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Research Article

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Lime Pelleting to Improve Pulse Production on Acid Soils: Evidence from Common Bean (*Phaseolus vulgaris* L.)

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Abstract

Liming is the key to success of crop production on acid soils. The practice however has not met wider adoption, due largely to the higher doses of lime requirement. To ascertain the effect of lime pelleting (seed pelleting with lime) *vis-a-vis* higher doses of lime as required for furrow application and broadcasting, we conducted a greenhouse pot experiment wherein common bean (*Phaseolus vulgaris*) was grown with five treatments: T_1: control (no lime), T_2: lime pelleting with gum arabic, T_3: lime pelleting with rice starch, T_4: lime application @ 300 kg ha^{-1} equivalent dose, and T_5: lime application @ 3000 kg ha^{-1} equivalent dose. Lime pelleting caused 12-14% improvement in crop yield compared to 31 and 38% increments at higher doses of lime application *i.e.,* T_4 and T_5, respectively, with a commensurate increase in associated yield parameters. Higher leaf chlorophyll content (SPAD index) caused by liming and lime pelleting suggested improved plant nutrition. Rhizosphere pH increased with liming ($p \leq 0.05$), with corresponding reductions in exchangeable Al and acidity, but the effects of lime pelleting were discernible only at lower levels of statistical significance ($p \leq 0.2$). Contrary to the popular belief, liming reduced soil P availability, implying that the growth stimulation by liming was not caused by increased P availability, but by reduced Al toxicity and ensuing improvement in plant's nutrient acquisition efficiency. To conclude, lime pelleting is proposed as an alternative low-cost, easily-adoptable technology for reducing lime requirement and for improving pulse productivity on acidic soils.

1. Introduction

Soil acidity is a major constraint for crop production in nearly one-third of Indian soils, particularly in northeastern India, where more than 95% of the soils are acidic in reaction (Sharma and Singh, 2002; Kumar, 2011). Phosphorus (P) deficiency and aluminum (Al) toxicity are among the primary acidity-induced factors affecting growth and yield of many crops, including pulses, on such soils (Sharma *et al*., 2006; Awomi *et al*., 2012; Kumar *et al*., 2012a; Bhattacharjee *et al*., 2013; Singh *et al.,* 2014a&b). It is therefore important to improve the phyto-availability of P and ameliorate the toxicity of Al for enhancing crop productivity on acidic soils. Lime application has long been advocated as the most important agronomic practice towards this end (Patiram, 1991; Kumar *et al*., 2012b). However, despite the proven benefit of liming, in terms of raising soil pH and correcting the acidity-induced biotic and abiotic constraints in soil, the practice is not very popular among the farming community, more so in northeastern region. This is largely because of high doses of currently-recommended lime requirement, high cost of its application and associated logistical limitations. It is therefore imperative to bring down the required dose of lime application and to increase the effectiveness of liming in order to render it more affordable and acceptable for the farmers.

Since higher doses of lime recommended for broadcasting (~10-20 t ha^{-1}) discourage farmers to adopt liming technology, furrow application of lime (300-500 kg ha^{-1}) has recently been advocated as an alternative practice to reduce the lime requirement, though liming has to be done more frequently in this practice compared to lime broadcasting. Yet another possible option would be 'seed pelleting with lime' which, if

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works, could drastically reduce the lime requirement (~ 10-15 kg ha^{-1}) to get an economically meaningful improvement in crop productivity. In this practice, (referred as "lime pelleting" hereafter), the seed is covered/ coated with as much lime as possible using a compatible adhesive (sticking agent) like gum Arabic, rice starch or other sticky materials. Clearly, crops with bigger seed size would be the suitable candidate for this technique as they can hold more amount of lime over their surface during lime pelleting.

The concept of lime pelleting came in the context of legume seed inoculation technology (Deaker *et al.,* 2004). The microbes involved in biological nitrogen fixation (BNF) in legume crops are usually very sensitive to soil acidity. Nodule formation and BNF in legume crops are thereby hampered to a certain extent due to soil acidity, particularly below pH 5.5. Lime pelleting of inoculated legume seed with superfine limestone ($CaCO_3$) was introduced to counteract the acidic effects of soil or superphosphate on the survival of the rhizobia (Jensen, 1943; Loneragan *et al*., 1955; Brockwell, 1962; Roughley *et al*., 1966). In addition to its positive effect on BNF in legumes, the transient reduction in soil acidity induced by lime pelleting can concurrently lead to alleviation of Al toxicity and P deficiency in rhizosphere soil, which would facilitate a better growth and proliferation of roots at the initial stages of crop establishment. This would help acquiring soil nutrients more efficiently in later stages too. Additionally, lime pelleting might also improve the rhizosphere activities of phosphorus solubilizing microorganisms, with possible increase in availability of phosphorus for plant growth. In light of these hypothesized benefits of lime pelleting in legumes, the present study was conducted to ascertain if lime pelleting could be effective in reducing P deficiency and Al toxicity in crop rhizosphere and whether it could lead to any substantial increase in growth and productivity of French bean/ common bean (*Phaseolus vulgaris* L.) in acid soil.

2. Materials and Methods

In order to evaluate the effect of lime pelleting *vis-a-vis* higher doses of lime as required for furrow application and broadcasting, we conducted a greenhouse pot experiment with common bean (RCFB 74), also known as French bean, as the test crop. Common bean was selected for the study based on its importance as a widely cultivated, nutritionally-rich pulse crop, and the general sensitivity of legumes to soil acidity. The crop was grown in 4-kg capacity pots (containing 3 kg soil) with 5 treatments: T1: control (no addition of lime), T2: lime pelleting with gum arabic, T3: lime pelleting with locally available rice starch, T4: lime application @ 300 kg ha^{-1} equivalent dose, and T5: lime application @ 3000 kg ha^{-1} equivalent dose. The experiment was conducted in completely randomized design, with four replications of each treatment. For T2 and T3, seeds were pelleted with lime using gum arabic (40%) and rice starch (local red rice) as sticking agents. Lime pelleted seeds were air-dried to make them ready for sowing. In T4 and T5, powdered lime ($CaCO_3$) was mixed with the soil before pot filling. The experimental soil was a Typic Hapludalf, collected from the research farm of Soil Science Division, ICAR Research Complex for NEH Region, Umiam, Meghalaya. The initial physico-chemical properties of the soil (Table 1) were analysed following the standard analytical procedures (Page *et al.,* 1982).

Table 1: General physico-chemical properties of experimental soil

Soil Properties	Values/ Description
Soil type	Typic Hapludalf
pH (1:2)	4.6
Sand (%)	52.7
Silt (%)	26.1
Clay (%)	21.2
Soil organic carbon (%)	0.94
Available N (mg kg^{-1})	140
Available P (mg kg^{-1})	22
Available K (mg kg^{-1})	65
Exch. Acidity (meq 100 g^{-1})	2.10
Exch. Al (meq 100 g^{-1})	1.72

Three plants were grown in each pot, of which, one was carefully taken out at 30 days after showing, and the remaining two plants were allowed to grow till maturity. Rhizosphere soils (closely adhering to roots) from the taken-out plants were carefully collected, processed and analysed for pH, Bray-1 P, exchangeable Al and exchangeable acidity. In order to avoid any moisture stress, pots were watered regularly to nearly two-third of field capacity. All standard agronomic practices were followed during crop growth. Leaf chlorophyll content was recorded at 45 days after showing, using the soil and plant analytical development (SPAD) meter (Minolta SPAD 502, Spectrum Technologies, Inc., Plainfield, Illinois, USA), and was expressed as SPAD index. Yield parameters (number of seeds per pot, seed weight per pot, test weight of seeds, total biomass yield and harvest index) were recorded after harvesting at maturity and drying them till constant weight. For easy comparison of the treatments' effect on seed yield, relative yield was calculated assuming yield at control to be unity (1.0), as suggested by Kumar *et al.,* (2016). Experimental data were analyzed following standard statistical methods of Gomez and Gomez (1984).

3. Results and Discussion

As hypothesised, lime pelleting and lime application at higher doses, corresponding to doses required for furrow application and broadcasting, did improve the growth and yield of common bean (Figure 1). Lime pelleting with gum arabic (T2) and rice starch (T3) resulted in 12% and 14% yield improvement over control, respectively. There were no significant differences between the effects of sticking agents used for lime pelleting. Higher doses of lime application caused further improvements in seed yield. Application of lime @ 300 kg ha^{-1} equivalent dose (T4) and @ 3000 kg ha^{-1} equivalent dose (T5) increased the relative yield up to 1.31 and 1.38, respectively as compared

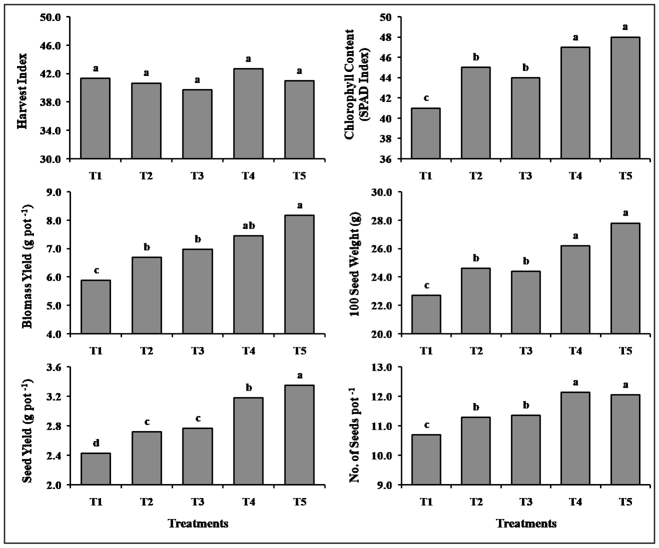

Figure 1: Comparative effect of lime pelleting on yield and growth parameters of common bean. *Bars with different letter/s within the same parameter are significantly different (p≤0.05) by the Duncan's Multiple Range Test. (T1: control; T2: Lime pelleting with gum Arabic; T3: Lime pelleting with rice starch; T4: Lime application @ 300 kg ha^{-1} equivalent; T5: Lime application @ 3000 kg ha^{-1} equivalent)*

to 1.0 at control (no liming), and 1.12 to 1.14 with lime pelleting treatments (Figure 2). There were corresponding increases in total plant biomass as well, though harvest index remained unaffected by liming treatments. Among the yield

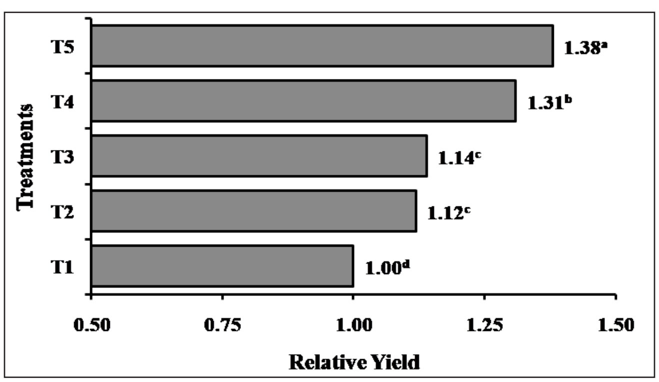

Figure 2: Comparative effect of lime pelleting on relative yield of common bean. *Bars with different letter are significantly different (p≤0.05) by the Duncan's Multiple Range Test. (T1: control; T2: Lime pelleting with gum Arabic; T3: Lime pelleting with rice starch; T4: Lime application @ 300 kg ha^{-1} equivalent; T5: Lime application @ 3000 kg ha^{-1} equivalent)*

determinants, number of seeds per pot and 100 seed weight registered significant improvement with lime pelleting, and even better improvements at higher doses of lime. The values of leaf chlorophyll content, in terms of SPAD Index, were commensurate with those of yield and yield determinants under various liming treatments.

Soil pH increased significantly (p≤0.05) with increasing doses of lime application (T4 and T5), with corresponding reductions in exchangeable Al and exchangeable acidity (Figure 3), but the increment in pH and the reduction in exchangeable Al and exchangeable acidity caused by lime pelleting (T2 and T3) were significant only at lower levels of statistical significance (p≤0.2). Interestingly, available P in rhizosphere soil decreased with increasing lime application.

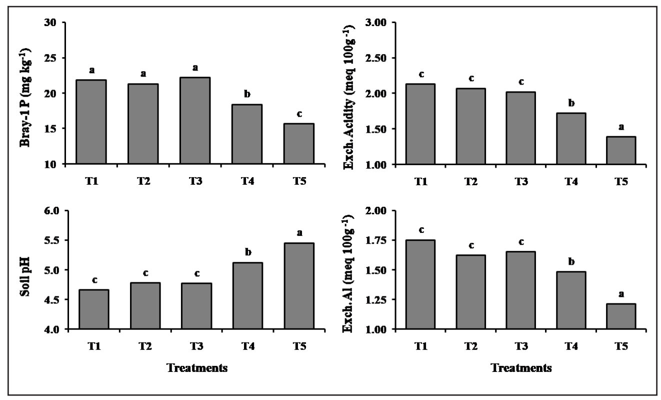

Figure 3: Comparative effect of lime pelleting on rhizosphere pH, P availability, exch. Al and exch. acidity. *Bars with different letter within the same parameter are significantly different (p≤0.05) by the Duncan's Multiple Range Test. (T1: control; T2: Lime pelleting with gum Arabic; T3: Lime pelleting with rice starch; T4: Lime application @ 300 kg ha^{-1} equivalent; T5: Lime application @ 3000 kg ha^{-1} equivalent)*

Lime-induced improvement in yield and growth parameters can be understood given the fact that common bean is a legume crop, and nodulation in legumes is highly sensitive to soil acidity (Evans *et al*., 1990; Ferguson *et al.,* 2013). In acidic soils, nodule formation has been observed to reduce by > 90% and nodule dry weight by > 50% in many legume species (Lie, 1969; Vargas and Graham, 1989; Alva *et al*., 1990; Evans *et al*., 1990). In bean, soil acidity is reported to reduce the number, ultra-structure and weight of nodules, in addition to the nitrogenase activity (Vassileva *et al*., 1997). In a study by Wolff *et al*., (1993), nodule number and nodule weight in *Phaseolus vulgaris* were strongly reduced at pH 4.5 compared to pH 5.5. In an Indian study by Chhonkar *et al*., (1971), pelleting of *Phaseolus aureus* L. seeds with lime and gypsum together with *Rhizobium* inoculation significantly increased growth, nodulation and nitrogen fixation in a saline alkali soil. Rhizobia growth, survival and abundance, apart from their competitiveness in nodulation, are also highly affected by soil pH (Graham *et al*., 1982; Vargas and Graham, 1988; Brockwell *et al*., 1991; Correa and Barneix, 1997; Ibekwe *et al*., 1997). Increased H^+ concentration and increased solubility of the toxic metal ions Al^{3+}, Cu^{2+} and Mn^{2+} are the primary causes of intercellular pH instability leading to growth inhibition in low pH soils (Bhagwat and Apte, 1989; Graham *et al*., 1994). Reduction in H^+ ion activity (*i.e.* increased pH) and exchangeable Al by liming in our study must have improved the process of biological N fixation consequent to better root nodulation and rhizobia growth in soil. The same explanation may hold good for the positive effect of lime pelleting on crop performance. Transient reduction in soil pH and Al toxicity, caused by lime adhering to the seed, in immediate vicinity of the root must have led to better nodulation, rhizobia activity and BNF in common bean. Reduced levels of Al toxicity facilitated better growth and proliferation of roots at the initial stages of crop establishment, leading to more efficient acquisition of soil nutrients in latter stages too. In fact, higher SPAD index (chlorophyll content) in leaves of the test crop grown in lime treated soil (and also with lime pelleted seeds) confirms the better overall nutrition of these plants. Additionally, lime pelleting might also have improved the rhizosphere activities of phosphorus solubilizing microorganisms, with possible benefits to the plant's P nutrition.

Liming is conventionally advised to increase P availability in acid soils by inactivation of Al and Fe in soil solution. We however observed a decline in soil P availability with increasing doses of lime application, which may be attributed to the adsorption or precipitation of soil P as calcium phosphate (Haynes, 1982). In a study by Panda (1987), liming of the acid soil containing more of exchangeable Al^{+3} reduced availability of P because of the freshly precipitated amorphous $Al(OH)^{3+}$ adsorbing P on their surfaces as compared to aged and crystalline $Al(OH)_3$. Amarasiri and Olsen (1973) also reported that for any level of phosphorus application, liming decreased soluble P and labile P until the pH reached about 6.5. In our study, however, all the soils had pH well below 6.0, rendering them available to the phenomenon of 'lime-induced decline in soil P availability'. Considering the better growth and yield of the experimental crop despite the reduced P availability caused by liming in our study, it may be hypothesized that the liming improves plant growth not by increasing soil P availability but by improving the plant's ability to acquire P and other nutrients more efficiently from a lime-treated soil; better growth and proliferation of root system due to reduced Al toxicity must understandably be the reason behind.

4. Conclusion

Lime pelleting resulted in a considerable improvement in crop yield (12-14%), though the effects were even bigger when lime was applied at higher rates. However, considering the drastically reduced requirement of lime for seed pelleting (~ 10-15 kg ha^{-1}) compared to its furrow application (300-500 kg ha^{-1}) and broadcasting (10-20 t ha^{-1}), lime pelleting can be recommended as an alternative low-cost, easily adoptable technology to improve the productivity of pulses on acidic soils.

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