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Effect of a thermal power plant waste fly ash on leguminous and non-leguminous leafy vegetables in extracting maximum benefits from P and K fertilization

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ABSTRACT: Although the Indian population is largely vegetarian, not much attention has been given to the cultivation of vegetables, as compared to other crops like cereals, pulses and oil seeds. Therefore, the present study was conducted on two leafy vegetables, spinach (*Spanacia oleracea* L.) and methi (*Trigonella foenum graecum* L.) commonly grown in Aligarh, as the two popular vegetables of Indian diet. The study was conducted for two successive years and during the first year, phosphorus and fly ash interactions with a uniform dose of nitrogen and potassium on both vegetables was observed. During the second year, while keeping nitrogen and phosphorus uniform, potassium and fly ash combinations were studied again with both vegetables, to determine the optimum dose of inorganic fertilizers and fly ash combination. It was observed that fly ash applied at the rate of 15 t ha^{-1} along with $N_{40}P_{15}K_{20,}$ proved optimum for spinach while in the case of methi, $N_{20}P_{30}K_{40}$ + FA_{10} was sufficient. Therefore, both vegetables can safely be grown with 10 to 15 t ha^{-1} of fly ash and a comparatively lower quantity of NPK.

Keywords: fly ash, methi, nitrogen, phosphorus, potassium, spinach, thermal power plant.

INTRODUCTION

Over the years, industrialization has enhanced the demand for electricity generation. Therefore, the rapid rise in thermal power generation has posed the problem of environmental pollution of air, along with massive fly ash generation, usually deposited in huge amounts near the power plants. On a global scale, the annual production of fly ash is estimated to be 56×10^6 metric tonnes (Adriano et al., 1980). Only three percent (3%) of this is utilized, mostly in the manufacturing of fly ash bricks or land filling. An equally negligible amount is used in the manufacture of pozzolonic cement. Ash experts attribute the current low level of utilization to factors like lack of publicity and knowledge, high cost of production of building materials and most importantly, lack of proper coordination between thermal power plant officials and ash users. It should be pointed out that coal is known to contain many naturally occurring elements, it is therefore not surprising that fly ash can also supply many essential elements like potassium, calcium, magnesium, phosphorus and sulphur in addition to trace elements like chlorine, boron, iron, manganese, zinc and copper etc. Therefore, it can be exploited in combination with chemical fertilizers to

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increase the yield of various agricultural crops, especially vegetables with lesser NPK doses. In addition to being a nutrient source, it also serves as a soil improver to correct nutrient deficiencies (Hill and Lamp, 1980; Singh et al., 2003; Jala and Goyal, 2006). The use of fly ash for soil amendment while growing field crops was reported a long time ago (Wochok et al., 1976; Elseewi et al., 1978a; Milliner and Street, 1982; El-Mogazi et al., 1988). However, enhancing crop yield by the application of fly ash was reported in the recent work of Yeledhalli et al. (2008), Pandey et al. (2009), Arivozhagen et al. (2011), Bilski et al., (2011a,b), Singh et al., (2011), Gautam et al. (2012), Katiyar et al. (2012), Mahale et al. (2012), and Muduli et al. (2014). In the present study, spinach (*Spanacia oleracea* L.) and methi (*Trigonella foenumgraecum* L.) were compared, the former (a non-leguminous crop) is unlike the latter (a legume) which can fix nitrogen symbiotically to overcome nitrogen deficiency in fly ash. Both are common leafy vegetables, their leaves as well as the seeds of methi are of medicinal value.

MATERIALS AND METHODS

Two experiments were conducted on the test crops side by side for two years.. An NPK fertilizer was given a day before sowing. For spinach, P @15 and 30 kg ha^{-1} with uniform dose of N and K @ 40 kg ha^{-1} each applied and supplemented with fly ash @ 15 t ha^{-1}. In the following year, K was applied @ 20 and 40 kg ha^{-1} with a uniform dose of N and P @ 30 and 40 kg ha^{-1} each while FA was applied @ 15 kg ha^{-1}.

For methi, during the first year, P@ 15 and 30 kg ha^{-1} with uniform dose of N and K @ 20 and 40 kg ha^{-1} and FA @ 10 t ha^{-1} were applied. Similarly, the second year experiment was performed keeping N and P uniform @ 20 and 30 kg ha^{-1} and FA @ 10 t ha^{-1} along with K @ 20 and 40 kg ha^{-1}. The treatment details are as shown in Table 1.

Fly ash was collected from Harduaganj thermal power plant located 15 km away from Aligarh. Fertilizer nitrogen in the form of urea, phosphorus as superphosphate and potassium as muriate of potash were applied. Seeds were sown at the rate of 100 per bed for both crops, to avoid germination failure. Thinning was done to maintain proper distance and weeding was done when needed. Sampling was done at 50 and 80 days after sowing (DAS) for spinach, and at 35, 50 and 65 DAS for methi. For spinach, photosynthetic rate was measured by the method of Tak (2010) in our laboratory, using (L-1-COR 6200) a portable photosynthetic system at 50 DAS. For this purpose, leaves of approximately the same age and size were selected and photosynthesis measurement was undertaken at saturating photosynthetic active radiation (11009/µmol/m^2/s) between 1100-1200 hrs. Leaf area was also calculated using a leaf area meter (LA21 systronics India).

All experiments were carried out according to a factorial randomized block design. To confirm the variability of data and validity of results, analysis of variance (ANOVA) was conducted. In order to determine whether differences among the treatments within respective DAS were significant as compared to control, Duncan's Multiple Range test was applied.

Table 1. Treatments details

	Ist year experiment (Varying doses of phosphorus)	**IInd year experiment (Varying doses of potassium)**
	For spinach	
1.	$FA_0 + P_{15} + N_{40}K_{40}$	$FA_0 + K_{20} + N_{30}P_{40}$
2.	$FA_0 + P_{30} + N_{40}K_{40}$	$FA_0 + K_{40} + N_{30}P_{40}$
3.	$FA_{15} + P_{15} + N_{40}K_{40}$	$FA_{15} + K_{20} + N_{30}P_{40}$
4.	$FA_{15} + P_{30} + N_{40}K_{40}$	$FA_{15} + K4_{40} + N_{30}P_{40}$
	For methi	
1.	$FA_0 + P_0 + N_{20}K_{40}$	$FA_0 + K_0 + N_{20}P_{30}$
2.	$FA_0 + P_{15} + N_{20}K_{40}$	$FA_0 + K_{20} + N_{20}P_{30}$
3.	$FA_0 + P_{30} + N_{20}K_{40}$	$FA_0 + K_{40} + N_{20}P_{30}$
4.	$FA_{10} + P_0 + N_{20}K_{40}$	$FA_{10} + K_0 + N_{20}P_{30}$
5.	$FA_{10} + P_{15} + N_{20}K_{40}$	$FA_{10} + K_{20} + N_{20}P_{30}$
6.	$FA_{10} + P_{30} + N_{20}K_{40}$	$FA_{10} + K_{40} + N_{20}P_{30}$

Subscript values showing the concentration of fly ash in t ha^{-1} and of NPK in kg ha^{-1}.

RESULTS AND DISCUSSION

Response of growth parameters in spinach

Plant fresh weight, leaf number, leaf area and photosynthetic rate in spinach at 50 DAS gave better response to treatment with $FA_{15}N_{40}P_{15}K_{40}$ showing 128.3% increase in fresh weight. Leaf number also showed an increase of 86.36% and 45.45% with $FA_0N_{40}P_{15}K_{40}$ or $FA_{15}N_{40}P_{30}K_{40}$ at two stages of growth. It seems that for leaf production an important character in leafy vegetables, phosphorus given @ 15 or 30 kg ha^{-1} was effective (Table 2). Leaf area was also significantly affected by phosphorus in spinach at both stages. Treatment $FA_{15}N_{40}P_{15}K_{40}$ gave an increase of 18.98 and 17.85%, at the two stages studied. Photosynthetic rate at 50 DAS was maximum when spinach was grown under $FA_{15}N_{40}P_{15}K_{40}$ showing 19.56% increase (Table 2).

Table 2. Effect of fly ash and phosphorus on various growth parameters of spinach

Treatments	Plant length (cm)		Plant fresh weight (g)		Plant dry weight (g)		Leaf number		Leaf area (cm^2)		Photosynthetic rate (µmol/m^2/sec)
	50 DAS	80 DAS	50 DAS	80 DAS	50 DAS	80 DAS	50 DAS	80 DAS	50 DAS	80 DAS	50 DAS
FA_0 P_{15}	24.67	46.00	7.66	48.00	1.02	8.78	7.33	12.33	50.43	103.00	7.33
FA_0 P_{30}	27.00	48.00	17.49	54.67	1.33	7.57	10.67	18.67	60.01	121.00	8.76
FA_{15} P_{15}	24.33	30.00	9.10	37.00	0.81	6.23	13.67	14.00	52.01	107.31	6.23
FA_{15} P_{30}	20.33	36.33	6.05	33.33	0.523	5.78	9.33	8.67	50.00	85.20	5.77
LSD at 5%	1.597	0.577	1.009	2.685	1.034	NS	4.351	1.772	0.698	2.260	0.765

Subscript values denote the levels of FA in t ha^{-1} and P in kg ha^{-1}. The dose of N and K was applied @ 40 kg ha^{-1} uniformly.

Fly ash and P_{15} increased leaf area which reflected in the photosynthetic rate at 50 DAS. It may be due to the availability of plant required nutrients in fly ash (Mittra et al., 2005; Jala and Goyal, 2006; Panigrahi et al., 2014). Coal is known to contain many naturally occurring elements, it is therefore not surprising that many trace elements were also found in coal ash (Page et al., 1979). Trace elements like B, Cd, Pb, Mo, Ni, Se and Zn were found in higher concentration than the soil and their environmental significance was established in our previous work (Sahay et al., 2014). The impact of each trace element depends on their state in coal ash. It can be seen in the present study and others that the soil of Aligarh fertilized with fly ash, contained trace elements within tolerable limits. Also, the use of fly ash in this study proved beneficial because it modifies soil texture (Fail and Wochok, 1977; Gangloff et al., 2000). Photosynthetic rate is also enhanced by fly ash, it may be due to faster growth where plants prefer to utilize more assimilated nutrients in leaf area development, so that it can capture more solar radiation which was reflected in photosynthetic rate. Again, it may also be due to the presence of micro and macro nutrients in fly ash, except nitrogen and unavailable phosphorus (Jala and Goyal, 2006). Spinach gave encouraging results during the second year (Table 3) for plant fresh weight, dry weight, leaf number and leaf area. Treatment $FA_{15}N_{40}P_{15}K_{20}$ proved good, giving 17.03% increase in fresh weight. Dry weight at 50 DAS was not significant but at 80 DAS treatments $FA_0N_{40}P_{30}K_{20}$ and $FA_{15}N_{40}P_{30}K_{40}$ were good showing 6.81% increase. Leaf area is an important trait in leafy vegetables, as increase in leaf area obviously reflects an increase in photosynthetic rate. It was observed that treatment $FA_{10}N_{40}P_{15}K_{40}$ or P_{30} proved better for this parameter giving maximum increase of 99.30% in leaf area (Table 3), followed by $FA_{15}N_{40}P_{30}K_{20}$, showing that fly ash @ 15t ha^{-1} does not have an adverse effect in any case (Table 3).

Photosynthetic rate shows positive correlation with leaf area. Treatment $FA_{15}N_{40}P_{15}K_{40}$ with phosphorus during the first year followed by $FA_{15}N_{40}P_{30}K_{20}$ gave an increase of 19.56%. But surprisingly $FA_0N_{40}P_{30}K_{20}$ and $FA_0N_{40}P_{30}K_{40}$ were equally good (Table 2). Plant factors which may influence the rate of photosynthesis are related to the structure and organization of plant leaves, chloroplast and chlorophyll. Various nutrients also influence the activity of enzymes and the level of various metabolites.

The photosynthetic rate during the second year with potassium $FA_{15}N_{40}K_{20}P_{15}$ proved best in increasing this parameter by showing a percentage increase of 33.57%, followed by $FA_0N_{40}P_{15}K_{40}$ with an increase of 20.34%, proving the nutritional role of fly ash in decreasing NPK levels (Table 3).

Table 3. Effect of fly ash and potassium on various growth parameters of spinach

Treatments	Plant length (cm)		Plant fresh weight (g)		Plant dry weight (g)		Leaf number		Leaf area (cm^2)		Photosynthetic rate ($\mu mol/m^2/sec$)
	50 DAS	80 DAS	50 DAS	80 DAS	50 DAS	80 DAS	50 DAS	80 DAS	50 DAS	80 DAS	50 DAS
$FA_{15}K_{40}$	26.30	29.60	6.20	24.02	1.270	6.326	6.33	9.67	99.3	146.00	7.17
$FA_{15}K_{20}$	22.03	26.03	7.25	24.65	0.928	6.033	8.67	14.33	72.7	107.67	7.96
FA_0K_{40}	24.97	26.97	3.43	24.96	0.385	6.807	11.6	10.67	42.93	103.67	6.84
FA_0K_{20}	23.50	23.63	4.03	19.73	0.605	4.328	8.00	8.00	43.61	81.00	5.96
LSD at 5%	1.660	3.993	1.900	1.607	NS	1.262	NS	1.918	3.475	2.396	0.667

Subscript values denote the levels of FA in t ha^{-1} and K in kg ha^{-1}. The dose of N and P were applied @ 30 and 40 kg ha^{-1} uniformly. NS- non-significant.

Response of growth parameters in methi

While growing methi, another leafy leguminous vegetable, leaf number and fresh weight showed good response to treatment $FA_{10}N_{20}P_{15}K_{40}$ proving the utility of fly ash. At 50 DAS, leaf number increased up to 82.29% followed by $FA_{10}N_{20}P_0K_{40}$, giving an increase of 34.38% (Table 4). The result shows that treatment with $FA_{10}N_{20}P_{15}K_{40}$ results in significant increase in leaf number. Plant fresh weight was also optimally enhanced by this treatment, proving the importance of phosphorus and fly ash. Fresh weight at 35 DAS with $FA_{10}N_{20}P_{15}K_{20}$ gave 258.9% increase and at 50 DAS, $FA_{10}N_{20}P_0K_{20}$ gave 131.05% increase followed by $FA_{10}N_{20}P_{15}K_{20}$ which gave 66.78% increase. Also, this treatment proved good for leaf area at 50 and 65 DAS (Table 4).

Regarding nodule production, methi fixes nitrogen symbiotically; therefore, the number of nodules is an important parameter for this crop. At both stages, FA_{10} and P_{15} or P_{30} with uniform N and K showed better results. It appears that P @ 15 kg ha^{-1} was deficient as the vegetable growth at later stage i.e. 50 DAS P_{30} gave better result. It may be due to the requirement of phosphorus for root development as the plant grows. Again, it can be inferred that FA @ 10t ha^{-1} proved beneficial and effective, as it did not show harmful effects in methi when given with P @ 15 kg ha^{-1} (Fig. 1).

During the second year, methi performed well with potassium and also with fly ash combination i.e $FA_{10}N_{20}K_{20}P_{15}$. Plant fresh weight at 50 DAS was increased by 41.50% with $FA_{10}N_{20}K_0P_{15}$ followed by treatment $FA_{20}N_{20}K_{20}P_{15}$ with an increase of 9.92%, proving that the application of fly ash @ 10 t ha^{-1} and potassium @ 20 kg ha^{-1} or 0 kg ha^{-1} can be equally effective. Thus, $N_{20}K_0P_{15}FA_{10}$ proved to be a suitable dose, showing that methi can be grown even without potassium, when fly ash is applied showing its nutritional value (Table 5). The application of fly ash was found to improve the growth of methi, because fly ash + soil medium reportedly increased the available water content of soil mixture (Gupta et al., 2002) because fly ash alone is not effective in retaining water content (Eary et al., 1990) and macro and micronutrients present in soil (Basu et al., 2009). An increase in root and shoot length, fresh weight, leaf area and number of nodules per plant with low level of fly ash incorporation was reported by Pandey et al. (2009).

The number of nodules in methi during the second year study with potassium and fly ash combination, was adversely affected by fly ash or even with K where K_{40} proved deleterious (Fig. 1). On the contrary, the number of nodules in methi improved with the application of phosphorus and nitrogen during the first and second years supplemented by fly ash @ 10 t ha^{-1}. Phosphorus being an important element expands root surface area through increase root growth and root hair development (Lynch and Brown, 1988; Gilroy and Jones, 2000). Similarly, the number of nodules gave response to available nitrogen for root nodule development in plant in the absence of K. The reason is due to NH_4^+-N and K^+ competing for the same carrier. In addition, legume species vary markedly in the number of root hair. The proportion of infected root hairs that gives rise to nodules can also vary. Root nodule as a plant organ, requires reduced carbon and nitrogen compounds for initiation, growth and maintenance. The complex flows of carbon and nitrogen compounds necessary to integrate root nodules into the intact plant has been described in several legumes. Undoubtedly, it is through the allocation of photosynthate and possible hormonal signals, that the plant controls N_2-fixation and maintains a balance between C and N metabolism, as environmental conditions change.

Fly ash has been used to ameliorate soil and may improve the physical, chemical and biological properties of the degraded soils and is a source of radially available plant micro and macro nutrients. The practical value of fly ash in agriculture as an eco-friendly and economic fertilizer can be established after repeated field experiments for each type of soil to confirm its quality and safety.

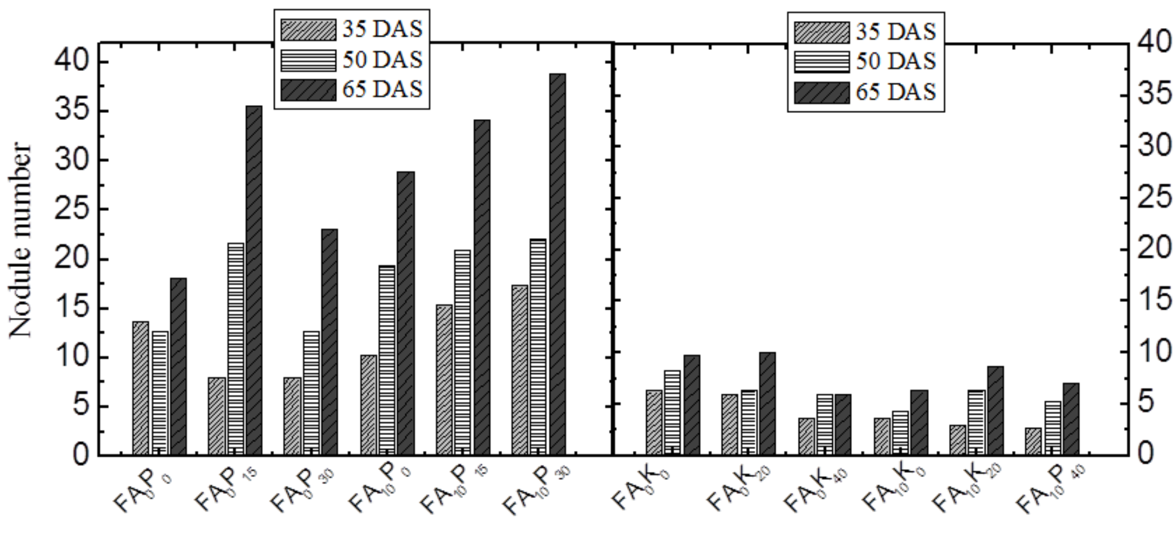

Fig. 1. Effect of flyash with phosphorus and flyash with potassium on nodule number of methi (*Trigonellafoenumgraecum* L.) at three growth stages

Table 4. Effect of fly ash and phosphorus on various growth parameters in methi.

Treatments	Plant length (cm)			Plant fresh weight (g)			Plant dry weight (g)			Leaf number			Leaf area (cm^2)		
	35 DAS	50 DAS	65 DAS	35 DAS	50 DAS	65 DAS	35 DAS	50 DAS	65 DAS	35 DAS	50 DAS	65 DAS	35 DAS	50 DAS	65 DAS
FA_0P_0	13.67	19.00	38.67	0.73	5.33	9.39	0.076	0.613	1.67	9.00	32.00	28.0	81.00	115.0	197.0
FA_0P_{15}	15.33	22.33	24.33	1.23	4.42	6.00	0.320	0.473	0.83	16.00	27.00	20.3	81.00	110.0	202.0
FA_0P_{30}	16.33	36.33	48.33	0.77	8.00	8.41	0.069	1.863	1.53	7.33	33.33	14.3	82.80	103.3	170.7
$FA_{10}P_0$	17.33	36.00	48.13	1.70	12.33	12.84	0.160	1.423	2.18	20.33	43.00	25.3	90.00	112.0	241.0
$FA_{10}P_{30}$	19.00	31.33	46.00	2.30	7.67	11.43	0.333	1.419	1.91	25.00	58.33	41.7	82.53	147.0	308.3
$FA_{10}P_{15}$	18.33	33.00	34.00	2.62	11.46	15.67	0.313	1.846	1.713	27.67	38.00	44.00	81.50	115.0	173.0
LSD @ 5%	NS	2.626	2.039	0.162	2.182	2.149	NS	0.240	0.652	1.733	2.629	2.118	NS	9.66	8.74

Subscript values denote the levels of FA in t ha^{-1} and P in kg ha^{-1}. The dose of N and K was applied @ 20 and 40 kg ha^{-1} uniformly. NS- non-significant

Table 5. Effect of fly ash and potassium on various growth parameters in methi

Treatments	Plant length (cm)			Plant fresh weight (g)			Plant dry weight (g)			Leaf number			Leaf area (cm^2)		
	35 DAS	50 DAS	65 DAS	35 DAS	50 DAS	65 DAS	35 DAS	50 DAS	65 DAS	35 DAS	50 DAS	65 DAS	35 DAS	50 DAS	65 DAS
$FA_0 K_0$	19.37	19.47	29.00	1.52	5.57	10.26	0.125	0.385	0.91	10.03	25.00	29.40	82.17	120.23	200.20
$FA_0 K_{20}$	19.97	22.33	25.00	2.94	5.81	11.12	0.285	0.596	0.98	9.93	18.33	29.90	151.69	128.13	212.33
$FA_0 K_{40}$	19.03	22.20	31.33	1.78	4.56	10.62	0.108	0.320	0.75	9.43	12.33	28.47	74.51	117.15	175.00
$FA_{10} K_0$	25.17	22.27	41.00	2.27	7.88	10.99	0.119	0.352	1.52	9.70	39.33	35.20	106.23	177.70	311.00
$FA_{10} K_{20}$	19.57	22.33	36.00	2.12	6.12	9.89	0.118	0.342	0.98	9.93	37.33	29.50	86.77	139.00	247.73
$FA_{10} K_{40}$	18.87	20.60	56.33	1.27	4.75	8.41	0.100	0.225	0.76	11.40	23.33	30.27	51.33	115.00	174.20
LSD at 5 %	2.446	NS	2.52	0.938	1.83	1.32	0.103	NS	NS	N.S	2.73	3.73	4.01	2.56	2.78

Subscript values denote the levels of FA in t ha^{-1} and K in kg ha^{-1}. The dose of N and P was applied @ 20 and 30 kg ha^{-1} uniformly. NS- non-significant

Application of fly ash along with chemical fertilizers and organic materials is an integrated way of saving fertilizer consumption, as well as increasing fertilizer use efficiency (FUE) (Mittra et al., 2003). They found that the integrated use of fly ash, as well as organic and inorganic fertilizers saved N, P and K fertilizers to the range of 45.8, 33.5 and 61.6%, respectively and gave higher FUE than normal chemical fertilizers alone or combined use of organic and chemical fertilizers. Similarly, in the present study after repeated experiments, it was concluded that NPK can be saved and there can be useful disposal of fly ash. Beneficial use of fly ash at the rate of 15 t ha^{-1} in case of spinach (*S. oleracea* L.) and 10 t ha^{-1} in case of methi (*T. foenumgraecum* L.) with saving of 15 kg P and 20 kg K ha observed in present study.

CONCLUSION

It may be concluded that the incorporation of fly ash in soil at the rate of 10 and 15 t ha^{-1} after N, P and K fertilization is not harmful to spinach and methi, if grown in Aligarh soil. Further, fly ash may facilitate convenient disposal in agricultural land. Moreover, in the present study fly ash reduced dependence on P and K fertilizers, therefore it may also be concluded that nutrients present in fly ash may alleviate the need to purchase expensive inorganic fertilizers.

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