Impact Fly ash on nutrient status of wetland rice cultivation

Abstract:

The phrase, "Rice is life" aptly describes the importance of rice in food as well in nutritional security, particularly in Asian countries. Soil nutrient management in case of rice cultivation mainly focus on the major nutrient application but rice plants require high quantity of silicate and micro nutrient but the cost is not affordable. Hence, Coal combustion fly ash has a high available Si content, alkaline pH as well as micronutrient was selected as a potential source in this study and the field experiment was conducted. Abundant supply of micronutrients like Zn, Fe, Cu and Mn along with P and K was recorded in the soil samples of plot treated with fly ash when compared with the plots with NPK alone. The availability of these nutrients has resulted in increased yield. Hence this would be scaled as an economically viable solution for hidden hunger in the areas in and around thermal power plants.

Key words: rice, fly ash, micro nutrients, major nutrients

Introduction:

Rice production in India is an important part of the National economy and livelihood. India is one of the world's largest producers for rice and counts for 20 per cent of world rice production. The rice plants require additional nutritional supply facilitating optimal nutrients to produce higher yields. In general the application of fertilizers involves only NPK and in most cases only N is supplied in the form of urea in India.

Even after 75 years of independence the resistant problem of under-nutrition persists, despite the increase in production to sustain the growing population leading to hidden hunger. Micronutrient deficiencies also known as Hidden hunger, afflicts more than 3 billion individuals, globally (UNICEF, 2021). Micronutrient malnutrition in humans is derived from deficiencies of these elements in soils and in-turn in foods (Shukla, 2014).The soil–plant system is instrumental to human nutrition and forms the basis of the "food chain" in which there is micronutrient cycling, resulting in an ecologically sound and sustainable flow of micronutrients (Yang, 2007).

In sub-tropical climate the high intense rainfall and high temperature is responsible for low soil productivity due to losses of bases and low organic matter content in soil. In acidic lateritic soil low availability of P posses nutritional imbalance which is generally corrected by lime materials. According to IPCC, agricultural lime application contributed to global warming through emission of CO_2 to the atmosphere. Use of fly-ash instead of lime as soil ameliorant could reduce net CO_2 emission and thereby lessen global warming (Sahu *et al*., 2017). Also, in India the production of coal combustion fly ash is increasing The addition of fly ash to soil neutralizes the acidity to a level suitable for agriculture, depending on the initial pH and increases the availability of silicate, sodium, potassium, calcium, magnesium, boron, sulfates, and other nutrients, but not of nitrogen (Neina, 2019; Fernández and Hoeft, 2009; Bagayoko et al., 2000). Even though silicate is not a commonly recommended fertilizer, rice crop have a good affinity towards silicate uptake to stimulate the availability and absorption of other nutrients (Guo et al., 2005). This study was focused on the availability of major and micronutrients namely Iron, Zinc, Copper and Manganese in the soil with the application of fly ash along with NPK.

MATERIALS AND METHODS:

Fly Ash collection and properties:

The Fly ash was collected from the thermal power plant in Neyveli and the Flyash was analyzed for the mechanical, physical properties and nutritional availability. The mechanical composition of Fly ash was determined by the International pipette method (Piper, 1966). The physical properties such as bulk density and particle density were determined by Keen Raczkowski Box Method (Keen and Raczkowski, 1921). pH was determined using glass electrode pH meter and the EC (Electrical Conductivity) was measured using a conductivity bridge. Soil organic carbon (SOC) was estimated by chromic acid wet digestion method (Walkley and Black, 1934), N by alkaline permanganate method, soil available phosphorus by Olsen's extractant method, soil available K by flame photometer, micronutrient using Atomic Absorption Spectrometer.

Field experiment

The field experiment was conducted with TNAU recommended dose of NPK alone and NPK along with Flyash at 20 tonnes/ha in Randomized Block Design during Rabi season.

Fertilizer application

The recommended dose of NPK for rice variety by TNAU is 150: 50: 50 NPK Kg ha^{-1}. The entire dose of single super phosphate (16% P_2O_5) was applied as basal before planting. Potassium in the form of muriate of potash (60% K_2O) and Nitrogen in the form of urea and Neem coated urea were applied in four equal splits as per the treatment at basal, tillering, panicle initiation and 50 per cent flowering stages.

Soil analysis

Collection of soil samples

Representative soil samples from all plots were collected at active tillering, panicle initiation, flowering and at maturity stages of rice. The samples were air dried, powdered with a wooden mallet, sieved through 2 mm sieve and stored in polythene bags until further analyses.

Chemical properties

The pH of soil was measured in water (1:2.5) after half an hour equilibration with a glass electrode pH meter (Model: Elico pH meter). The electrical conductivity (EC) of the supernatant suspension was measured using a conductivity bridge (Model: Elico conductivity bridge) (Jackson, 1973).

Soil Organic Carbon

Soil organic carbon (SOC) was estimated by chromic acid wet digestion method (Walkley and Black, 1934). Soil weighing 0.5 g (100 mesh sieved) was taken in a 500 ml conical flask and added 10 ml of 1 N K_2Cr_2 O_7 and 20 ml of conc. H_2SO_4.The contents were then allowed to stand for 30 minutes. Then distilled water (200 ml), H_3PO_4 (10 ml) and diphenylamine (1 ml) indicator were added. This was titrated against 0.5 N Fe $(NH_4)_2$ (SO_4). $6H_2O$. towards the end point of a bright green color.

Available nitrogen

The available N content of the soil was determined by the alkaline permanganate method (Subbiah and Asija, 1956). Five grams of soil (2 mm sieved) was taken in a distillation flask and 25 ml of each 0.32 % $KMnO_4$ and 2.5 % NaOH was added to the soil. Twenty ml of 2 % boric acid with a drop of double indicator was taken in a beaker and kept near the delivery end. The distillation was carried out and the liberated NH_3 was collected and titrated against 0.02 N sulphuric acid. From the titre value, the soil available nitrogen was calculated.

Available Phosphorus

Soil available phosphorus was determined by Olsen's extractant method (Olsen *et al.*, 1954). Five gram of soil was taken in a polycarbonate shaking bottle. Fifty ml of 0.5 M$NaHCO_3$ adjusted to pH 8.5 and a pinch of activated carbon (Dargo G 60) were added to the soil and shaken for 30 min. The extract was filtered using Whatman No. 40 filter paper. Five ml of filtrate was pipetted out into a 25 ml volumetric flask and 4 ml of reagent B was added and made up to 25 ml. After 30 min the absorbance value of the colour developed in the sample was read at 660 nm in a spectrophotometer (Elico-Model BL 198) and the available phosphorus was calculated from the standard curve.

Available Potassium

The available K as extracted in neutral normal $CH_3COOHNH_4$ was determined. Five grams of the soil was taken in a 100 ml shaking bottle and 25 ml of 1 N $CH_3COOHNH_4$ was added, shaken for 5 min. and then filtered. The $CH_3COOHNH_4$ – K in the extract was determined using a flame photometer (ESICO – Model: 1382) (Jackson, 1973).

DTPA extractable micronutrients

The available micronutrients were extracted with DTPA (0.005 M Diethylene Triamine Penta Acetic Acid + 0.1 M Triethanolamine + 0.01 M $CaC1_2$) extractant adjusted to pH 7.3 ± 0.5 using 1:1 dilute HCl at 1:2 ratio (Soil : DTPA-extractant) after shaking for two hours, filtered through Whatman No.42 filter paper. The DTPA extractable copper, zinc, manganese and iron were estimated in the extractant using Atomic Absorption Spectrometer (Lindsay and Norvell, 1978).

Grain yield

Grain yield from net of each treatment was weighed at 14 per cent moisture content and expressed in kg ha^{-1}.

Straw yield

The yield of straw from each plot was weighed after sun drying for 10 days after harvest and expressed in kg ha^{-1}.

Harvest Index (HI)

Harvest Index is the ratio between economical and biological yield of rice. HI was worked out by using the following formula suggested by Donald and Humblin (1976). This was computed for each treatment.

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

RESULT AND DISCUSSION

Properties of Fly Ash

The results showed the texture to be clay loam. Porosity, water holding capacity, nutrient availability and many other factors determines the bulk density of the material. Since the soil is clay loam with 42.8 per cent pore space and maximum WHC to be 65 per cent, the bulk density is 1.05 g cm^{-1}. Fly ash is alkaline in nature with slight salinity (EC 2.45 ds m^{-1}). It was also found to have a high amount of available silicate, exchangeable calcium and magnesium. The nature of the lignite, combustion process, and the other processes that it undergo determines the properties of Fly ash (Panda and Biswal, 2018). The data is presented in the table 1.

Table 1. Textural and Physico chemical properties of Fly ash

Fly Ash characteristics		
I.	**Textural properties (Piper, 1966)**	
	i. Clay (%)	8
	ii. Silt (%)	65
	iii. Fine sand (%)	20
	iv. Coarse sand (%)	6.1
	v. Textural class	Clay loam
	vi. Bulk density (g cm^{-1})	1.05
	vii. Pore space	42.8
	viii. Maximum WHC (%)	65
II.	**Physico Chemical properties**	
	i. pH (1:2 soil water suspension)	10.6

ii. EC (ds m^{-1})	2.45
iii. Organic carbon (%)	0.23
iv. Available silicate (mg ka^{-1})	1123
v. Available Nitrogen (mg kg^{-1})	45
vi. Available Phosphorus (mg kg^{-1})	23
vii. Available Potassium (mg kg^{-1})	389
viii. Exchangeable Calcium (C mol (p^+)kg^{-1})	19.6
ix. Exchangeable Magnesium (C mol (p^+)kg^{-1})	20.1
x. DTPA Zn (mg kg^{-1})	6.1
xi. DTPA Fe (mg kg^{-1})	39.7
xii. DTPA Cu (mg kg^{-1})	1.8
xiii. DTPA Mn (mg kg^{-1})	9.9

SOIL ANALYSIS:

Soil pH and Soil EC

The observation made from the data presented on soil pH statistical significance was observed between treatments at all the four stages of observation (Table 2). A higher soil pH of more than 8 was observed in the plots where Fly ash was applied as compared to the treatment with NPK alone at all the stages of observation. The increase in pH was found to be 4 to 5 per cent in the plots with NPK+ Flay ash. Similar increase in alkalinity was also noticed by Kalra et al (2000), Lee et al. (2002) and Yadav and Pandita, (2019). The Indian fly ash were found to have alkaline pH , hence it could be applied to used as liming material to neutralization of acidic pH (Yousuf et al.,2020). The reason behind this increase might be due to the neutralization of hydrogen cations by alkali salts (Keller et al., 2020) or precipitation of the cations present in the fly ash amended soils (Gupta et al. 2002). The soil pH plays a major role in the availability of the minerals for the plants. For example, the availability of the Al is higher at the pH of above 8, at which the Aluminium ions become soluble and becomes toxic to plants. Even though, Al at higher concentration is toxic to the plants, the pH of the wetland soils is always acidic and hence this nutrient exits in relatively insoluble form.

The electrical conductivity points out the amount of salts present in the soil. The evaluated soil EC between treatments differed significantly in all the stages of observation, it was interesting to note that significantly more soil EC in Flyash applied plots. The EC of the soil during the active tillering stage was found to be 74 per cent higher in the plots that were treated with Fly ash when compare with the plots in which NPK alone were applied. Decrease in the increment of the EC was also noticed with the progress of the crop. At the maturity stage, the increment in the EC with the application of flyash was only 34 per cent. This shows the dynamics of the soil system in buffering the impact of external material on the nature. The increase in EC of the soil with the application of Fly ash is due to the higher availability of minerals that acts as electron carrier to conduct the electrical pulse.

Table 2. Impact of Flyash on the soi pH and EC of the soil.

	SOIL pH		SOIL EC	
	NPK	NPK+ FA	NPK	NPK+ FA
Active Tillering stage	7.9	8.3	0.39	0.67
Panicle Initiation stage	7.9	8.3	0.48	0.70
50% flowering stage	7.8	8.2	0.43	0.61
Maturity stage	7.8	8.2	0.45	0.61

Soil organic carbon

Soil organic carbon content higher than 1 percent is very important for better growth of rice. Considering this value soil organic carbon content was estimated. The value was ranging from 0.41 to 0.52 % across the four stages of observations. The mean value between different stages also found to be static rather than dynamic. Whatever might be the role of soil organic carbon in rice soils, the results were statistically non-significant in all the four stages of observation concluding that Flyash had no impact on organic carbon. Similar results were also reported by Lee et al. (20012); Dwivedi et al. (2014).

Soil availability of major nutrients

The data on percentage increase in availability of major plant nutrients (NPK) depicted in the figure 1. The soil available nitrogen was found ranging from 260.3 to 211.0 kg ha^{-1}. Statistically significance was not obtained between treatments in the four stages studied. In general, from the mean data across stages it was found that there was a decreasing trend on the available soil nitrogen from active tillering stage to maturity stage. The increment was to the maximum of 5 percent and occurred during the maturity stage of the crop.

The soil available Phosphorus values ranged from 17.5 to 34.5 kg ha^{-1}. In all the stages the treatment plots with NPK+FA did exhibit higher values for soil available Phosphorus when compared with treatment plots with NPK alone. This increase was due to the presence of 23 mg of P per kg of fly ash and was supplied with 4.66 kg of available P per hectare by application of 20 tonnes of flyash ha^{-1}. The increment was between 27 and 39 per cent among the different stages of the rice crop. Also, the presence of higher amount of silicate interacts with the availability of P and enhances its availability (Lee et al., 2007, Schaller et al., 2019, Frank Stephano et al., 2021).

The result of potassium was similar to the results for soil available Phosphorus at active tillering, panicle initiation, 50 per cent flowering and maturity stages. 32 to 46 percent increment in the availability of potassium was recorded in the treatments with fly ash.

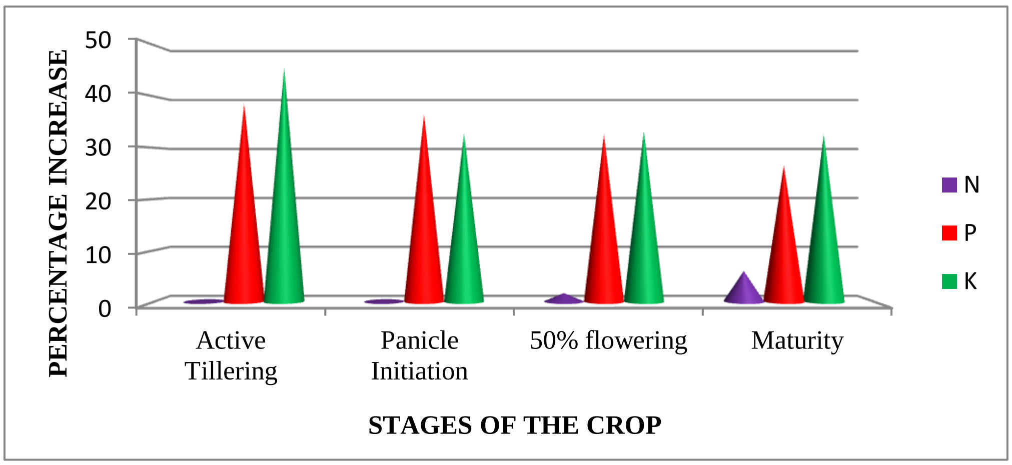

Figure 1 The percentage increase in availability of major nutrients

DTPA Micronutrient availability (mg kg^{-1})

Significant difference were observed between the treatments in all the four stages. The observation on mean values revealed that there was a decrease in trend in DTPA nutrients from active tillering to maturity stage. The increment in the amended soils was about 9.7 to 15.6 % in case of DTPA copper, 5.9 to 18.3 % in case of DTPA Zinc, 3.4 to 5.2 % in case of DTPA Iron and 6.5 to 11.3 per cent in case of Manganese (Figure 2).

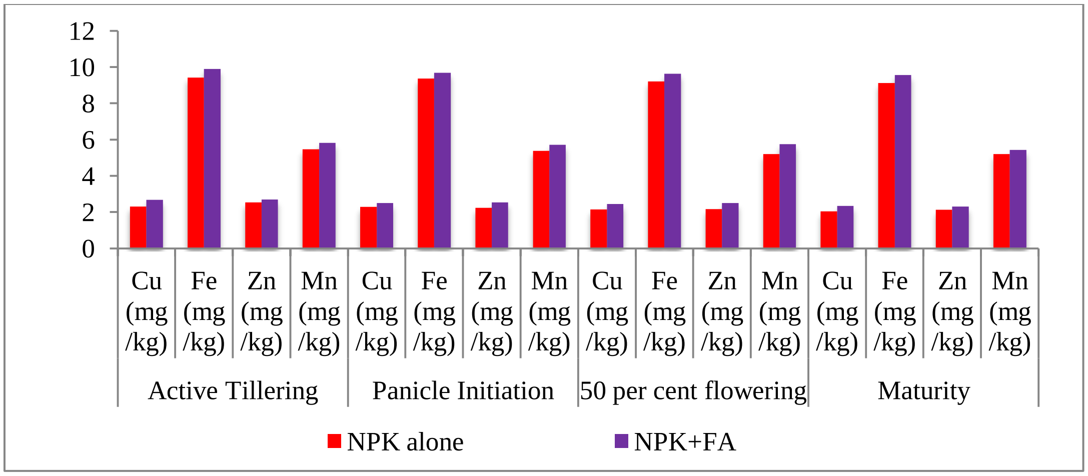

Figure 2 The percentage increase in availability of micro-nutrients

Impact of Fly ash on grain yield and straw

Yield was found higher under the treatment with FA and lowest yield of 5606 kg ha^{-1} was registered by the plots wherein recommended fertilizers were alone applied to the rice plant (Table 3). It is worth to observe from the data that fly ash application increases the rice productivity.

The results on grain yield showed that fly ash had increased grain yield significantly over control. This significant increase in grain yield of paddy in the experiment was possible due to the availability of better nutrients and improved development of the plants, along with greater proliferation of roots and tillers due to the favorable effect of the amendments on soil physical characteristics. Abundant supply of micronutrients like Zn, Cu and Mn along with P and K was recorded in the soil samples of plot treated with fly ash which would have induced increase in yield in the present investigation. The increased absorption levels of P and K by the plants following the application of the fly ash mixture, as evidenced by the apparent increase in rice yield. It is also evident from the study that fly ash application along with mineral fertilizer positively changed the Zn, Mn, Cu and P, K availability and micro nutrient uptake by the plants. Similar observation was reported by Selvakumari *et al.,* (2000), Lee *et al.,* (2007), Yelendhalli *et al.,* (2008) and Reddy *et al.,* (2010)

The health of the rice plant during the season could be identified at harvest by employing the tool harvest index, wherein the harvest index is ratio between economical yield and biological yield. In other way the physiology concept on source to sink could be effectively seen through this harvest index. The variation in harvest index was reported to be between 17 and 56 per cent of the total biological yield (Bueno and Lafarge, 2009; Ju et al., 2009). In the present investigation the harvest index was 0.39 and 0.42 indicating the validity of the experiment conducted.

Table 3. Influence of different soil amendments and fertilizers on yield and Harvest Index

Treatments	**Grain Yield (kg ha^{-1})**	**Straw Yield (kg ha^{-1})**	**Harvest Index**
NPK alone	5606	8687	0.39
NPK + FA	6234	8515	0.42

Conclusion

Flyash is rich in silicate which is an important nutrient in case of rice cultivation and it enhances the availability of other nutrients. Therefore, it could be concluded that a combination of fly ash at 20 t ha^{-1} along with recommended dose of NPK in field experiment would help to increase availability of the major nutrients P and K and micronutrients like Zn, Cu, Fe and Mn in the soil, since fly ash is a rich in those nutrients. The better availability of nutrients has led to raising up the yield. Not only increasing the yield but also it would act as overall supplement to other inorganic soil amendments for improving the nutritional balance in the wetland paddy soil and a viable source of nutrients to rice plants hence increasing the Rice yield and in turn enhancing the livelihood of the rice farmers.

Reference

Bagayoko, M., Alvey, S., Neumann, G., & Bürkert, A. (2000). Root-induced increases in soil pH and nutrient availability to field-grown cereals and legumes on acid sandy soils of Sudano-Sahelian West Africa. Plant and Soil, 225(1), 117-127.

Bueno, C. S., & Lafarge, T. (2009). Higher crop performance of rice hybrids than of elite inbreds in the tropics: 1. Hybrids accumulate more biomass during each phenological phase. Field Crops Research, 112(2-3), 229-237.

Dwivedi, A., and Jain, M. K. (2014). Fly ash–waste management and overview: A Review. Recent Research in Science and Technology, 6(1).

Fernández, F. G., & Hoeft, R. G. (2009). Managing soil pH and crop nutrients. Illinois agronomy handbook, 24, 91-112.

Frank Stephano, M., Geng, Y., Cao, G., Wang, L., Meng, W., & Meiling, Z. (2021). Effect of silicon fertilizer and straw return on the maize yield and phosphorus efficiency in Northeast China. Communications in Soil Science and Plant Analysis, 52(2), 116-127.

Guo, W., Hou, Y. L., Wang, S. G., & Zhu, Y. G. (2005). Effect of silicate on the growth and arsenate uptake by rice (Oryza sativa L.) seedlings in solution culture. Plant and Soil, 272(1), 173-181.

Gupta, D. K., Rai, U. N., Tripathi, R. D., & Inouhe, M. (2002). Impacts of fly-ash on soil and plant responses. Journal of Plant Research, 115(6), 401-409.

Jackson M L. 1973. Soil Chem. Analysis. Prentice Hall of India (Pvt.) Ltd., New Delhi, India. 449.

Ju, J., Yamamoto, Y., Wang, Y., Shan, Y., Dong, G., Miyazaki, A., & Yoshida, T. (2009). Genotypic differences in dry matter accumulation, nitrogen use efficiency and harvest index in recombinant inbred lines of rice under hydroponic culture. Plant Production Science, 12(2), 208-216.

Kalra, N., Harit, R. C., & Sharma, S. K. (2000). Effect of flyash incorporation on soil properties of texturally variant soils. Bioresource Technology, 75(1), 91-93.

Keen B A and H Raczkowski. 1921. The relation between clay content and certain physical properties of soil. J. Agric. Sci. 11: 441-449.

Keller, V., Stopić, S., Xakalashe, B., Ma, Y., Ndlovu, S., Mwewa, B., ... & Friedrich, B. (2020). Effectiveness of fly ash and red mud as strategies for sustainable acid mine drainage management. Minerals, 10(8), 707.

Lee C H, S Y Kim, M B. Villamil, P Pramanik, C O Hong and P J Kim. 2012. Different response of silicate fertilizer having electron acceptors on methane emission in rice paddy soil under green manuring. Biol. Fert. Soils. 48: 435-442.

Lee Y B, H S Ha, B K Park, J S Cho, P J Kim. 2002. Effect of a fly ash and gypsum mixture on rice cultivation. Soil Sci. Plant. Nutr. 48: 171– 178.

Lee, C. H., Lee, H., Lee, Y. B., Chang, H. H., Ali, M. A., Min, W., ... & Kim, P. J. (2007). Increase of Available Phosphorus by Fly-Ash Application in Paddy Soils. Communications in soil science and plant analysis, 38(11-12), 1551-1562.

Lee, H., Ha, H. S., Lee, C. H., Lee, Y. B., & Kim, P. J. (2006). Fly ash effect on improving soil properties and rice productivity in Korean paddy soils. Bioresource technology, 97(13), 1490-1497.

Lindsay W L and WA Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Amer. J. 42:421-428.

Neina, D. (2019). The role of soil pH in plant nutrition and soil remediation. Applied and Environmental Soil Science, 2019.

Olsen B R, C L Cole, P S Watanab and D A Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S.D.A. Circ. 939.

Panda, R. B., & Biswal, T. (2018). Impact of fly ash on soil properties and productivity. International Journal of Agriculture, Environment and Biotechnology, 11(2), 275-283.

Piper, C. S. (1966). Mechanical analysis of soil by International Robinson‟ s Pipette method. Soil and plant analysis.

Reddy T, U Prabhakar, M Rao, and R Chandrasekhar. 2010. Effect of fly ash and farm yard manure on soil properties and yield of rice grown on an inceptisol. Agric. Sci. Digest. 30: 281-285.

Sahu, G., Bag, A. G., Chatterjee, N., & Mukherjee, A. (2017). Potential use of flyash in agriculture: A way to improve soil health. Journal of Pharmacognosy and Phytochemistry, 6(6), 873-880.

Schaller, J., Faucherre, S., Joss, H., Obst, M., Goeckede, M., Planer-Friedrich, B., ... & Elberling, B. (2019). Silicon increases the phosphorus availability of Arctic soils. Scientific reports, 9(1), 1-11.

Selvakumari G, M Bhaskar, D Jayanthi and K K Mathan. 2000. Effect of integration of flyash and fertilizers and organic manure on nutrient availability, yield and nutrient uptake of rice on Alfisols. J. Indian Soc. Soil Sci. 48: 268- 278.

Shukla, A. K., Tiwari, P. K., & Prakash, C. (2014). Micronutrients deficiencies vis-a-vis food and nutritional security of India. Indian J. Fert, 10(12), 94-112.

Subbiah B V and G L Asija. 1956. A rapid procedure for estimation of available nitrogen in soils. Curr. Sci., 25: 259 – 260.

UNICEF. (2021). The state of food security and nutrition in the world 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all.

Walkley A and C A Black. 1934. An estimation of methods for determining organic carbon and nitrogen in the soils. J. Agric. Sci. 25: 598-609.

Yadav, V. K., & Pandita, P. R. (2019). Fly ash properties and their applications as a soil ameliorant. In Amelioration Technology for Soil Sustainability (pp. 59-89). IGI Global.

Yang, X. E., Chen, W. R., & Feng, Y. (2007). Improving human micronutrient nutrition through biofortification in the soil–plant system: China as a case study. Environmental Geochemistry and Health, 29(5), 413-428.

Yeledhalli N A, S S Prakash, M V Ravi and K Narayanarao. 2008. Long term effect of fly ash on crop yield and soil properties. Kar. j. of Agric. Sci. 21(4): 507-512.

Yousuf, A., Manzoor, S. O., Youssouf, M., Malik, Z. A., & Khawaja, K. S. (2020). Fly ash: production and utilization in India-an overview. J Mater Environ Sci, 11(6), 911-921.