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RESEARCH ARTICLE

Impact of integrated application of fly ash and lime on nutrient availability, uptake and yield of lentil in acid soil under different fertilizer levels

Tusarkanta Behera[1], Anand Prakash Singh[1], Jitendra Kumar Nayak[2]* & Bishnupriya Patra[2]

[1]Department of Soil Science & Agricultural Chemistry, Banaras Hindu University 221 005, Uttar Pradesh, India
[2]Department of Agronomy, Faculty of Agricultural Sciences, Siksha 'O' Anusandhan Deemed to be University, Bhubaneswar 751 003, Odisha, India

*Correspondence email - jitendrakumarn86@gmail.com

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Abstract

Fly ash (FA), a coal combustion solid residue has been considered problematic waste due to challenges in its management and disposal issue. To address disposal challenges, the application of FA to agricultural soils offers a sustainable management strategy. FA exhibits liming properties and contains oxides and hydroxides of P, K, Ca, Mg, Fe, Mn, etc. making it both a nutrient source for plants and a soil amendment. Therefore, a pot culture experiment was conducted during winter of 2020 with lentil (*Lens culinaris* Medik.) cv. Malviya Viswanath as test crop in the net house of the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi to investigate the impact of using FA either alone or in conjunction with lime in acid soil on nutrient availability and uptake by lentil crop. Application of FA, lime and different doses of fertilizers had significant impact on available N, P and K of soil among treatments. The application of 100 % recommended dose of fertilizer ($RDF_{100\%}$) + 20 % lime requirement ($LR_{20\%}$) + FA rate ($FAR_{80\%}$) recorded significantly higher soil available N, whereas highest available P and K was registered with the treatment comprising $RDF_{100\%}$+ $FAR_{100\%}$. Application of $FAR_{100\%}$ had significantly increased available P and K of soil over control by 20.2 and 7.1 % respectively. The incorporation of $FAR_{80\%}$ along with $RDF_{100\%}$ and $LR_{20\%}$ resulted in the highest seed yield (5.7 g pot^{-1}) among the treatments. Similarly, the application of FA in combination with lime and fertilizer had significant effect on macronutrient content and uptake by the crop. A positive linear relationship was observed between seed nutrient uptake and seed yield of lentil.

Keywords: fly ash; lentil; lime; nutrient availability; nutrient uptake; recommended dose of fertilizers

Introduction

The demand for energy in India has significantly expanded due to growth of industries such as manufacturing and construction, as well as large-scale infrastructure development projects like transportation networks and urban housing. Coal plays a crucial role in meeting the world's energy needs. It is used in thermal power plants to produce electricity and is the primary energy source for the steel and cement sectors (1, 2). Typically, coal is pulverised and fed into the combustion chamber of the boiler. Coal ignites in the combustion chamber, generating heat energy. During the course of combustion of coal, a few byproducts known as coal ash are created. Fly ash (FA), a coal combustion solid residue has been considered as problematic waste due to its management and disposal issues (3). One approach to managing FA disposal is its application to agricultural soils. The importance of FA application to soil as an amendment has drawn the attention in India (4). FA is an amorphous, ferro-aluminosilicate material that contains silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), iron oxide (Fe_2O_3) calcium oxide (CaO), magnesium oxide (MgO), potassium oxide (K_2O), phosphorous pentoxide (P_2O_5), sulphur trioxide (SO_3), etc (5). The presence of these elements in FA creates an opportunity for its utilization in enhancement of soil fertility and crop productivity (6). The FA exhibits liming properties due to presence of different metal oxides and hydroxides thereby affecting the nutrient availability in soil. Therefore, it is frequently applied as an ameliorant material to improve soil quality of acid soil.

Soil acidity is a significant obstacle to improving global food and nutritional security due to its detrimental effects on biological and economic productivity of ecosystem (7–9). The availability of nutrients is affected by different forms of soil acidity; for instance, micronutrient availability, specifically that of Fe, Cu, Mn and Zn increases whereas that of Ca, Mg and K decreases (10). Because of the soil acidity and exchangeable Al^{3+} ions, the microbial biomass and enzyme activity in the soil are negatively impacted. Therefore, managing soil acidity is essential for enhancing regional and global food security. The use of lime and other liming materials to ameliorate the soil acidity is one of the most significant and practical management strategies (11, 12). Use of lime in the form of carbonate or oxide in acid soil is not seen due to its high cost. Therefore, FA is used as an alternative source for the reclamation of acid soil due to its liming potential and is a great way to lower the cost of agricultural inputs (13). FA is used as a soil ameliorant to enhance the physical characteristics of the soil and as a source of readily available plant macronutrients and micronutrients (14, 15). It is well acknowledged that pulses are essential for maintaining the long-term productivity of soil, particularly in vulnerable locations and for ensuring household nutritional security, particularly for the poorer members of society.

Lentil (*Lens culinaris* Medik.) is a widely cultivated leguminous plant of significant agricultural and economic value. It is a short-statured, annual, self-pollinated and high value crop which has great significance in cereal-based cropping system (16–18). Its protein is easily digested, has a high protein efficiency ratio and excellent biological value. The growth and production of lentil in acid soil is relatively less due to poor availability of nutrient. As FA shows liming properties and contains essential nutrients required by plant, current research was conducted to explore the possibility of using FA as an amendment either alone or in conjunction with lime in acidic soil and to evaluate its effect on yield, nutrient availability and nutrient uptake of lentil crop.

Materials and Methods

Experimental setup

A pot culture experiment was conducted during the winter season of 2020 with lentil (cv. Malviya Viswanath) as test crop in the net house of the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttarpradesh, India. Soil sample was collected from Rajgarh block (24°52' N latitude and 82°50' E longitude) and kept in shade for air drying purpose. The air-dried soil sample was processed and sieved through a 2 mm sieve and later analysed for different physico-chemical properties. The FA sample, collected from the Singrauli Super Thermal Power Station, Uttar Pradesh was oven-dried at 105 °C for 24 hr to remove excess moisture. After complete drying, the FA sample was ground and sieved. The initial properties of soil and FA sample are presented in Table 1. Each earthen pot (17 cm × 16 cm × 30 cm) was filled with 10 kg of processed soil and amended with the calculated quantities of FA, lime and NPK fertilizers as per the respective treatments. The FA amount which was equivalent to full lime requirement (5.4 t ha^{-1}) was calculated by using calcium carbonate equivalent (CCE) value and lime requirement (LR) value. The lime requirement for 10 kg of soil was calculated to be 24 g. The calcium carbonate equivalent (CCE) value of FA was 7.75 %, indicating that 100 g of FA was equivalent to 7.75 g of effective lime. Therefore, to meet the lime requirement of 24 g, approximately 310 g of FA was required. The values of 100 % lime requirement (LR) and 100 % FA rate (FAR) were 24 g and 310 g per pot respectively. Likewise different percentage of LR and FAR were calculated and applied in the pots according to treatments. The recommended dose of fertilizer (RDF) for lentil crop is 40:60:20 kg $N:P_2O_5:K_2O$ ha^{-1}. The 100 % recommended dose of NPK fertilizer per pot was 178 mg N, 267 mg P_2O_5 and 89 mg K_2O. Similarly, the different percentages of recommended dose of NPK fertilizers were calculated and applied in the pots according to treatments. Each treatment was replicated for three times. Finally, six plants were kept in the pot and their pods and stover were harvested and analysed.

Table 1. Initial characteristics of soil and fly ash used in pot culture experiment

Physico chemical properties	Soil	Fly ash
pH	5.62	8.76
EC (dS m^{-1})	0.11	0.52
Available N (mg kg^{-1})	121.5	_____
Available P (mg kg^{-1})	10	
Available K (mg kg^{-1})	86	_____
CCE (%)		7.75
Lime requirement (t ha^{-1})	5.4	_____

Note: EC= Electrical conductivity; CCE= Calcium carbonate equivalent.

Analysis of chemical properties of soil

The post-harvest soil samples were collected in 1 kg polythene bag and brought to the laboratory individually. Soil samples were dried at room temperature and pulverised with a wooden roller on a wooden plank before being sieved using a 2 mm sieve. The processed soil samples were analysed for estimation of available N, P and K. The available N was determined by alkaline potassium permanganate method (19), available P by using $BrayP_1$ extractant (0.03N NH_4F+ 0.025N HCl) (20) and available K by flame photometry using 1 N ammonium acetate as the extractant (21).

Yield parameters of crop

At harvest, pods were counted on six plants per pot and the average number of pods per plant was computed. During harvesting, the number of seeds per pod was calculated by dividing the total number of seeds with total number of pods. After sun-drying the harvested produce for several days, the seed yield of lentil from each pot was determined by weighing. The seed yield was measured in gram per pot (g pot^{-1}). After removal of pod, leaves and roots from plant, the left-over portion i.e., stover weight was measured from each of the pot. The stover yield was measured in g pot^{-1}.

Analysis of nutrient content in seed and stover

After harvest, the pods and stover of the lentil crop were air-dried. The total N in seed and stover was estimated by the micro-kjeldahl method. For the determination of total P content, ground seed and stover samples were digested with di-acid mixture (HNO_3:$HClO_4$ in 3:1 ratio) and the P content in the acid digest was then estimated by vanadomolybdo–yellow colour method using a spectrophotometer. The total K content in seed and stover was determined by using di-acid mixture (HNO_3:$HClO_4$ in 3:1 ratio) extractant and potassium content of digested seed and stover was determined by flame photometer (22).

Statistical analysis

Experimental data were obtained in triplicate and were analyzed by one-way analysis of variance (ANOVA). Significant differences among treatment means at $p \leq 0.05$ were determined using Duncan's multiple range test (DMRT).

Results and Discussion

The results are discussed in terms of (a) the effects of FA, lime and fertilizers on available primary macronutrient content of post-harvest soil; (b) yield attributes and yield of lentil; (c) nutrient content

Table 2. Effect of fly ash, lime and fertilizers on primary macro nutrient content of post-harvest soil

Treatments	Available N (mg kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})
T_1: Control	104.5^{h}	9.4^{j}	84^{h}
T_2: 100 % RDF	115.5^{bcdef}	11.8^{efgh}	96^{c}
T_3: 100 % FAR	105.9^{h}	11.3^{ghi}	90^{def}
T_4: 100 % LR	107.3^{gh}	10.2^{ij}	84.5^{gh}
T_5: 100 % RDF + 100 % LR	117.4^{abcde}	12.0^{efgh}	97^{c}
T_6: 100 % RDF + 80 % LR + 20 % FAR	121^{abc}	12.5^{defg}	97.5^{bc}
T_7: 100 % RDF + 50 %LR + 50 % FAR	123.8^{a}	12.9^{cdef}	99^{abc}
T_8: 100 % RDF + 20 % LR + 80 % FAR	119.6^{abc}	14.3^{ab}	100.5^{ab}
T_9: 100 % RDF + 100 % FAR	116.5^{abcde}	14.9^{a}	102^{a}
T_{10}: 75 % RDF + 100 % LR	115.5^{bcdef}	11.7^{fgh}	91^{de}
T_{11}: 75 % RDF + 80 % LR + 20 % FAR	118.3^{abcd}	11.8^{efgh}	91.5^{d}
T_{12}: 75 % RDF + 50 % LR+ 50 % FAR	122.4^{ab}	12.6^{defg}	92.5^{d}
T_{13}: 75 % RDF + 20 %LR + 80 % FAR	118.4^{abcd}	13.4^{bcd}	96.5^{c}
T_{14}: 75 % RDF + 100 % FAR	111.4^{defgh}	14.2^{abc}	98^{bc}
T_{15}: 50 % RDF + 100 % LR	114^{cdefg}	10.9^{hi}	87^{fgh}
T_{16}: 50 % RDF + 80 % LR + 20 % FAR	110^{efgh}	11.7fgh	88efg
T_{17}: 50 % RDF + 50 % LR + 50 % FAR	107.3^{gh}	12.3^{defgh}	89.5^{def}
T_{18}: 50 % RDF + 20 % LR + 80 % FAR	108.6^{fgh}	13.2^{bcde}	90.5^{de}
T_{19}: 50 % RDF + 100 % FAR	110^{efgh}	13.5^{bcd}	92^{d}
SEm ±	2.38	0.43	3.24
CD ($p \leq 0.05$)	6.8	1.3	1.1

Note: RDF= Recommended dose of fertilizer, LR= Lime requirement, FAR= Fly ash rate. Mean values within a column for each parameter followed by the same lowercase letter are not significantly different at $p < 0.05$ according to DMRT.

in seed and stover of lentil and (d) nutrient uptake by seed and stover of lentil.

Available primary macronutrient content of post-harvest soil

The data related to available N, P and K in post-harvest soil are presented in Table 2. There were significant differences in available soil N due to different treatments. Application of RDF at 100 % (T_2) resulted in a significant 10.53 % increase in available N of soil compared to the control (T_1). Available N contents of soil in $FAR_{100\%}$ (T_3) and $LR_{100\%}$(T_4) treated pots were at par with T_1. With increase in FA dose, no significant difference in available N was found in the treatments ranging from $T_6$to T_9 over T_2. The highest available N in the soil was observed in T_8: $RDF_{100\%}$ + $LR_{20\%}$+ $FAR_{80\%}$(119.6 mg kg^{-1}). The higher availability of N in FA, lime and fertilizers treated soil might be due to supply of N through fertilizer application as well as high rate of mineralization of organic N to inorganic N. Application of lime with FA might increase microbial activity by elevating soil pH which in turn enhanced the mineralization process. Enhancement of N status by application of FA with chemical fertilizers has also been reported (13). The results revealed that application of FA, lime and different doses of fertilizers had significant impact on soil available P among treatments. Available P in T_2 was significantly higher than T_1. Similarly, application of FA at 100 % (T_3) had caused significant increase in available P of soil over control. Available P of soil with $LR_{100\%}$(T_4) was at par with $FAR_{100\%}$ (T_3). When RDF was reduced from 100 % to 50 %, there was significant reduction in available P of soil. The available P of soil was significantly lower in T_{19}($RDF_{50\%}$+ $FAR_{100\%}$) when compared to T_9($RDF_{100\%}$+ $FAR_{100\%}$), whereas available soil P in T_{14}($RDF_{75\%}$+ $FAR_{100\%}$) was at par with T_9. The highest available P was found in T_9(14.9 mg kg^{-1}). The treatments which include lime showed higher availability of P in soil. This might be due to increase in soil pH resulting in desorption of Fe- and Al-bound Pinto the available form (23).

The highest soil available P was observed in the T_9 treatment, which may be attributed to the addition of P through FA and phosphatic fertilizers. The liming effect of FA also increased soil pH, resulting in greater availability of soil P. Application of FA to soil increased the available P (4). The current results also showed significant differences in soil available K among the different treatments. The available K in T_2 was significantly higher than T_1. Similarly, application of FA at 100 % (T_3) had significantly increased available soil K over control. Available K of soil in T_4 was significantly lower than T_3. When RDF was reduced from 100 % to 50 %, there was significant reduction in available K of soil. In the treatments consisting of FA and different doses of fertilizer i.e., T_9, T_{14} and T_{19} a significant reduction in available K of soil was observed with decrease in RDF. The highest available K content of soil in T_9 might be due to addition of K through potassic fertilizer and FA (4, 24).

Yield attributes and yield of lentil

Application of FA with fertilizers and lime had a significant impact on yield attributes of lentil like the number of pods per plant and 1000-seed weight. However, number of seeds per pod were not significantly varied with the application of FA combined with fertilizers and lime (Table 3). The number of pods per plant and the 1000-seed weight in T_2 were significantly higher than the T_1. The number of pods per plant and the 1000-seed weight in T_3 and T_4 were at par with control, whereas the application of FA at 100 % with RDF at 100 % (T_9) significantly increased the number of pods per plant and the 1000-seed weight over T_1. Similarly, when lime at 100 % was applied in conjunction with RDF at 100 % (T_5) significantly increased the number of pods per plant over control. The 1000-seed weight recorded under T_5 (18.9 g) was significantly higher over T_1. In the treatments, T_6 to T_8, an increase in the number of pods per plant and the 1000-seed weight was observed over control. Similarly increasing FA doses in the treatments $T_{11}$to T_{13}, resulted in higher number of pods per plant and greater 1000-seed weight compared to control. The number of pods per plant in T_{11} ($RDF_{75\%}$+ $LR_{80\%}$+ $FAR_{20\%}$) and T_{12} ($RDF_{75\%}$+ $LR_{50\%}$+ $FAR_{50\%}$) was significantly higher than T_1, whereas the 1000 seed weight in $T_{11}$and $T_{12}$was at par with the T_1. The number of pods per plant and the 1000-seed weight in T_{13} ($RDF_{75\%}$+ $LR_{20\%}$+ $FAR_{80\%}$) were significantly higher than the T_1. In the treatments T_{16} to T_{18}, an increasing trend in the number of pods per plant was also observed.

Table 3. Effect of fly ash, lime and fertilizers on yield attributes and yield of lentil

Treatments	Number of pods plant^{-1}	Number of seeds pod^{-1}	1000-seed weight (g)	Seed yield (g pot^{-1})	Stover yield (g pot^{-1})
T_1	7.7^{k}	1.2	18.4^{e}	1.0^{k}	3.0^{h}
T_2	29.7^{bcd}	1.3	18.8^{bcd}	4.3^{c}	6.8^{bcd}
T_3	10.3^{ijk}	1.2	18.5^{e}	1.3^{ij}	3.3^{h}
T_4	9.0^{jk}	1.2	18.5^{e}	1.1^{jk}	3.1^{h}
T_5	17.3^{fghi}	1.2	18.9^{bcd}	2.3^{g}	5.9^{def}
T_6	32.3^{abc}	1.2	19.1^{ab}	4.4^{c}	7.3^{ab}
T_7	35.7^{ab}	1.2	19.2^{a}	5.1^{b}	7.4^{ab}
T_8	38.7^{a}	1.3	19.3^{a}	5.7^{a}	8.0^{a}
T_9	24.0^{def}	1.2	18.7^{cde}	3.3^{e}	6.1^{cde}
T_{10}	13.0^{hijk}	1.2	18.5^{de}	1.7^{h}	5.7^{efg}
T_{11}	21.3^{efg}	1.2	18.6^{cde}	2.8^{f}	6.6^{bcd}
T_{12}	27.0^{cde}	1.3	18.7^{cde}	3.8^{d}	7.0^{bc}
T_{13}	31.3^{bc}	1.2	18.9^{bc}	4.3^{c}	7.4^{ab}
T_{14}	13.3^{hijk}	1.2	18.6^{cde}	1.7^{h}	5.5^{efg}
T_{15}	11.7^{ijk}	1.2	18.5^{e}	1.6^{hi}	5.1^{fg}
T_{16}	12.7^{hijk}	1.2	18.5^{de}	1.6^{h}	5.8^{def}
T_{17}	15.3^{ghij}	1.2	18.6^{cde}	2.1^{g}	6.3^{cde}
T_{18}	19.0^{fgh}	1.3	18.6^{cde}	2.6^{f}	6.7^{bcd}
T_{19}	11.0^{ijk}	1.1	18.5^{e}	1.4^{ij}	4.9^{g}
SEm ±	2.18	0.04	0.09	0.08	0.29
CD ($p \leq 0.05$)	6.2	NS	0.3	0.2	0.8

Note: Mean values within a column for each parameter followed by the same lowercase letter are not significantly different at p < 0.05 according to DMRT.

The data related to seed yield per pot and stover yield per pot are presented in Table 3. The results also revealed that seed yield and stover yield in T_2 was significantly higher than T_1. Significant differences in seed and stover yield of lentil were observed across treatments. Application of FA at 100 % (T_3) significantly increased the seed yield over control, whereas the stover yield in $T_3$was at par with T_1. The seed yield and stover yield in T_4 were at par with the T_1. Application of FA at 100 % with RDF at 100 % (T_9) significantly increased the seed yield and stover yield over T_1. Similarly, when lime at 100 % was applied in conjunction with RD Fat 100 % (T_5), it significantly increased the seed and stover yield over control. In the treatments, T_9, T_{14} and T_{19}, a decreasing trend in the seed yield and stover yield was observed with a decrease in the fertilizer doses. In the treatments, T_6 to T_8, an increase in the seed yield and stover yield was observed over control. Similarly in the treatments T_{11} to T_{13}, with an increase in FA doses, the seed yield and stover yield increased over control. In the treatments $T_{16}$to T_{18}, an increasing trend in the seed yield and stover yield was also observed. A better seed yield with the addition of FA has been reported earlier (25–27).

Nutrient content in seed and stover of lentil

The application of FA lime and fertilizers improved N content in lentil seed and stover (Table 4). In general, across the treatments, the N content was higher in seed compared to stover. There were significant differences in N content in seed and stover of lentil among treatments. Application of RDF at 100 % in T_2 significantly increased N content in seed over control, whereas N content of stover in $T_2$was at par with control. The N content of seed and stover in T_3 and T_4 was at par with the T_1. In the treatments, T_6 to T_8, an increase in N content in seed and stover of lentil was observed. Similarly in the treatments T_{11} to T_{13}, with the increase in FA doses, N content in seed and stover increased. The N content of stover in T_{11} was at par with T_1. In the treatments T_{16} to T_{18}, an increasing trend in N content in seed and stover of lentil was observed. The results showed that the application of FA in combination with fertilizers and lime had a significant effect on P content in the seed and stover of lentil (Table 4). The P content of seed and stover in T_2 was significantly higher than the T_1. The P content of seed and stover in T_3 and T_4 was at par with the T_1. When lime at 100 % was applied with RDF at 100 % in T_5, P content in seed and stover was significantly increased over control. In the treatments, T_6 to T_9, an increase in P content in seed and stover of lentil was observed over control. Similarly in the treatments T_{11} to T_{14}, with the increase in FA doses, P content in seed and stover increased over control. The P content in seed and stover of lentil in T_9 was significantly higher than T_2, whereas the P content in seed and stover of lentil in T_{14} was at par with T_2. In the treatments T_{16} to T_{19}, an increasing trend in P content in seed and stover of lentil was observed. Application of NPK fertilizers in T_2 significantly increased the K content in seed and stover of lentil over control (Table 4). In the FA amended treatment (T_3), K content in seed and stover increased, though the effect was not statistically significant compared to control. Significant differences in K content of seed and stover were observed among the treatments. The K content of seed and stover in T_4 was at par with T_1. In treatments T_6 to T_9, an increase in K content in the seed and stover of lentil was observed compared to the T_1. Similarly in the treatments T_{11} to T_{14}, with the increase in FA doses, K content in seed and stover increased over T_1. The K content in seed and stover of lentil in T_9 was significantly higher than T_2, whereas K content in seed and stover of lentil in T_{14} was at par with T_2. In the treatments T_{16} to T_{19}, an increasing trend in K content in seed and stover of lentil was observed. The highest N content in seed and stover was observed in T_8 whereas, the highest P and K content in seed and stover was observed in T_9 ($RDF_{100\%}$+ $FAR_{100\%}$). The increase in N, P and K content in the seed and stover of lentil with FA application might be ascribed to the improved physical and chemical properties of acidic soil. The positive effect of FA application on nutrient content in the seeds of wheat and maize and in the fruits of eggplant was reported earlier (28).

Nutrient uptake by seed and stover of lentil

The application of FA, lime and fertilizers significantly affected N uptake in lentil seeds and stover (Table 5). In general, across the treatments, the N uptake was higher by seed as compared to stover. Application of RDF at 100 % in T_2 significantly increased N uptake by seed and stover over control. The N uptake by seed and stover in T3 and T4 was at par with the control. In the treatments, T_6 to T_8, an increase in N uptake by seed and stover of lentil was observed. The N uptake by seed and stover in T_7 ($RDF_{100\%}$+ $LR_{50\%}$+ $FAR_{50\%}$) and T8 was

Table 4. Effect of fly ash, lime and fertilizers on nutrient content in seed and stover of lentil

Treatments	N ($g\ kg^{-1}$)		P ($g\ kg^{-1}$)		K ($g\ kg^{-1}$)	
	Seed	**Stover**	**Seed**	**Stover**	**Seed**	**Stover**
T_1	35.1^{f}	11.6^{g}	3.6^{h}	2.8^{i}	11.9^{g}	13.2^{g}
T_2	39.4^{bcde}	13.4^{cdef}	4.8^{bcdef}	3.8^{cdefg}	12.8^{bcdef}	14.3^{bcde}
T_3	34.5^{f}	11.2^{g}	4^{fgh}	3.2^{ghi}	12.2^{efg}	13.6^{efg}
T_4	35.4^{f}	11.4^{g}	3.7^{gh}	2.9^{hi}	12.1^{fg}	13.3^{fg}
T_5	39.7^{bcde}	13.6^{bcdef}	4.9^{bcdef}	4^{bcdef}	12.8^{bcde}	14.4^{bcde}
T_6	40.4^{abcd}	13.8^{abcde}	5.1^{abcde}	4.1^{bcdef}	13^{bcd}	14.6^{abcd}
T_7:	40.8^{abc}	14.4^{abc}	5.3^{abc}	4.4^{abcd}	13.2^{abcd}	14.8^{abc}
T_8	41.8^{a}	14.9^{a}	5.6^{ab}	4.7^{ab}	13.5^{ab}	15.1^{ab}
T_9	39.6^{bcde}	13.9^{abcde}	5.9^{a}	4.9^{a}	13.8^{a}	15.4^{a}
T_{10}	39.2^{cde}	13.1^{def}	4.6^{cdefg}	3.6^{efgh}	12.6^{cdefg}	14_{cdefg}
T_{11}	38.6^{de}	12.9^{def}	4.8^{bcdef}	3.9^{cdefg}	12.7^{bcdef}	14.2^{bcdef}
T_{12}	40.2^{abcde}	14^{abcd}	5.4^{abc}	4.2^{abcde}	12.9^{bcde}	14.5^{abcde}
T_{13}	41.2^{ab}	14.6^{ab}	5.6^{ab}	4.4^{abcd}	13.2^{abcd}	14.7^{abc}
T_{14}	39.4^{bcde}	13.5^{bcdef}	5.7^{ab}	4.5^{abc}	13.4^{abc}	15^{ab}
T_{15}	38.4^{e}	12.6^{f}	4.2^{efgh}	3.2^{ghi}	12.4^{defg}	13.7^{defg}
T_{16}	38.8^{de}	12.8^{ef}	4.3^{defgh}	3.4^{fghi}	12.5^{defg}	13.9^{cdefg}
T_{17}	40.4^{abcd}	13.7^{bcdef}	4.6^{cdefg}	3.7^{defg}	12.7^{bcdef}	14.2^{bcdef}
T_{18}	39.8^{bcde}	14.3^{abc}	5^{abcde}	3.9^{cdefg}	13^{bcd}	14.4^{bcde}
T_{19}	38.5^{de}	13.1^{def}	5.2^{abcd}	4.1^{bcdef}	13.1^{abcd}	14.6^{abcd}
SEm ±	0.58	0.34	0.29	0.23	0.68	0.29
CD ($p \leq 0.05$)	1.7	1.0	0.8	0.7	0.2	0.8

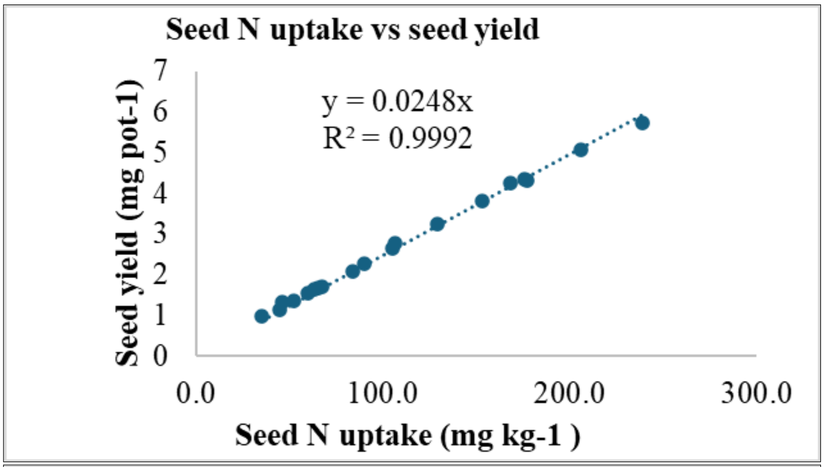
Note: Mean values within a column for each parameter followed by the same lowercase letter are not significantly different at $p < 0.05$ according to DMRT.

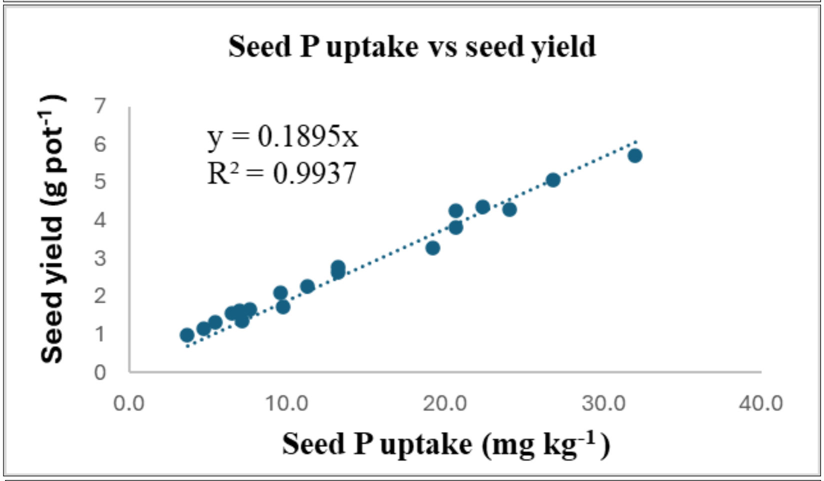
Table 5. Effect of fly ash, lime and fertilizers on nutrient uptake by seed and stover

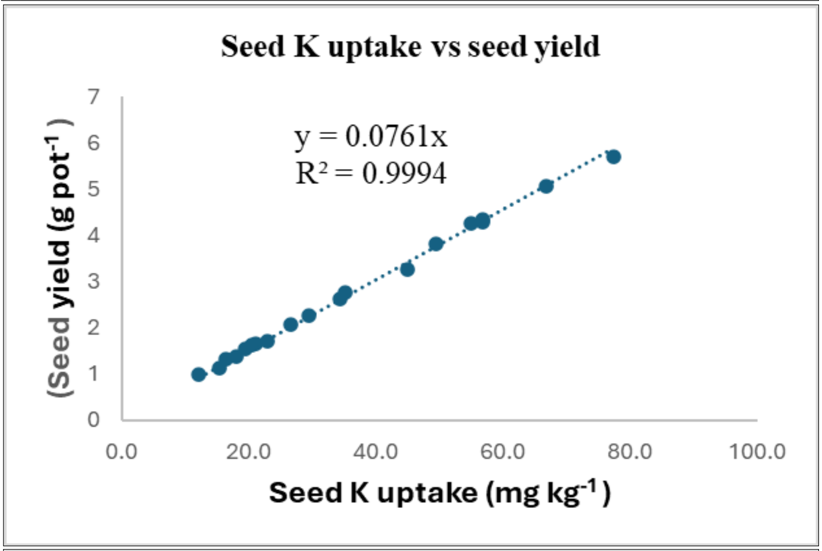
Treatments	N ($mg\ pot^{-1}$)		P ($mg\ pot^{-1}$)		K ($mg\ pot^{-1}$)	
	Seed	**Stover**	**Seed**	**Stover**	**Seed**	**Stover**
T_1	35.4^{j}	34.8^{i}	3.7^{i}	8.4^{h}	12.0^{i}	39.6^{i}
T_2	168.7^{c}	90.6^{de}	20.7^{cd}	25.7^{cde}	54.8^{c}	96.7^{de}
T_3	46.0^{ij}	36.7^{i}	5.4^{ghi}	10.5^{h}	16.3^{hi}	44.5^{i}
T_4	44.6^{ij}	35.8^{i}	4.7^{hi}	9.2^{h}	15.3^{hi}	41.8^{i}
	90.1^{fg}	80.8^{fg}	11.3^{ef}	23.8^{ef}	29.3^{ef}	85.5^{fg}
T_6	176.1^{c}	100.2^{bc}	22.4^{bcd}	29.7^{bc}	56.7^{c}	106.0^{bc}
T_7	206.4^{b}	106.5^{b}	26.8^{b}	32.5^{b}	66.8^{b}	109.5^{b}
T_8	239.2^{a}	118.8^{a}	32.0^{a}	37.5^{a}	77.2^{a}	120.3^{a}
T_9	129.0^{de}	84.3^{ef}	19.2^{d}	29.7^{bc}	44.9^{d}	93.4^{e}
T_{10}	65.4^{ghi}	74.1^{g}	7.7^{fghi}	20.3^{fg}	21.0^{fghi}	79.3^{g}
T_{11}	106.5^{ef}	85.5^{ef}	13.3^{e}	25.8^{cde}	35.0^{e}	94.1^{de}
T_{12}	153.6^{cd}	97.5^{cd}	20.6^{cd}	29.2^{bcd}	49.3^{cd}	101.0^{cd}
T_{13}	177.2^{c}	107.6^{b}	24.1^{bc}	32.4^{b}	56.8^{c}	108.3^{b}
T_{14}	67.3^{ghi}	74.6^{g}	9.7^{efg}	24.8^{de}	22.9^{fgh}	82.9^{fg}
T_{15}	59.7^{hij}	63.7^{h}	6.5^{fghi}	16.1^{g}	19.3^{ghi}	69.3^{h}
T_{16}	63.2^{ghi}	74.7^{g}	7.0^{fghi}	19.9^{fg}	20.4^{fghi}	81.1^{g}
T_{17}	84.0^{fgh}	86.4^{ef}	9.6^{efgh}	23.3^{ef}	26.4^{efg}	89.5^{ef}
T_{18}	105.2^{rf}	95.9^{cd}	13.2^{e}	26.2^{cde}	34.4^{e}	96.5^{de}
T_{19}	52.7^{ij}	63.7^{h}	7.1^{fghi}	19.9^{fg}	17.9^{ghi}	71.0^{h}
SEm ±	8.66	2.55	1.5	1.43	2.91	2.37
CD ($p \leq 0.05$)	24.8	7.3	4.31	4.1	8.34	6.78

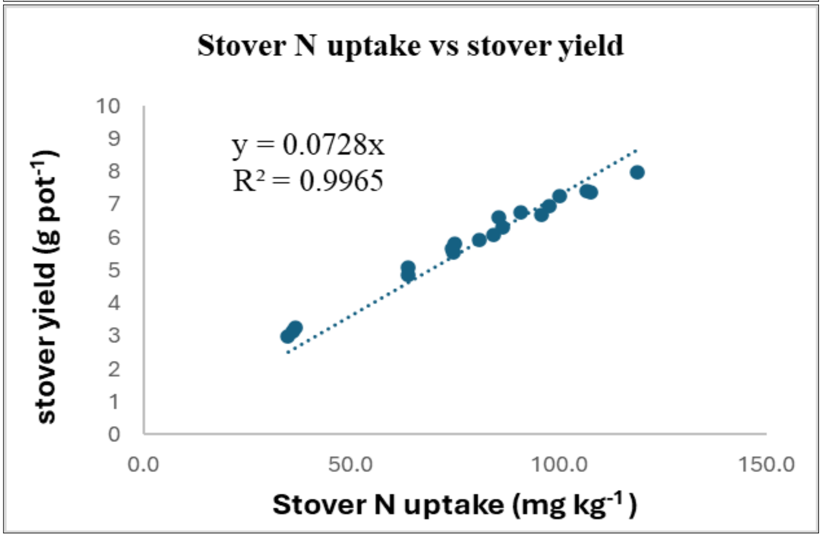
Note: Mean values within a column for each parameter followed by the same lowercase letter are not significantly different at $p < 0.05$ according to DMRT.

significantly higher than T_2. There were significant differences in P uptake by seed and stover of lentil under different treatments (Table 5). The P uptake by seed and stover in T_2 was significantly higher than the T_1. The P uptake by seed and stover in T_3 and T_4 was at par with T_1. In the treatments T_6 ($RDF_{100\%}$+ $LR_{80\%}$+ $FAR_{20\%}$), T_{11} and T_{16} ($RDF_{50\%}$+ $LR_{80\%}$+ $FAR_{20\%}$) with decrease in fertilizer doses, the P uptake by seed and stover was significantly decreased. In the treatments, T_6 to T_9, an increase in P uptake by seed and stover of lentil was observed. A similar increasing trend in P uptake was observed in the treatments T_{11} to T_{14}. In the treatments T_{16} to T_{19}, an increasing trend in P uptake by seed and stover of lentil was observed. Application of NPK fertilizers in T_2 significantly increased the K content in seed and stover of lentil over control (Table 5). In FA amended treatment (T_3: $FAR_{100\%}$) an increase in K uptake by seed and stover but a nonsignificant effect was found over control–T_1. In contrast, the combined application of the recommended dose of fertilizer and FA (T_9) significantly increased the K uptake by seed and stover over control. There were significant differences in the K uptake by seed and stover of lentil receiving different treatments. The K uptake by seed and stover in T_4 was at par with T_1. In the treatments, T_6 to T_9, an increase in K uptake by seed and stover of lentil was observed over T_1. Similarly in the treatments T_{11} to T_{14}, an increasing trend in K uptake by seed and stover was observed. The highest N, P and K uptake by seed and stover was observed in T_8. An increase in N, P and K uptake by lentil seed and stover with the application of FA in conjunction with lime might be associated with the higher nutrient availability in soil (29). The integrated use of FA in combination with organic wastes and chemical fertilizers has been


Seed N uptake vs seed yield
y = 0.0248x
R² = 0.9992
Seed yield (mg pot-1)
7
6
5
4
3
2
1
0
0.0
100.0
200.0
300.0
Seed N uptake (mg kg-1)


Seed P uptake vs seed yield
y = 0.1895x
R² = 0.9937
Seed yield (g pot-1)
7
6
5
4
3
2
1
0
0.0
10.0
20.0
30.0
40.0
Seed P uptake (mg kg-1)


Seed K uptake vs seed yield
y = 0.0761x
R² = 0.9994
(Seed yield (g pot-1)
7
6
5
4
3
2
1
0
0.0
20.0
40.0
60.0
80.0
100.0
Seed K uptake (mg kg-1)


Stover N uptake vs stover yield
y = 0.0728x
R² = 0.9965
stover yield (g pot-1)
10
9
8
7
6
5
4
3
2
1
0
0.0
50.0
100.0
150.0
Stover N uptake (mg kg-1)

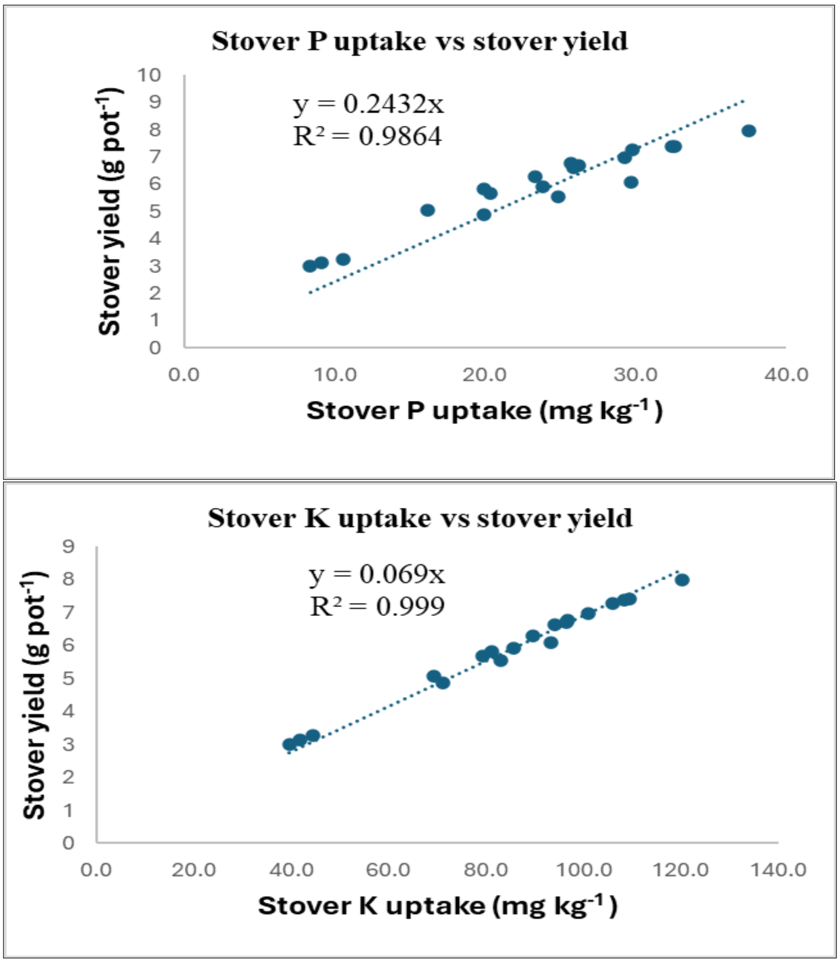


Fig. 1. Linear regression between yield and nutrient uptake in seed and stover of lentil.

reported to enhance nutrient uptake in a rice–mustard cropping sequence (15). The increase in the yield of seed and stover might be due to increase in N, P and K uptake by seed and stover of lentil. There was a linear progression between nutrient uptake by seed and seed yield of lentil (Fig. 1). A positive correlation between K uptake and crop yield was observed by (30, 31). An increase in the uptake of N and P has been reported to improve grain yield (31, 32).

Conclusion

The present investigation demonstrated the enhanced availability of N, P and K in soils treated with FA along with lime and fertilizers. Therefore, it can be concluded that applying FA to soil in conjunction with lime and chemical fertilizers significantly improved primary macronutrient availability in post-harvest soil compared to the sole application of recommended dose of fertilizers to soil. Application of FA at 80 % in conjunction with lime at 20 % LR and 100 % RDF was more beneficial for the growth and yield as well as nutrient uptake by seed and stover of lentil than the sole use of recommended dose of fertilizers. This study points out that lentil is safe and suitable for cultivation in FA amended acid soils for better nutrient uptake by seed and stover. Moreover, the application of FA as a means of reducing the amount of industrial waste and lowering the cost burden of exclusive lime use as a soil ameliorant for acid soils could be a viable strategy.

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Authors' contributions

TB was responsible for conducting lab, field research work and manuscript preparation. APS was involved in conceptualizing, designing and monitoring the research. The statistical analysis, table, figure designing and communication was carried out by JKN. Manuscript editing and formatting was done by BP.

Compliance with ethical standards

Conflict of interest: There is no visible conflict of interests related to publication of this article.

Ethical issues: None

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