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Release and Uptake of Potassium and Sodium with Fly Ash Application in Rice on Reclaimed Alkali Soil

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The effects of fly ash applied @ 0, 2.5, 5.0, 7.5 and 10.0 t ha^{-1} to rice were studied rice-wheat cropping system on reclaimed Typic Natrustalf. Besides crop yields and K and Na contents in ———, release pattern of exchangeable, non-exchangeable and total K and Na were also monitored. Graded levels of fly ash increased grain and straw yield of rice but the overall effects were non-significant. Fly ash did not influence K content but significantly reduced Na content in rice. The residual effects of fly ash was non-significant on wheat yields and contents of K and Na in plantations. Averaged over fly ash levels, 71.8% exchangeable K and 68.4 % exchangeable Na was removed in the first extraction. Similarly, more than 35% non-exchangeable K was extracted in first extraction and a considerable part of it was also released in the subsequent extractions. Fly ash had non-significant effect on the release of exchangeable K but significantly reduced the exchangeable Na content. Non-exchangeable K, total K and total Na contents in soil were also not significantly affected by fly ash additions. Though, the soil pH and soluble salt content did not change significantly with fly ash application, but a significant reduction in Na content in rice and exchangeable Na suggested that it can be used as a resource for reclamation and management of the alkali soils.

Key words: Rice, wheat, fly ash, exchangeable K, non-exchangeable, K, Na, release behaviour, reclaimed alkali soil

Fly ash, chemically an amorphous ferro-alumino silicate generated from coal-fed power plants, is a loose waste material. In India, the coal used for thermal power generation has ash content of around 40%. The annual generation of fly ash may exceed 175 million tonnes (Mt) by 2012, which would require about 40,000 hectares of land for the construction of ash ponds. Though there has been a constant increase in the fly ash utilization yet the unutilized fraction is growing considerably, increasing from 39 Mt in 1993-94 to 70 Mt in 2006-2007 (Singh 2010).

Physically fly ash occurs as fine particles, and has low to medium bulk density, high surface area and very light texture with pH varying from 4.5 to 12.0 depending upon S content in the coal (Page *et al.* 1977). As an ameliorant, low pH fly ash improves properties of alkali soils. The effect is determined primarily by chemical composition and the dose of ash applied. Many reports reveal that moderate level of fly ash substantially increased the rice and wheat yields (Desmukh *et al.* 2000; Jala and Goyal 2006; Kumar and Singh 2003; Sikka and Kansal 1995). The application of fly ash of higher doses might decrease the crop yields due to pozzolonic effect inducing poor aeration and soil compaction. Crop yields are reduced after its deposition on plant foliage. Germination of some crops may get reduced at high levels of fly ash application. Fly ash also contains various amounts of toxic metals, which may accumulate in the soil or leach to the ground water with time. Food crops grown on the soils added with large amounts of flyash for longer periods can soak up hazardous concentrations of arsenic and other toxic elements.

Major matrix elements found in fly ash are Si, Al, Fe together with significant percentage of Ca, K, Na and Ti. It contains considerable amounts of ammonium acetate extractable K, which is highly variable and can be as high as 258 mg K kg^{-1} (Lal *et al.* 1996) and adequate amount of total K ranging between 5.64 to 22.4 g kg^{-1} based upon the type of coal used (Adriano *et al.* 1980).

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Addition of K in Indian agricultural system is not proportionate to its removal. Most of the crop production systems are running under negative K balance. Under these circumstances in addition to fertilizers, farmyard manure (FYM) and crop residue incorporation, waste materials like fly ash could also be a good source of K. Besides K, contents of Na (the relative uptake of these two governs the crop tolerance to sodicity) in fly ash also varied between 1.49 to 4.2 g kg^{-1} (Adriano *et al.* 1980; Page *et al.* 1979). Considering contents of K, Na and other elements, which interact among themselves, application of fly ash may affect K availability indices and Na release behaviour in the soil, which are very important for higher crop yields and management of the alkali soils. Alkali soils occupy nearly 2.5 mha area in Indo-Gangetic plains of India and are rich in K-bearing minerals like illite but are dominated by Na on exchange complex. These soils are reclaimed with gypsum and adoption of rice-wheat cropping system. The information on release kinetics of K and Na in rice – wheat cropping system on alkali soil is rather scanty. Therefore, present investigation was undertaken to study the effect of fly ash on crop yield, release and uptake of K and Na in rice–wheat cropping system on the reclaimed alkali soil.

Materials and Methods

A field experiment with rice (Jaya) was carried out at CSSRI, Karnal during 2002 - 2005 on a reclaimed alkali soil having pH 8.70, electrical conductivity 0.24 dS m^{-1} and organic carbon 4 g kg^{-1}. The experimental site is located at 75°57'E longitude and 29°43'N latitude. The climate of the area is subtropical and semiarid with an average rainfall of around 700 mm. The soils are dominantly illitic in clay fraction with moderate amounts of inter-grade minerals and have been classified as Typic Natrustalfs. Initially these soils were highly sodic, but after application of gypsum and cropping, the pH and exchangeable sodium percentage (ESP) in the upper 15 cm surface layer got reduced to 8.70 and 32.0, respectively. Fly ash collected from Panipat Thermal Power Plant was applied @ 0, 2.5, 5.0, 7.5 and l0 t ha^{-1} before puddling and mixed well in the surface soil in rice plots of 10 m x 5 m size in triplicate with randomized block design. Fly ash used in the present study had pH 7.3, electrical conductivity 0.1 dS m^{-1} and contained 120 and 146 mg kg^{-1} exchangeable K and Na (1*N* NH_4OAc extractable), respectively. The content of non-exchangeable K, total K and Na in fly ash used was found to be 186, 3720 and 1190 mg kg^{-1}, respectively. The total contents of Si, Fe, Mn, Zn, Cu and Pb in fly ash used were 355, 10.6, 0.98, 0.10, 0.80 and 1.5 g kg^{-1}, respectively.

Thirty-five days old seedlings of rice cultivar Jaya were transplanted in second week of July every year with a row to row distance of 20 cm and plant to plant distance of 15 cm and the crop was harvested in the last week of September. The crop was fertilized with 120 kg N, 50 kg P_2O_5 and 8 kg Zn through urea, single superphosphate and zinc sulphate, respectively. Rice grain yield was adjusted to 14% moisture and straw yield was recorded on the oven-dry basis. Oven-dried grain and straw samples were digested in a mixture of HNO_3 and $HClO_4$ (3:1) and analyzed for potassium and sodium using flame photometer. After rice, wheat cultivar HD 2329 was grown with recommended agronomic package of practices to study the residual effects of fly ash on wheat yield and contents of sodium and potassium in soil and wheat plant.

Bulk soil samples were collected from 0-15 cm layer from each plot after the harvest of rice in 2004. Therefore, the crop yield data applicable for the year 2004 - 05 were utilized. Soil samples were air-dried and passed through a 2 mm sieve. The soil samples were analyzed for pH, electrical conductivity, organic carbon and other parameters by the methods — by Jackson (1973). The soil samples were also analyzed for exchangeable and non-exchangeable potassium and exchangeable sodium by sequential extraction. Exchangeable K and Na were determined by using 1*N* NH_4OAc (pH 7.0). For sequential extraction of exchangeable K and Na, 5 g soil was taken in a centrifuge tube in which 25 mL 1 *N* NH_4OAc was added. The sample was shaken for 5 minutes and centrifuged at 5000 rpm. The supernatant was analyzed for K and Na by flame photometer. Such extractions were continued until the release of K and Na was constant in the supernatant.

The release of non-exchangeable K was estimated by taking 2.5 g soil samples in 100 mL beakers in which 25 mL of 1*N* HNO_3 was added. The samples were kept for boiling for 10 minutes. Samples were filtered through Whatman filter paper No. 1 and final volume was made to 100 mL. The process was continued till the constant release of K was observed in the filtrate. Total potassium and sodium in the soil were estimated with the help of flame photometer after digestion in hydrofluoric acid in a closed vessel as per the method described by Sridhar and Jackson (1974). The data for crop and soil were analyzed statistically for significance of application of fly ash on crop yield, release and uptake of potassium and so-

Table 1. Effect of fly ash application on yield (t ha^{-1}) and contents of Na (mg kg^{-1}) and K (%) in rice and wheat

Fly ash,(t ha^{-1})	Rice						Wheat					
	Yield		Na		K		Yield		Na		K	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
0.0	5.73	4.57	88	1223	0.32	1.59	4.46	5.65	76	515	0.36	1.38
2.5	5.78	4.76	88	1180	0.32	1.63	4.49	5.68	65	591	0.36	1.38
5.0	5.85	4.92	82	1114	0.32	1.63	4.46	6.00	76	573	0.37	1.41
7.5	5.95	5.00	72	1129	0.31	1.67	4.36	5.68	55	531	0.38	1.44
10.0	5.98	5.09	67	1039	0.32	1.67	4.55	6.15	65	482	0.36	1.43
Mean	5.86	4.87	79	1137	0.32	1.64	4.46	5.83	67	538	0.37	1.41
CD (P=0.05)	NS	NS	15	NS	NS	NS	NS	NS	NS	NS	NS	NS

dium by following standard procedure (Panse and Sukhatme 1967).

Results and Discussion

Crop Yields and Uptake of Potassium and Sodium

Under graded levels of applied fly ash, grain and straw yield of rice ranged from 5.78 to 5.98 and 4.57 to 5.09 t ha^{-1}, respectively (Table 1). The effects of fly ash application were non-significant on grain and straw yields of rice. In wheat, grain and straw yields ranged from 4.36 to 4.55 and 5.65 to 6.15 t ha^{-1}, respectively with fly ash application to the previous rice crop. There was no conspicuous trend in grain and straw yields and were not influenced by fly ash treatments.

Fly ash treatments did not influence K content in rice and wheat (Table 1). The contents of Na in grain and straw of rice were significantly less at higher levels of fly ash application compared to control, which indicates the beneficial impact of fly ash on rice towards sodicity tolerance. The values of K both in rice grain and straw did not vary significantly with fly ash application. Concentration of Na in wheat grain and straw was also not affected by fly ash application to rice and the mean concentration of Na averaged over various levels of fly ash was 67 and 538 mg kg^{-1}, respectively. In general the contents of Na in wheat grain and straw were lower than their respective values recorded in rice. Similar to Na, contents of K in wheat grain and straw were 0.37 and 1.41%, respectively and did not significantly differ with fly ash application.

Sikka and Kansal (1995) noted the beneficial effects of moderate rates (2-4% w/w) of fly ash application on rice yields but as recorded in the present study the residual effects on successive wheat crop were non-significant. Tiwari *et al.* (1992) found significantly higher rice and wheat yield with application of 10 and 20 Mg ha^{-1} fly ash on highly sodic soils of 10.0 pH. The beneficial effects of fly ash were not realized in the present study as the soils were slightly sodic (pH 8.70). Adriano *et al*. (1980) observed that fly ash containing Si had positive interaction with applied K on rice yields. However, in the present study, fly ash application resulted in non-significant release of K; which could affect the crop yields and K content in rice. In second extraction onwards there was no impact of fly ash on release of K; therefore, it did not influence the yield and K content in residual wheat crop. Moreover, clay minerals present in these soils are predominantly illitic having high K content and hence release of K from these minerals might have satisfied the crop requirement. Additional K released from fly ash had no significant effect on crop yields. Adriano *et al*. (1980) reported that increase in crop yields in fly ash were mainly because of correction of nutrient deficiencies but in the present study the crop was supplied with adequate amount of nutrients through fertilizers therefore, the beneficial effects as recorded by many other workers were not found in study conducted. Silicon contained in fly ash could also be responsible for reduced uptake of Na in rice (Yeo *et al*. 1999). Mixing of 2% fly ash in soils varying in texture and $CaCO_3$ significantly improved the K content in rice but had non-significant impact on Na uptake (Lee *et al*. 2006; Sikka and Kansal 1995). Although fly ash contained 120 mg kg^{-1} K, but the K in fly ash is apparently not as available as fertilizer K, possibly the higher amount of Ca and Mg in the fly ash interfered K absorption by plants. The non-significant residual effects of fly ash on elemental composition of successive wheat crop were also recorded by Sikka and Kansal (1995).

Release Behaviour of Potassium and Sodium with Fly Ash

The sum of exchangeable K extracted in seven sequential extractions ranged from 195.6 to 208.6 mg kg^{-1} with a mean value of 202.0 mg kg^{-1} soil. With

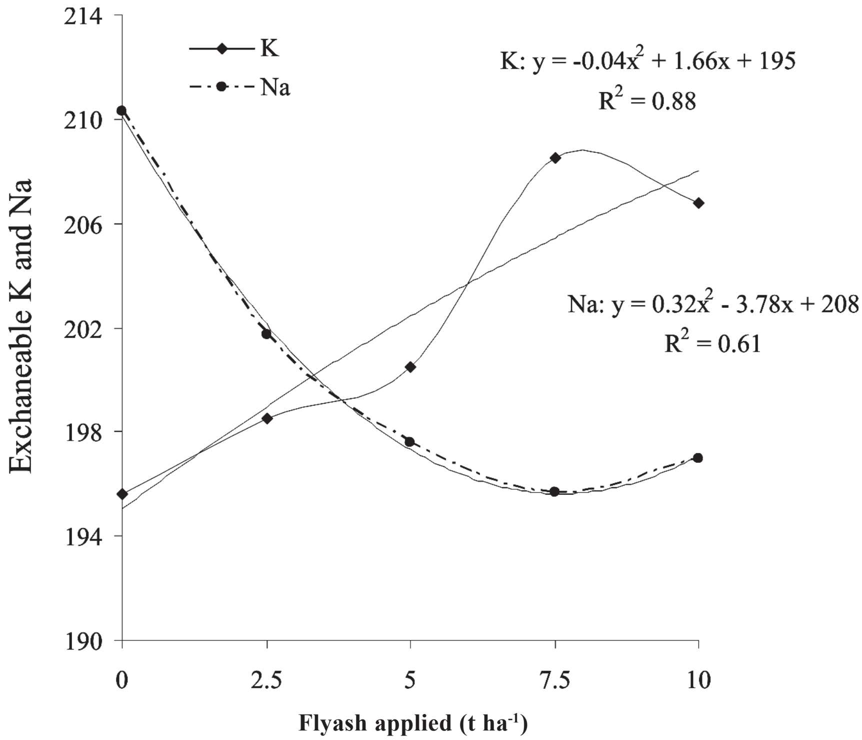

Fig. 1. Effect of flyash on total extracted exchangeable K and Na (mg kg^{-1})

addition of graded levels of fly ash from 2.5 to 7.5 t ha^{-1}, the magnitude of cumulated exchangeable K extracted increased by 1.5 to 6.6% compared to control. Contrary to K, the amount of total exchangeable Na varied from 195.7 to 210.3 mg kg^{-1} soil and was reduced by 4.1 to 6.9% with fly ash application. Both the exchangeable K and Na were significantly correlated with fly ash levels applied as indicated by the respective coefficient of determination values of 0.88 and 0.61. (Fig. 1). Majority of exchangeable K, ranging from 70.7 to 72.4% was extracted in the first extraction itself and 16.0 to 17.2% in second extraction (Table 2). Irrespective of the fly ash levels, the amount of exchangeable K decreased drastically with subsequent extractions and got stabilized on an average at 4.0 mg kg^{-1} soil after 3^{rd} extraction. The exchangeable K extracted in first extraction increased with the increase in fly ash level from 0 to 7.5 t ha^{-1}, however, the effects were non-significant. With different levels of fly ash applied to rice, amount of exchangeable Na released in the first extraction varied from 132.3 to 146.3 mg kg^{-1} with a mean value of 137.1 mg kg^{-1} (Table 2). Application of more than 5 t fly ash ha^{-1} significantly reduced the release of exchangeable Na. The amount of exchangeable Na was drastically reduced in the second extractions and was stabilized after third extraction (Table 2). Increase in exchangeable K with addition of fly ash was reported by Lal *et al.* (1996) and Grewal *et al.* (1998). It was mainly because of higher content of exchangeable K in fly ash than the soil and very high levels of fly ash (0 to 100% soil to fly ash ratio on weight basis) taken in their case. In the present study, non-significant effects of fly ash on exchangeable K were because the amounts of potassium added in exchangeable form with the application of highest dose of fly ash (10 t ha^{-1}) were only 1.2 kg K ha^{-1} every year. Moreover, the content of exchangeable K in fly ash and the experimental soil was more or less the same. Further, fly ash used was more or less an inert material and the majority of its particles (more than 95% on weight basis) were in the sand and silt-sized fractions. Selvakumari *et al.* (2000) also recorded slight but non-significant increase in available K status of soil due to addition of fly ash. Grewal *et al*. (1998) also observed higher release of exchangeable K in the first extraction and a drastic decrease in subsequent extractions in soils of Haryana. The contents of exchangeable Na in soil and fly ash were also not very different but the total Na in fly ash was 8.5 times less than the soil. Contents of Ca in fly ash may vary up to 22.2% (Jala and Goyal 2006), thus addition of high amount of Ca through fly ash could have replaced the sodium from soil exchange complex thereby reducing

Table 2. Effect of fly ash on sequential extraction of exchangeable K and Na (mg kg^{-1})

Fly ash (t ha^{-1})	No. of extractions							
	K				Na			
	I	II	III	Av. (IV-VII)	I	II	III	Av. (IV-VII)
0.0	138.3	33.7	8.0	3.9	146.3	33.7	10.3	4.4
2.5	142.7	31.8	8.0	4.0	139.7	32.3	8.7	5.2
5.0	144.3	32.5	7.3	4.1	132.3	35.3	9.7	5.3
7.5	149.2	33.3	8.3	4.0	133.3	29.7	9.7	5.7
10.0	151.0	33.9	8.0	3.9	134.0	32.3	8.3	4.7
Mean	145.1	33.0	7.9	4.0	137.1	32.7	9.3	5.1
CD at 5%	NS	NS	NS	NS	11.9	NS	NS	NS

Table 3. Effect of fly ash on non-exchangeable K (mg kg^{-1}) (sequentially extracted), total K and total Na

Fly ash (t ha^{-1})	No. of extractions for non-exchangeable K					Total K	Total Na
	I	II	III	Av. (IV-VII)	Total	(%)	(%)
0.0	336	988	486	217	3815	0.86	1.06
2.5	1475	939	431	201	3782	0.87	1.05
5.0	1354	976	503	230	3893	0.83	1.04
7.5	1434	983	441	203	3797	0.87	1.02
10.0	1414	981	439	224	3866	0.84	1.01
Mean	1403	974	460	215	3831	0.85	1.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS	0.05

the exchangeable Na contents. Kumar and Singh (2003) also observed that fly ash application increased available K and Ca but decreased Na status in the sodic soil of Punjab.

Release of cumulative non-exchangeable K varied from 3782 to 3893 mg kg^{-1} soil and 34.8 to 39.0 % of it was removed in the first extraction itself (Table 3). In the second extraction also a considerable amount of non-exchangeable K (24.8 to 25.9% of the cumulative non-exchangeable K extracted) was recorded. Release of non-exchangeable K decreased with subsequent extractions. Irrespective of fly-ash levels applied, non-exchangeable K tended to get stabilized at about 215 mg kg^{-1} soil after 3rd extraction. The levels of fly ash applied did not significantly affect the release of non-exchangeable K.

Total K and Na estimated in the soil varied from 0.83 to 0.87 and from 1.01 to 1.06% with mean values of 0.85 and 1.04% mg kg^{-1}, respectively. Levels of fly ash applied had non-significant effect on the release of total K. The major portion of total K is localized in interior matrix which is not readily accessible. The contents of total Na with 10 t ha^{-1} fly ash application were about 4.5% less compared to no fly ash application mainly because of comparatively less sodium in fly ash than in the soil.

Impact of Fly Ash on Soil Properties

The amended soil showed only slight decrease in pH after the harvest of rice with increasing levels of fly ash application but the effects were non-significant. There was no discernible particular increasing or decreasing trend with respect to soil pH after wheat with fly ash. Similar to soil pH, fly ash had no effect on soluble salt content as evidenced by the almost similar electrical conductivity values with or with out fly ash.

The soil had an alkaline pH which was only slightly higher but non-significant than the pH of the fly ash used. Moreover, the inherent buffering capacity of the soil would also resist the small changes if any. Similar non-significant changes of fly ash on soil pH were also observed by Sikka and Bansal (1995). Adriano *et al.* (1978) reported that addition of slightly acidic fly ash may not cause any appreciable changes in soil pH even at high rates but can still increase the available calcium and magnesium in the soil. Otherwise in highly sodic soils of pH 10.0, sequioxides of the fly ash hydrolyze in water with formation of insoluble hydroxides and ionizable acids which are mainly responsible for lowering of soil pH with addition of fly ash. Although application of unweathered fly ash could increase the salt content in soil but weathering of fly ash before application in form of lagooning, stockpiling and leaching reduces the soluble salt content considerably.

Conclusions

Results showed that the fly ash applied to rice crop did not influence grain and straw yield of rice and subsequent wheat crop. The potassium contents in grain and straw of rice and wheat were also not varied with addition of fly ash. The non-significant increase in exchangeable K but significant decrease in sodium in rice and exchangeable as well as total sodium in soil with fly ash can help in inducing sodicity tolerance in rice and consequently management of the sodic soil.

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