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Evaluation of Finely Powdered LD Slag and Potassium Feldspar based Fertilizer Formulations on Growth and Yield of Paddy

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ABSTRACT

The present study was undertaken to evaluate the Linz-Donawitz slag (LDS) and potassium potassium feldspar based fertilizer formulations on growth and yield of paddy under submerged condition in acidic soil. A pot culture experiment was conducted in complete randomized design (CRD) with five different LD and PF based fertilizer formulations consisting varying proportions of LDS and PF *viz.,* LDS 50 + PF 50, LDS 40 + PF 60, LDS 30 + PF 70, LDS + PF 80 and LDS10 + PF 90 per cent in comparison with control (Recommended dose of fertilizer-RDF) and sole application of LDS and PF. These eight treatments were replicated thrice. A significant improvement in growth and yield of paddy was observed with the application of the LDS and PF based fertilizer formulations over control. However, application of LDS 10 + PF 90 formulation @500 kg ha^{-1} along with the application of recommended dose of N and P_2O_5 recorded significantly higher plant height (54.17 ± 0.60 cm and 92.57 ± 3.23 cm at 45 days after planting and at harvest, respectively), number of tillers (13.67 ± 1.53), panicle length (24.11 ± 0.86 cm), test weight (24.91 ± 0.76 g) as well as yield attributes*viz.,* grain yield (22.32 ± 1.69 g pot^{-1}), straw yield (18.36 ± 1.39 g pot^{-1}) and total biomass (40.68 ± 2.59 g pot^{-1}) of paddy over that of control (RDF@ 100:50:50 kg N, P_2O^5 and K_2O ha^{-1}, respectively), sole application of LDS and PF.

Keywords : Paddy, LD slag, Potassium feldspar, LDS and PF based formulations, Growth, Yield

MEETING the food consumption needs of the ever increasing population with the limited availability of resources as a result of intensive cultivation has put forth tremendous challenges of food security for global agriculture. An effective exploitation of alternate nutrient resources in a cost effective way, with minimal / no environmental consequence is of greater concern. The use of locally and naturally available nutrient resources as well as safe recycling of industrial by products could be a viable option in this context. Linz-Donawitz (LD) slag generated in LD-Converter (basic oxygen converter) is one of the important waste materials in steel plant which is recyclable. The total generation rate of LDS is 150-180 kg t^{-1} of crude steel in India (Chand *et al.,* 2015). The disposal of this large quantity of slag is really challenging as it may pose serious environmental pollution. Thus, reuse of waste in steel plants is important with regard to environmental and economic consideration. Out of the total slag generated, only 25 per cent is being reused in India compared to 70 - 100 per cent in other countries (Umadevi *et al.,* 2010). Slags are the residual by-products generated during steel manufacturing. Steel slags predominantly contain oxides of silicon (SiO_2), aluminium (Al_2O_3), iron (FeO), calcium (CaO), phosphorus (P_2O_5), magnesium (MgO) and manganese (MnO) (Yildirim *et al.,* 2011 & Piatak *et al.,* 2015). The nutrient composition of LDS makes it an attractive source of soil fertilization whose potential is largely unexplored.

Potassium feldspar (PF) is a naturally occurring aluminosilicate rock comprised of substantial amounts of Si (52 - 65 %) and K (5 - 12 %) whose utilization in agricultural crops still remained primitive though India has vast reserves of PF (Tanvar and Dhawan, 2019). In this context, our idea is to formulate LDS and PF based fertilizer in combination with PF, which can able to meet nutritional requirements of crop including Si, K, Ca, Mg and micronutrients like Fe and Mn.

Under current scenario of economic development, the use of LDS and PF based fertilizer, as a source of plant nutrients would play a vital role soil fertilization and crop nourishment due to the non-availability as well as the higher price of established fertilizers. Therefore, the utilization of LDS in combination with PF would be an imperative way to satisfy overall nutritional demand of crop for major, secondary and micronutrients, besides achieving maximum fertilizer use efficiency in different soils and crops for the applied nutrient in a cost-effective manner. Therefore, improving the utilization rate of LDS along with PF would be an imperative way for effective exploitation of unconventional sources to realize sustainable crop production in agriculture. In this context, an investigation was conducted to evaluate LDS and PF based formulations using varied levels of LDS and PF and their efficacy in terms of contribution to paddy crop growth and yield under pot culture experiment.

Material and Methods

Sources and Composition of LD Slag and Potassium Feldspar

The LDS of 60 mesh size was procured from Tata Steel Ltd., Jamshedpur, Jharkhand, India and potassium feldspar (PF) of 100 mesh size was procured from a mining industry in Hyderabad, Telangana, India. The LDS and PF were further reduced to a size of 200 mesh and subjected for total elemental analysis using Energy Dispersive X-ray Fluorescence (ED-XRF). The composition of LDS and PF is presented in Table 1. The LDS chiefly comprised of CaO (56.33 %), Fe_2O_3 (18.32 %) and SiO_2 (15.21). Wherein PF was mainly constituted with SiO_2 (65.85 %), K_2O (10.1 %).

Preparation of LDS and PF based Formulations

The LDS and PF were further blended with ball mill (Retsch MM 400) to prepare LD slag based formulations of 200 mesh with varied proportions of LDS and PF *viz.,* LDS 50 + PF 50, LDS 40 + PF 60, LDS 30 + PF 70, LDS 20 + PF 80 and LDS 10 + PF 90 by combining LDS and PF at 50:50, 40:60, 30:70, 20:80 and 10:90 proportions, respectively. The formulations were then analysed for nutrient composition (Table 2).

Table 2

Nutrient composition of LDS and PF based formulations

LDS and PF based formulations	Composition of different formulations (%)		
	SiO_2	CaO	K_2O
LDS 50 + PF 50	42.50	30.44	5.90
LDS 40 + PF 60	48.38	20.70	6.77
LDS 30+ PF 70	52.60	15.90	7.40
LDS 20 + PF 80	58.41	9.90	8.34
LDS10 + PF 90	62.74	5.13	8.96

LDS- Linz-Donawitz Slag; PF-Potassium Feldspar. The results are average of four repetitions

Soil Characteristics

Surface bulk soil (0 - 15 cm depth) from K-block, University of Agricultural Sciences, GKVK (N 13° 4' 54.6672", E 77° 34' 33.5172"), Bengaluru was collected. The soil was air-dried, powdered and passed through 2 mm sieve and analyzed for various chemical properties. The pH (1:2.5) and EC of soil were determined by pH meter and conductivity meter, respectively (Jackson, 1973). The available N, P_2O_5 and K_2O was determined by alkaline potassium permanganate method (Subbiah and Asija, 1956), Brays extraction (Bray and Kurtz, 1945) and neutral normal NH_4OAc extraction and analyzed using flame photometer (Jackson, 1973), respectively. Exchangeable Ca^{2+} and Mg^{2+}, available sulphur (S),

Table 1

Nutrient composition of LD slag and potassium feldspar

Sources	Composition (%)							
	SiO_2	CaO	K_2O	Fe_2O_3	Na_2O	MgO	P_2O_5	MnO
LDS	15.21	56.33	-	18.32	-	3.36	2.39	0.46
PF	65.85	0.36	10.10	1.14	2.49	0.25	-	0.01

LDS - Linz-Donawitz Slag; PF - Potassium Feldspar. The results are average of four repetitions micronutrients (Fe^{2+}, Mn^{2+}, Cu^{2+} and Zn^{2+}) by complexometric titration method (Baruah and Barthakur, 1997), turbidiometric method (Williams and Steinbergs, 1959) and DTPA extraction (Lindsay and Norvell, 1978), respectively. The Plant-available Si content in soil was extracted by 0.01 M $CaCl_2$ (Haysom and Chapman 1975) and 0.5 M acetic acid (Narayanaswamy and Prakash, 2009) and estimated using UV visible spectrophotometer.

Initial analysis for physico-chemical properties revealed that the soil under the experiment is of acidic reaction with pH 4.98 and EC was found to be in the normal (Table 3). The soil was recorded with low available N (182.38 kg ha^{-1}), high available P_2O_5 (61.22 kg ha^{-1}) and medium available K_2O (197.56 kg ha^{-1}) status. The exchangeable Ca was high and Mg was low (2.84 and 1.31 c mol (p^+) kg^{-1} soil, respectively) and available S was medium (16.60 ppm) in range. The acetic acid (AASi) and $CaCl_2$ (CCSi) extractable Si content were medium (44.37 ppm) and low (8.83 ppm), respectively.

Pot Culture Experiment

A pot culture experiment was conducted in the Green house, Department of Soil Science and Agricultural Chemistry, UAS, GKVK, Bengaluru. Five kg of air dried, 0.2 mm sieved soil was filled in plastic pots. The soil was then treated with 1.11 g of each of LDS and PF based formulations to the respective treatments @ 500 kg ha^{-1} along with recommended dose of N and P_2O_5 @ 100:50 kg ha^{-1} through Urea and DAP. The P_2O_5 was supplied through DAP. As DAP supply both N and P_2O_5, the N supplied through DAP was taken into consideration and remaining required N was applied through urea. There was no external source of potassium (K_2O) other than the graded levels of PF in the study. However, in the control, RDF @ 100:50:50 kg ha^{-1} of N, P_2O_5 and K_2O were applied through urea and DAP, DAP and MOP, respectively. The fertilizers were mixed homogenously with soil and submergence was maintained with distilled water. Further, each pot was transplanted with two paddy seedlings of variety Jaya of 21 days old. The crop was maintained under submergence using distilled water till harvest.

TABLE 3
Initial properties of soil

Parameter	
pH (1:2.5; soil: water)	4.98
EC (dS m^{-1})	0.11
OC (g kg^{-1})	0.71
Avail. Nitrogen (kg ha^{-1})	182.38
Avail. P_2O_5 (kg ha^{-1})	61.22
Avail. K_2O (kg ha^{-1})	197.56
Exch. Ca (c mol (p^+) kg^{--1} soil)	2.84
Exch. Mg (c mol (p^+) kg^{-1} soil)	1.31
Avail. S (ppm)	16.60
Fe (mg kg^{-1})	20.65
Mn (mg kg^{-1})	97.42
Cu (mg kg^{-1})	4.31
Zn (mg kg^{-1})	3.92
Acetic Acid Silicon (mg kg^{-1})	44.37
Calcium chloride Silicon (mg kg^{-1})	8.83

TABLE 4
Treatment details

Sl. No	Treatment
1	T_1: Control (RDF)
2	T_2: LDS 50 + PF 50
3	T_3: LDS 40 + PF 60
4	T_4: LDS 30 + PF 70
5	T_5: LDS 20 + PF 80
6	T_6: LDS 10 + PF 90
7	T_7: LDS 100
8	T_8: PF 100

*LDS- LD Slag; PF-Potassium Feldspar; RDF applied was 100:50:50 kg ha^{-1} N, P_2O_5 and K_2O
Note: The LDS and PF based formulations were applied along with recommended dose of N and P_2O_5

Biometric observations *viz.,* plant height (cm) at 45 DAT and at harvest, number of tillers, test weight (weight of 1000 grains in grams) panicle length (cm), grain yield (g pot^{-1}), straw yield (g pot^{-1}) and total biomass (g pot^{-1}) were recorded. The significance between the treatments was tested by complete randomized design (CRD). The data recorded under the study were analysed for statistical significance with one-way ANOVA. Standard error mean (S Em ±) and critical difference (CD) were also computed.

RESULTS AND DISCUSSION

The results revealed that, application of LDS along with PF has significant effect on growth and yield of paddy under submerged condition. Application of varied levels of LDS from 10 to 50 per cent along with PF from 50 to 90 per cent, respectively along with recommended dose of N and P_2O_5 has recorded significant increase in plant height (cm), number of tillers, number of panicles, panicle length (cm) over control (Table 5).

Significantly higher plant height of 54.17 ± 0.60 and 92.57 ± 3.23 at 45 DAT and at harvest, respectively was recorded with treatment receiving 10: 90 per cent LDS and PF along with recommended dose of N and P_2O_5 over control (45.70 ± 3.30 and 78.67 ± 9.87 at 45 DAT and at harvest, respectively). Statistically significant variations in number of tillers, panicle length (cm) and grain test weight were observed among the treatments (Table 5). The higher number of tillers (13.67 ± 1.53), average panicle length (24.11 ± 0.86 cm) and grain test weight (24.91 ± 0.76 g) were recorded with LDS-10 + PF-90 along with recommended dose of N and P_2O_5 followed by LDS-20 + PF-80, LDS-30 + PF-70, LDS-40 + PF-60 and LDS-50 + PF-50, respectively. All the levels of LDS and PF has performed significantly over control (RDF) and application of LD slag and PF alone. The sole application of LDS and PF found to significantly reduce the number of tillers, panicle length (cm) and grain test weight over control (Table 5).

The grain yield, straw yield and total biomass of paddy was also observed to be significantly influenced by LDS and PF based formulations in the study (Table 6). The grain, straw yield and total biomass of paddy significantly increased with varied levels of LDS and PF over control (RDF). Nevertheless, the highest grain yield, straw yield and total biomass of paddy (22.32 ± 1.69, 18.36 ± 1.39 and 40.68 ± 2.59 g pot^{-1}, respectively) was recorded when crop was fertilized with LDS-10 + PF-90 along with recommended dose of N and P_2O_5.

In general, a linear increase in grain yield (from 7 to 60 %), straw yield (3 to 31 %) and total biomass (5 to 46 %) of paddy were observed with the increased levels of PF application. The increased levels of LDS from 10 to 50 per cent showed decreased grain yield, straw yield and total biomass (Table 6). The lowest grain, straw yield and total biomass of paddy (11.53 ±

TABLE 5

Effect of different LDS and PF based formulations on growth parameters of paddy under pot culture

Treatments / Formulations	Plant height (cm)		No. of tillers per hill	Panicles length (cm)	Test weight (g)
	At 45 DAS	At harvest	At 45 DAS	At harvest	
Control (RDF)	45.70 ± 3.30	78.67 ± 9.87	8.67 ± 0.58	22.20 ± 1.25	19.53 ± 0.62
LDS 50 + PF 50	44.33 ± 1.50	83.00 ± 1.73	9.33 ± 1.15	22.57 ± 0.69	21.00 ± 0.62
LDS 40 + PF 60	45.37 ± 1.70	86.33 ± 2.08	10.33 ± 2.08	23.17 ± 0.47	22.66 ± 0.78
LDS 30+ PF 70	49.53 ± 2.54	89.17 ± 7.22	10.33 ± 0.58	22.78 ± 0.48	23.53 ± 0.58
LDS 20 + PF 80	49.90 ± 3.12	90.73 ± 1.91	11.67 ± 0.58	23.81 ± 0.07	24.00 ± 0.00
LDS10 + PF 90	54.17 ± 0.60	92.57 ± 3.23	13.67 ± 1.53	24.11 ± 0.86	24.91 ± 0.76
LDS	42.20 ± 1.95	69.67 ± 12.01	6.67 ± 0.58	20.78 ± 0.56	12.92 ± 1.02
PF	44.53 ± 2.03	80.67 ± 6.11	10.33 ± 1.53	22.12 ± 0.78	16.27 ± 3.39
S. Em ±	1.32	3.66	0.70	0.43	0.74
CD @ 5 %	3.76	10.48	1.99	1.22	2.12

LDS: Linz-Donawitz Slag, PF: Potassium Feldspar, RDF: Recommended dose of fertilizer

TABLE 6
Effect of different LDS and PF based formulations on yield parameters of paddy under pot culture

Treatments / Formulations	Grain Yield (g pot^{-1})	Straw Yield (g pot^{-1})	Total Biomass (g pot^{-1})
Control (RDF)	13.93 ± 2.15	13.91 ± 3.98	27.84 ± 3.00
LDS 50 + PF 50	14.97 ± 0.20	14.42 ± 0.83	29.39 ± 0.64
LDS 40 + PF 60	15.34 ± 2.32	15.28 ± 1.30	30.62 ± 3.40
LDS 30+ PF 70	18.46 ± 2.81	15.69 ± 2.81	34.15 ± 1.04
LDS 20 + PF 80	18.86 ± 2.07	16.81 ± 1.54	35.67 ± 1.01
LDS10 + PF 90	22.32 ± 1.69	18.36 ± 1.39	40.68 ± 2.59
LDS	11.53 ± 1.55	11.62 ± 1.43	23.15 ± 2.98
PF	12.72 ± 0.66	12.86 ± 0.50	25.59 ± 1.15
S. Em ±	1.02	0.99	1.45
CD @ 5 %	2.92	2.84	4.16

LDS: Linz-Donawitz Slag, PF: Potassium Feldspar, RDF: Recommended dose of fertilizer

1.55, 11.62 ± 1.43 and 23.15 ± 2.98 g pot^{-1}, respectively) was recorded in the treatment where only slag was applied, followed by sole application of PF in comparison to control (RDF) and treatments receiving varied levels of LDS and PF.

The increased growth attributes *viz.,* plant height, number of tillers, panicle length, test weight and yield attributes, grain, straw yield and total biomass of paddy with application of varied levels of LDS and PF was mainly ascribed to the greater availability of Si, K_2O along with substantial amounts of Ca, Mg, Fe through LDS and PF. Rice is a typical Si accumulator crop which can accumulate Si nearly 10 per cent of shoot dry weight, which is considerably higher than that of many other macro nutrients and known to remove 200- 400 kg Si ha^{-1} on an average from soils (Ma and Takahashi, 2002 & Majumdar and Prakash, 2017). The increased levels of Si application, through LDS and PF based formulations ranging from 42.5 to 62.74 per cent (Table 2) might have improved grain and straw yield. Si is known to play an important role in the mineral nutrition of rice, enhancing plant defence response against diseases, protecting plants against insect pests, increasing plant photosynthesis and growth, preventing lodging, alleviating water and mineral toxicity stresses and thus, imparts higher crop yields (Rodrigues and Datnoff, 2015 & Sandhya and Prakash, 2016).

Apart from Si, the increased availability of K (Table 2) also contributed for performance of rice crop. It is established fact that, K has important role in starch synthesis and grain development. Thus, its supply through PF showed a positive effect in producing heavier rice grain. Studies have suggested the application of adequate K fertilizer at vegetative phase has shown more dry matter. Thus, K application has a direct influence on rice yield which is attributed to increased photosynthetic capacity and translocation of photo-assimilate availability of NPK for plant which further enhances the growth, plant height and tillering of rice plants (Li *et al.,* 2015). Increased rate of potassium helps to produce large amounts of starch due to K-mediated carbohydrate metabolism. Besides, it helps in efficient translocation of photo-assimilates to the developing sinks / spikelets (Islam and Muttaleb, 2016) and enables the plants to utilize fully applied N and P fertilizers. Thus, K helps the rice grain and straw to gain large volume and heavier weight.

Observation corroborates other studies that revealed significant improvement in grain yield by 10.3 - 15.2 per cent and straw yield by 17.4 - 22.0 per cent in Indica and Japonica genotypes of rice when LD slag was applied @ 2.0 Mg ha^{-1} under greenhouse experiment (Gwon *et al.,* 2018). Wang *et al.* (2015) also noticed yield increase by 8.3 per cent and 9.1 per cent in paddy with the application of 4 and 8 Mg ha^{-1} of steel slag, respectively. Studies on PF application in agricultural have showed that, utilization has attributed to increased leaf mineral content, vegetative growth, yield and fruit characteristics in Banana, in comparison with potassium sulphate (Merwad *et al*., 2016). The field trials conducted with okra in Egypt (Abdel Mouty and El-Greadly, 2008) and onions (Ali and Taalab, 2008) reported significant improvement in yield of the crops with feldspar fertilizer. Badr (2006) suggested that use of K-enriched compost from ground feldspar recorded significant improvement in available K, uptake, recovery of K and tomato yield over other compost, where no K (through feldspar) was added.

Application of PF has shown positive effects on the performance of rice crop which is mainly due to contribution of Si and K_2O. Many previous researchers also revealed that PF application could be effective in enhancing growth, yield and overall performance of the crops such as rice (Abd El-Hakeem and Fekry, 2014), potato (Abdel-Salam and Shams, 2012 & Labib *et al.,* 2012), corn (Sousa *et al.,* 2010).

The applied LDS and PF formulations were basically alkaline with substantial amounts of Ca and Mg, which have high potential in increasing the pH of acidic towards neutrality and thereby increased the bioavailability of major and micronutrients to the rice crop (Gwon *et al.,* 2018). The increase in soil pH due to the dissolution of Ca and Mg from alkaline materials can further influence the solubility and the availability of Si for crop utilization (Ma and Takahashi, 2002). Hence, the application of LDS together with PF increased the bioavailability of nutrients and further contributed for improved growth and yield of paddy in acidic soil.

The present investigation aims at exploiting the possibilities of efficient usage of LDS generated from steel manufacturing industries in combination with naturally occurring potassium feldspar as a means of nutrient source in agriculture. The study has shown that the use of LDS along with PF could be an imperative and highly novel way to meet the nutritional requirements of rice crop beside maintaining soil fertility in a low-cost, environment friendly way to achieve sustainable yields. Further studies are necessary to evaluate their efficacy in different crops under filed conditions.

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