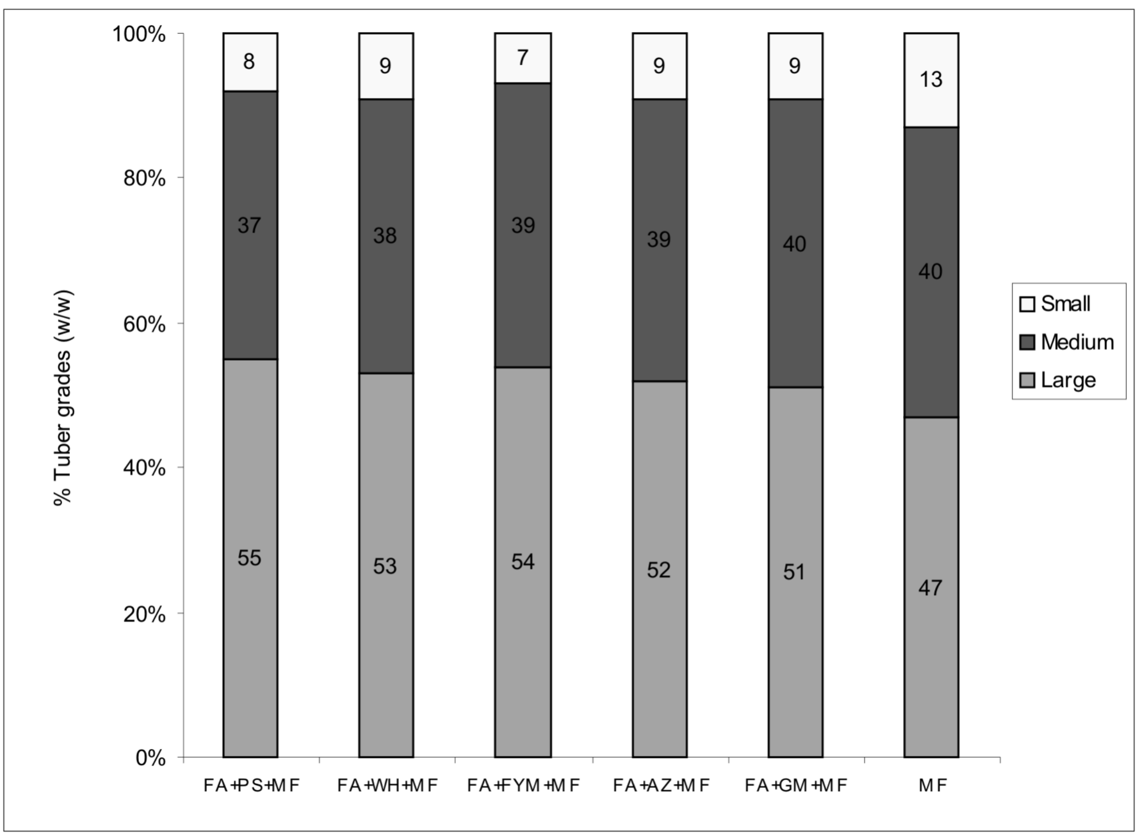

Figure 1: Tuber grades as influenced by residual effect of fertilisation sources.

FA+PS+MF = FA 10 t +Paddy straw 5 t + 57.5 kg N and 18.5 kg P through mineral fertilisers ha^{-1}, FA+WH+MF = FA 10 t + Water hyacinth compost 2.5 t+ 58.7 kg N and 16.5 kg P through mineral fertiliser ha^{-1}, FA+FYM+MF = FA 10 t + Farmyard manure 5 t + 45.0 kg N and 10.5 kg P through mineral fertiliser ha^{-1}, FA+AZ+MF = FA 10 t +*Azolla* 0.75 t + 57.0 kg N, 20.7 kg P and 10.9 kg K through mineral fertiliser ha^{-1}, FA+GM+MF = FA 10 t + Green manure 2.5 t + 35.5 kg N, 22.0 kg P and 17.2 kg K through mineral fertiliser ha^{-1}, MF = 90 kg N, 26 kg P and 33 kg K through mineral fertiliser ha^{-1}.

be observed (Table 3). Acid lateritic soils get compacted after irrigation, which is not congenial for optimum growth and development of tuber. A marginal reduction in bulk density is presented in Table 4 and similar results are available in literature (Karmakar et al., 2003, Rautaray et al., 2003b). Thus, the soil resistance towards development of tubers might be comparatively low as a result of which there was considerable improvement in tuber size under the residual effect of integrated fertilisation sources compared with the MF. In other words, the increase in tuber size might be due to the combined effect of nutrient supply and soil physical conditions. Improvement in tuber size led to increase in yield, as there was significant positive correlation between them (r = 0.87 and 0.70 for the first and second year, respectively).

Table 3: Available nitrogen (N), phosphorus (P), potassium (K), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) content (mg kg^{-1}) of soil after harvest of potato as influenced by the residual effect fertilisation sources (Mean of 1996-97 and 1997-98)

Treatments	*N*	*P*	*K*	*Fe*	*Mn*	*Zn*	*Cu*
FA_{10}+PS_5+MF	96.9	18.0	55.0	76.9	14.8	0.86	1.34
FA_{10}+$WH_{2.5}$+MF	94.6	17.2	52.8	80.9	15.8	0.76	1.30
FA_{10}+FYM_5+MF	95.5	17.6	49.9	78.4	14.1	0.84	1.35
FA_{10}+$AZ_{0.75}$+MF	92.5	15.9	46.5	75.3	15.2	0.74	1.26
FA_{10}+$GM_{2.5}$+MF	91.9	15.4	46.9	76.0	14.2	0.75	1.23
MF	86.0	12.9	40.5	82.8	16.4	0.68	1.05
LSD (P=0.05)	7.1	1.8	3.0	5.9	1.4	0.10	0.21

FA_{10}+PS_5+MF = FA 10 t + Paddy straw 5 t + 57.5 kg N and 18.5 kg P ha^{-1} through mineral fertiliser, FA_{10}+$WH_{2.5}$+MF = FA 10 t + Water hyacinth compost 2.5 t + 58.7 kg N and 16.5 kg P ha^{-1} through mineral fertiliser, FA_{10}+FYM_5+MF = FA 10 t + Farmyard manure 5 t + 45.0 kg N and 10.5 kg P ha^{-1} through mineral fertiliser, FA_{10}+$AZ_{0.75}$+MF = FA 10 t +*Azolla* 0.75 t + 57.0 kg N, 20.7 kg P and 10.9 kg K ha^{-1} through mineral fertiliser, FA_{10}+$GM_{2.5}$+MF = FA 10 t + Green manure 2.5 t + 35.5 kg N, 22.0 kg P and 17.2 kg K ha^{-1} through mineral fertiliser.

Table 4: Bulk density, pH and organic carbon of soil after harvest of potato as influenced by the residual effect of fertilisation sources

Treatments	*1996-97* Bulk Density (g cc^{-1})	*1996-97* pH	*1996-97* Organic Carbon (g kg^{-1})	*1997-98* Bulk Density (kg m^{-3})	*1997-98* pH	*1997-98* Organic Carbon (g kg^{-1})
Residual effect of fertilisation sources						
FA_{10}+PS_5+MF	1.56	6.28	3.2	1.53	6.37	3.5
FA_{10}+$WH_{2.5}$+MF	1.58	6.27	3.1	1.56	6.36	3.3
FA_{10}+FYM_5+MF	1.56	6.25	3.0	1.54	6.35	3.4
FA_{10}+$AZ_{0.75}$+MF	1.59	6.24	2.9	1.57	6.29	3.2
FA_{10}+$GM_{2.5}$+MF	1.58	6.23	2.7	1.57	6.26	3.2
MF	1.64	6.17	2.7	1.64	6.15	2.7
LSD (P=0.05)	0.07	0.06	0.4	0.07	0.13	0.5

FA_{10}+PS_5+MF = FA 10 t + Paddy straw 5 t + 57.5 kg N and 18.5 kg P ha^{-1} through mineral fertiliser, FA_{10}+$WH_{2.5}$+MF = FA 10 t + Water hyacinth compost 2.5 t+ 58.7 kg N and 16.5 kg P ha^{-1} through mineral fertiliser, FA_{10}+FYM_5+MF = FA 10 t + Farmyard manure 5 t + 45.0 kg N and 10.5 kg P ha^{-1} through mineral fertiliser, FA_{10}+$AZ_{0.75}$+MF = FA 10 t +*Azolla* 0.75 t + 57.0 kg N, 20.7 kg P and 10.9 kg K ha^{-1} through mineral fertiliser, FA_{10}+$GM_{2.5}$+MF = FA 10 t + Green manure 2.5 t + 35.5 kg N, 22.0 kg P and 17.2 kg K ha^{-1} through mineral fertiliser.

Besides the effect of fertilisation sources on yield, study on the fate of soil fertility is important from sustainability point of view. There was higher available P, K, Zn, Cu and N status of soil under the integrated fertilisation sources. Higher residual fertility under integrated fertilisation sources might be due to addition of P, K and Zn through FA (FA 10 t provided 30 kg P, 21 kg K and 0.6 kg Zn) as additional source and slow release nature of organic materials. Higher residual fertility under paddy straw based treatments can be ascribed to its slower rate of decomposition. Soil organic carbon was highest (3.5 g kg^{-1}) under FA_{10}+PS_5+MF while it was minimum under the treatment MF. After two crop cycles under rice potato cropping sequence, the soil pH was increased to 6.37 under FA_{10}+PS_5+MF as compared to 6.15 under the treatment MF.

Rice-sweet Potato System

In this investigation, rice variety IR 36 and sweet potato variety, Samrat were used in wet and dry seasons, respectively. Sweet potato was grown in rice fallow after wet season. Equivalent nutrient level of 90:26:33 kg ha^{-1} N:P:K was supplied to rice crop through organic material (paper factory sludge) and MF. After harvest of rice, sweet potato was grown with direct fertilisation at an equivalent nutrient level of 60:17:50 kg N:P:K ha^{-1} through paper factory sludge and MF. Effect of lime (2 t ha^{-1}) was compared with FA (10 t ha^{-1}) in the acid soil under integrated fertilisation system (Mittra et al., 2000).

Results revealed that rice grain yield (3.89 t ha^{-1}) was higher when integrated fertilisation source of 10 t FA, 4.2 t paper factory sludge and the complimentary dose of MF was used as compared to the use of MF alone (3.38 t ha^{-1}) at equivalent nutrient level. Tuber yield of sweet potato was highest (24.2 t ha^{-1}) under the integrated fertilisation source of 10 t FA, 5 t paper factory sludge, and the complimentary dose of MF. Equivalent yield of the rice-sweet potato cropping sequence was increased to 27 % under the integrated fertilisation source as compared to the MF.

Addition of organic manure with FA decreased the bulk density of soil and thereby improved soil condition. Loose soil is expected to offer less resistance for the bulking of tubers. This might have helped for higher tuber yield under the integrated fertilisation source involving FA, organic source and MF (bulk density 1.49 g cc^{-1}) vis-à-vis MF (bulk density 1.59 g cc^{-1}). Application of FA raised soil pH from 5.4 to 6.1, which was comparable to lime application (pH 6.4). This suggests possibility of substituting the costly lime by FA. There was considerable improvement of soil organic carbon and available N, P and K under the integrated fertilisation source involving FA, organic source and MF.

Rice-groundnut System

Rice variety IR 36 was used for evaluation of direct effects of integrated fertilisation involving FA, organic materials (FYM and paper factory sludge) and MF. For integrated nutrient sources, the organic materials were applied at 30 kg N ha^{-1} and the remaining 60 kg N was met through MF and FA. Recommended dose of 26 kg P and 33 kg K ha^{-1} for rice crop were maintained through organic materials (FYM and paper factory sludge), FA and MF. Lime at 2 t was compared with FA at 10 t ha^{-1} for their suitability under acid lateritic soil. No fertiliser control was taken for comparison. Residual effects of fertilisation sources applied to rice crop were studied by growing groundnut variety (JL-24) in the same experimental layout. To study the residual effect of fertilisation sources alone or in presence of direct fertilisation with MF, each plot was divided into two sub-plots. One received recommended dose of 30:26:33 kg N:P:K/ha through MF and the other sub-plot without it.

Application of organic materials (FYM or paper factory sludge) in conjunction with MF helped in improving the nutrient supplying capacity of the soil (Karmakar et al., 2003) and thus, sustained crop productivity compared with the use of MF alone. A superiority trend of paper factory sludge combinations as compared to FYM combinations was reflected. Thus, this industrial waste can partly meet the huge requirement of organic materials for use in agriculture. The residual effect on groundnut pod yield revealed that the plots treated with organic source, FA and MF recorded higher yield (34%) over MF alone. Rice equivalent yield of rice ground sequence was similar under lime + PFS + MF and FA + PFS + MF. This suggests ample scope of substituting costly lime with the industrial waste FA. The equivalent yield of rice groundnut sequence was higher to the extent of 10% under integrated fertilisation source involving FA, organic source and MF as compared to the MF.

The effect of integrated fertilisation involving FA, organic source and MF improved the bulk density of soil under rice-groundnut sequence (Karmakar et al., 2003) as compared to the use of MF alone. This is desirable for upland crops, in general, and crops like groundnut, sweet potato and potato in particular, as the economic part of the latter crops grow under ground. Organic carbon and available N, P and K content were higher in soils treated with organic source. The advantages of integrated fertilisation sources were further established on the basis of nutrient use efficiency and saving of MF (Karmakar et al., 2003). Nutrient use efficiency was more under the integrated use of FA, organic source and MF as compared to the use of MF alone. A saving of MF by 45.8% N, 33.5% P and 69.6% K was optimum considering higher yield and nutrient use efficiency at this level.

Some ashes are rich in heavy metals such as Cd, As, Se and Ni (Carlson and Adriano, 1993). Therefore, it is imperative to study the effect of FA based fertilisation sources on heavy metal content in plants and soil. In rice-groundnut system, addition of FA resulted in an increase in Se and Ni contents in plants and soil but a decrease in Cd and As content (Karmakar et al., 2003, Mittra et al., 2000). The adsorption of specific elements depends upon its content and original pH of the material added to the soil (Adriano et al., 1980, Petruzzelli et al., 1986). As per the prevention of food adulteration act, heavy metal concentration in plant parts remained within the safe limit (Karmakar et al., 2003). The radioactivity in the soil remained within safe limits even after application of FA at 10 t ha^{-1} for all the four seasons (Karmakar et al., 2003, Mittra et al., 2000). The radioactivity due to addition of FA was subjected to dilution in soil. However, those marginal variations remained within the safe limit (Nesic and Djuniac, 1991).

Rice-mustard System

Direct effect of fertilisation sources on rice was studied at equivalent nutrient level of 90:26 kg N:P ha^{-1}. The nutrient requirement was met through MF or organic material and MF (Rautaray et al., 2003b). The addition of nutrients through FA was not taken into account while calculating the equivalent nutrient level. After rice harvest, mustard was grown in the same layout to study the residual effect of FA, organic materials and MF applied to the rice crop. Each plot was divided into two. One received recommended dose of fertiliser i.e., 60:17:33 kg N:P:K ha^{-1} supplied through MF and the other half without it.

Direct application of integrated fertilisation sources involving FA, organic material and MF resulted in higher grain yield of rice as compared to MF alone or the combined use of FA and MF. The residual effect of integrated fertilisation sources on seed yield of mustard was higher up to 48% as compared to MF alone. Rice equivalent yield of the rice-mustard cropping sequence was more under the integrated fertilisation sources involving FA, organic material and MF (up to 19%) than under MF. Interestingly, the beneficial effect of FA was greater (up to 14%) when used in combination with organic materials and MF than in combination with only MF (10%).

Soil pH was higher under the residual effect of integrated fertilisation sources including FA, organic materials and MF as compared to sole application of MF. This can be ascribed to addition of basic cations through application of organic materials (Aitken, 1992) and alkaline FA (Adriano et al., 1980). However, it is well known that continuous use of urea results in net increases in soil acidity. After two crop cycles in the rice-mustard cropping sequence, the organic carbon content of the soil increased from an initial value of 2.9 g kg^{-1} to as high as 3.7 g kg^{-1}under FA_{10}+PS_5+MF (Rautaray et al., 2003b). The low organic carbon content under continuous use of MF was mostly due to rapid mineralization of the organo-mineral complex (Yoshida and Padre, 1975).

At the end of two crop cycles, the available N status in soil was increased from an initial value of 76 mg kg^{-1} to as high as 92 mg kg^{-1} under FA_{10}+PS_5+MF (Rautaray, 1999; Rautaray et al., 2003b). The higher status of available N under treatments involving organic matter can be ascribed to fixation and accumulation of organic N (Savant and De Datta, 1982). The build-up of P was greater under treatments involving FA than without it. This was due to addition of P through FA. It can be observed from Table 1 that the available P status in FA was 10 times higher than in the test soil. The available K status in soil was higher under the treatments receiving FA and paddy straw. The beneficial effect of residual fertility was noted on nutrient use efficiency (Rautaray, 2002). Although mustard crop received uniform fertiliser dose of 60:17:33 kg N:P:K ha^{-1} from urea, SSP and MOP, there was wide variation in nutrient use efficiency under the residual effect of fertilisation sources applied to the rice crop. Lowest nutrient use efficiency of 14.2, 50.7 and 26.2 kg seed per kg of N, P and K, respectively was noted under continuous use of MF. It was highest under the integrated fertilisation system to rice followed by MF to mustard.

Study on the effects of integrated fertilisation sources on some heavy metal content revealed a decrease in Cd and Ni in rice grain and straw under the direct effect of FA in acid lateritic soil (Rautaray et al., 2003b). The residual effect on mustard resulted in increased Cd content; but no such variation in Ni content was noted. The variation in Cd content was largely due to precipitation and dissolution reaction (Rautaray et al., 2003b).

It is concluded that yields from different rice-based cropping systems were higher when fly ash, organic materials and mineral fertilizers were utilized in an integrated manner as compared to the application of mineral fertilizer alone. This was due to improved nutrient availability and beneficial soil properties.

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