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Effect of liming materials and phosphorus on soil properties and soybean yield in a dystrudepts of Nagaland

L Somendro Singh and PK Singh

Abstract
An experiment was laid out in a split plot design (SPD) with sixteen treatments and replicated thrice during the kharif season of 2018 and 2019 on different liming materials and phosphorus levels to evaluate the influence of different liming materials and levels of phosphorus on yield attributes, nutrients uptake, soil properties and yield of soybean [*Glycine max* (L.) Merr.]. Application of liming materials and P levels significantly increased pods plant^{-1}, 100 seed weight, grain and stover yield. Interaction effect of liming material and P was also significant for number of pods plant^{-1}, stover and grain yield. The highest yield was found with an application of calcium silicate @ 0.4 LR along with 80 kg P_2O_5 ha^{-1}. Maximum uptake of N, P, K, S and Ca were found with CS @ 0.4 LR and 80 kg P_2O_5 ha^{-1}.Their interaction was significantly influenced in nutrients uptake by soybean. Application of liming materials of CS @ 0.4 LR increased with pH-5.41 from the initial pH 5.31. The highest OC% was found in the plots receiving CS @ 0.4 LR (1.17%) and 80 kg P_2O_5 ha^{-1} (1.24%).The available N, P & exchangeable Ca^{2+} and Mg^{2+} in soil increased by application of liming materials and phosphorus and their interaction.

Keywords: Soybean, liming materials, phosphorus, soil properties, yield, dystrudepts

Introduction
Soils of Nagaland state are acidic and deficient in available P. Low availability of phosphorus in these soils is due to fixation of P by Fe and Al oxides. Liming is the addition of a compound containing calcium or calcium plus magnesium to the acid soils that are capable of reducing the acidity of the soil. Soybean is the world's most important legume in terms of production and trade and has been became a dominant oilseed since the 1960s (Smith and Hyser, 1987) [21]. Soybean (*Glycine max* (L.) Merrill) is known as 'Golden bean' and miracle crop of 20th century (Naik *et al*., 2018) [15]. It contains about 40-42% protein and 20-22% oil (Barik and Chandel, 2001) [2]. In addition to its nutritional values, soybean is also used as important nitrogen (N_2)-fixing crop throughout the world for the restoration and maintenance of soil fertility in a sustainable way and consequently the improvement of crop yields. Soybean has the capacity to fix about 240-250 N ha^{-1} through symbiosis. The nitrogen requirement of soybean is substantially fulfilled through symbiotic nitrogen fixation with rhizobium. In India, it is now the second largest oilseed after groundnut. Total area of soybean in India is 11.67 million ha with production of 8.59 m t during year 2015-16 with an average national yield of 737 kg ha^{-1}. Soybean occupied 42% of India's total oilseeds and 25% of edible oil production (Source - Agricultural Statistic at a Glance 2016, Directorate of Economics & Statistics, Ministry of Agriculture, Govt. of India). In Nagaland, it was estimated that the area, production and productivity of soybean during the year 2015-2016 was 24.68 thousand ha, 31.17 thousand tonne and 1254 kg ha^{-1} respectively (Statistical Handbook of Nagaland, Directorate of Economics & Statistics Govt. of Nagaland, 2017) [14]. Nagaland soil is acidic in nature and occupies 99.5 per cent of total geographical area in Nagaland. Out this area, about 1.60 m ha of acid soil (pH less than 5.5) is strongly acidic in nature. Another 0.5 m ha of acid soil (pH 5.5-6.5) is moderate to slightly acidic in nature. Soils of the state are acidic and deficient in available P. Low availability of phosphorus in these soils is due to fixation of P by Fe and Al oxides. Liming is the addition of a compound containing calcium or calcium plus magnesium to the acid soils that are capable of reducing the acidity of the soil. Low phosphorus in soil is a major constraint for soybean growth and production, which are atmospheric nitrogen (N_2) dependent (Bordeleau and Prévost, 1994) [4] because phosphorus is particularly important for symbiotic N_2 fixation in legumes (Zahran,

1999) [27]. When phosphorus rate in soil is low, this process can be strongly undermined and thus becomes a principal yield-limiting nutrient. Most leguminous plants require a neutral or slightly acidic soil for growth (Brockwell *et al*., 1991) [5]. Soybeans thrive in the pH range of 6.0 to 6.8. Soil phosphorus tests provide an indication of the level of soil phosphorus in plant. The test provides an index of phosphorus measurement that can be taken up by plant (Watson and Mullen, 2007) [25]. Soybean is emerging as an important crop of Nagaland. Soybean being a leguminous oilseed requires relatively large amounts of phosphorus than other crops (Laltlanmawia *et al*., 2004) [13]. Adequate supply of phosphorus in early stage of plant growth is important for development of roots as well as for seed formation and yield. As very little information is available on liming materials and phosphorus in acid soil of Nagaland, the present investigation was conducted to study the individual and interaction effect of liming materials and phosphorus levels on nutrient uptake, qualitative properties and yields of soybean.

Materials and Methods

A research experiment was conducted at the research farm of SASRD, Nagaland University, Medziphema (20˚45'43" N and 93˚53'04" E) during *kharif* season in 2018 and 2019 with average annual rainfall of 200 - 250 cm and temperature 13˚C - 32˚C.The experiment was laid out in a split plot design on soybean variety JS-335 with liming materials i.e., no liming material, wood ash (WA) @ 0.4 LR, paper mill sludge (PMS) @ 0.4 LR and calcium silicate (CS) @ 0.4 LR (M_0, M_1, M_2 andM_3 respectively) in main plot and phosphorus levels i.e., 0, 40, 60and 80 kg P_2O_5 ha^{-1} as single supper phosphate(P_0, P_{40}, P_{60} and P_{80} respectively) in sub plot with 16 treatments and each treatment replicated three time. The soil of experimental plot was sandy clay loam having pH 5.3, organic carbon 0.9%, available N, P, K and S as 240.69, 10.82, 229.93 and 2.62 kg ha^{-1} and lime requirement 9.88 t $CaCO_3$ ha^{-1}. The initial and post-harvest soil sample were analyzed for different soil properties such as pH with a pH meter in soil: Water suspension 1:2.5, Jackson 1973, organic carbon by Walkely and Black rapid titration method, available N by Alkaline $KMnO_4$ method, Subbiah and Asija 1956, available P by Ascorbic acid method, Bray and Kurtz, 1982, available K by Flame photometer method, Hanway and Heidel 1952and available S by Turbidimetric method using $BaCl_2$, Chesin and Yien 1951**.** A common basal dose of 20 kg N ha^{-1} as urea and 30 kg K_2O ha^{-1} as muriate of potash were also applied to all plots. The observations were recorded on randomly selected 5 samples and their mean was taken for analysis at 90 DAS. Observations to be recorded under yield attributes *viz*. numbers of pods plant^{-1}, number of seed pod^{-1}, seed test weight, grain and stover yield. The grain and stover sample were collected at full maturity and analyzed for N by micro kjeldahl method, P by vanado-molybdate yellow colour method, K by Flame photometric method, S by turbidimetry and Ca by EDTA titration method. Protein content was calculated by multiplying N content with the factor 6.25. Oil and protein yield were calculated as product of seed yield and their content respectively. All the observed data were statistically analyzed by method of analysis of variance prescribed by Gomez and Gomez, 1984 [10].

Results and Discussion

Yield and Yield Parameters

Application of calcium silicate @ 0.4 LR and 80 kg P_2O_5 ha^{-1} produced significantly higher grain and stover yield as compared to control (Table 1). The highest grain yield (2196.44 kg ha^{-1}) was recorded with application of calcium silicate @ 0.4 LR and 80 kg P_2O_5 ha^{-1}. Application of calcium silicate @ 0.4 LR and 80 kg P_2O_5 ha^{-1} had resulted in highest stover yield of 2742.62 kg ha^{-1} over control yield of 1926.75 kg ha^{-1}.The grain and stover yields increased 10.27% and 14.91% by with CS @ 0.4 LR while the same were increased by 8.11% and 10.71% and 6.42% and 5.56%, respectively, by WA @ 0.4 LR and PMS @ 0.4 LR over the control. The positive response of soybean to applied lime and P might be due to the improvement of soil pH in response to lime amendment, which enhanced growth and yield of the plant, as a result of increased availability of P that might have increased intensity of photosynthesis, flowering, seed formation and fruiting (Chalk, 2010) [6]. Ameyu and Asfaw (2020) [1] also reported the similar results. The increase in seed yield might be due to more number of pods per plant, seeds per pod and hundred seed weight. Ilbas and Sahn (2005) [11], Tapas and Gupta (2005) [23] and Jain (2015) [12] also reported that seed yield of soybean increase with inoculation and applying higher levels of phosphorus.

The number of pods plant^{-1} of soybean was significantly increased with different liming materials and increasing levels of P over control. Among the limning materials, calcium silicate @ 0.4 LR recorded the highest pods plant^{-1} (63.57) and the plot receiving 80 kg P_2O_5 ha^{-1} was found the highest pods plant^{-1} (77.37) (Table 2). Among the interaction, treatment combination of calcium silicate @ 0.4 LR along with 80 kg P_2O_5 ha^{-1} gave the highest pods plant^{-1} (88.50). All the levels of P increased the pods plant^{-1} significantly at each liming materials. The result indicated that the utilization of P for plant growth was associated with a concomitant supply of liming materials. Wijanarko *et al*. (2016) [26] also reported that liming increased number of pods plant^{-1}. The higher value of stover yield at higher level of phosphorus is owing to significantly higher value of dry matter per plant beside the other growth and yield parameters. These finding are in conformity with the results of Sarker, *et al.* (2014) [19]. This might be attributed to significant increase in nodulation, nitrogenase activity, growth and efficient nutrient uptake (Srivastava *et al*. 1998) [22]. Seeds pod^{-1} was found non-significant with application liming materials and P levels. Seed test weight was significantly increased with different liming materials and increasing levels of P over control. Calcium silicate @ 0.4 LR recorded the highest seed test weight (12.23 g) and the lowest (12.15 g) with no liming material. The plot receiving 80 kg P_2O_5 ha^{-1} was found the highest seed test weight(12.27 g) and lowest with 0 kg P_2O_5 ha^{-1} (12.15 g). Their interaction was not significant effect on seed test weight of soybean.

Protein and oil content

The protein and oil contents of the soybean seed increased with different liming materials and with increasing levels of P (Table 3). On an average, CS @ 0.4 LR increased protein and oil content 24.71% and 8.96% respectively over the control. The increase in protein and oil content due to WA @ 0.4 LR and PMS @ 0.4 LR were 22.96% and 6.33% and 22.82% and 2.57% respectively. The increased in protein and oil content due to 80 kg P_2O_5 ha^{-1} was 32.33% and 17.11% respectively. The increase oil content with P application could be due to the fact that P helped in synthesis of fatty acids and their esterification by accelerating bio-chemical reactions in glyoxalate cycle (Dwivedi and Bapai 1998) [8]. The increase in protein and oil content due to 60 and 40 kg P_2O_5 ha^{-1} were 28.06% and 11.03% and 24.57% and 8.46% respectively. The interaction between liming materials and phosphorus was significant. All the P levels increased both protein and oil content significantly at different liming materials. The maximum protein and oil content recorded with a treatment combination of CS @ 0.4 LR and 80 kg P_2O_5 ha^{-1}. Ghosh *et al*. (2006) [9] supported the finding that liming tended to exhibit better nodulation and higher seed yield with more oil content and protein than control.

Protein and oil yield

The protein and oil yields were influenced more by phosphorus than by liming materials. The protein and oil yields increased significantly with liming materials and increasing doses of phosphorus. The protein and oil yields increased 37.37% and 20.23% by with CS @ 0.4 LR while the same were increased by 32.59% and 15.42% and 30.39% and 9.32%, respectively, by WA @ 0.4 LR and PMS @ 0.4 LR over the control (Table 3). All the doses of P increased the protein and oil yield significantly at each level of phosphorus. The protein and oil yields increased 61.20% and 44.35% by with 80 kg P_2O_5 ha^{-1} while the same were increased by 52.42% and 34.14% and 41.56% and 24.18%, respectively, by 60 and 40 kg P_2O_5 ha^{-1}over the control. The interaction between liming materials and phosphorus was significant indicating that the combined application of liming materials and phosphorus would be more useful for the improvement of seed quality of soybean when P was deficient in the acidic soil.

Nutrient uptake

The N, P, K, S and Ca uptake by soybean increased significantly with liming materials and increase in doses of P (Table 4). The N, P, K, S and Ca uptake were higher in seed than stover, which might be due to the fact that absorbed N, P, K, S and Ca were partitioned more in the seed which led to their apparent depletion in stover. The liming materials and P interaction was significant for N, P, K, S and Ca uptake and followed the pattern of seed yield. The highest N, P, K, S and Ca uptake by soybean was recorded with the combination of calcium silicate @ 0.4 LR along with 80 kg P_2O_5 ha^{-1}. Application of lime and along with P might have released and retained more P in solution form for a longer period than P alone resulting in higher P sorption. The increase in P uptake by soybean on liming might be due to the increase in the available soil phosphorus content as it breaks the aluminum and iron phosphates in the soil. Reported that N, P, K S, Ca and Mgcontent in seed increased significantly with increasing P level upto 100 kg P_2O_5 ha^{-1}. Lynrah and Nongmaithem (2017) [14] found the similar results that application of lime @ 1.5 t ha^{-1} gave highest values of growth and yield attributes. The N, P and K uptake by soybean was also found to be highest under application of lime @1.5 t ha^{-1}.

Soil Properties

The available P content of post-harvest soil increased markedly at all the levels of P and liming materials (Table 4). Available P increased from 11.66 to 13.05 and 9.92 to 14.61 due to liming materials and phosphorus levels, respectively. The overall beneficial effect of liming on available P appeared to be related to the suppressing of exchangeable Al content (Dey and Nath, 2015) [7]. The interaction of liming materials and P levels was significantly increased the available P content of post-harvest soil. Bhakare and Sonar (1998) [28] found that application of 100 kg P_2O_5 ha^{-1} to soybean showed increase in soil available P which could be attributed to higher P fertilization and a leguminous crop soybean having the tendency to fix the atmospheric N and defoliation, thereby increasing organic matter. Liming resulted in a significant increase in pH, exchangeable Ca and Mg (Table 4). The increase in soil pH under lime treatment was due to addition of CaO which reacts with water leading to production of OH^- ions which forms Al $(OH)_3$ and H_2O thus raising the soil pH (Wijanarko and Taufiq, 2016 and Nekesa *et al*., 2005) [26, 16]. The organic carbon content also increased significantly with the application of liming materials and P which might be due to the addition of organic carbon through incorporation of biomass through root and leaf fall from the plants in varying degrees and creation of favorable condition for growth of soil microorganisms.

Table 1: Effect of liming materials and phosphorus on yield and yield attributes of soybean (Pooled mean of 2 years)

Grain yield (kg ha^{-1})					
Main Plot	**Sub plot**				**Mean**
Liming materials	**Phosphorus levels**				
	P_0	**P_{40}**	**P_{60}**	**P_{80}**	
M_0	1501.59	1711.38	1803.56	1835.79	1713.08
M_1	1598.08	1773.33	1801.22	1913.53	1771.54
M_2	1623.39	1794.05	1965.08	2102.38	1871.23
M_3	1655.88	1826.19	2090.35	2196.44	1942.22
Mean	1594.74	1776.24	1915.05	2012.04	
SEm±	M=18.83		P=13.18 MxP=26.37		
CD (P=0.05)	M=58.04		P=37.49MxP=74.98		
Stover (kg ha^{-1})					
M_0	1926.75	2246.43	2345.4	2436.03	2238.65
M_1	2033.97	2349.6	2467.54	2651.11	2375.56
M_2	2133.25	2367.54	2570.71	2664.6	2434.03
M_3	2214.06	2422.7	2573.89	2742.62	2488.32
Mean	2077.01	2346.57	2489.39	2623.59	
SEm±	M=15.47		P=18.22 MxP=36.44		
CD (P=0.05)	M=47.67		P=51.81 MxP=103.61		
Number of pod $plant^{-1}$					
M_0	58.27	68.30	70.93	77.37	68.72

M_1	60.30	69.57	74.77	81.27	71.48
M_2	61.07	72.27	77.37	83.33	73.51
M_3	63.57	74.90	83.33	88.50	77.58
Mean	60.803	71.26	76.6	82.62	
SEm±	M=0.59		P=0.79 MxP=1.09		
CD (P=0.05)	M=1.83		P=2.25 MxP=3.11		
Number of seed pod^{-1}					
M_0	2.73	2.83	2.87	2.87	2.83
M_1	2.77	2.73	2.87	2.87	2.81
M_2	2.83	2.80	2.80	2.87	2.83
M_3	2.93	2.90	2.97	2.97	2.94
Mean	2.82	2.82	2.88	2.90	
SEm±	M=0.03		P= 0.03 MxP=0.05		
CD (P=0.05)	M=NS		P= NS MxP=NS		
100 grain weight (g)					
M_0	12.15	12.18	12.20	12.27	12.20
M_1	12.17	12.22	12.25	12.30	12.24
M_2	12.20	12.25	12.28	12.33	12.27
M_3	12.23	12.30	12.35	12.38	12.32
Mean	12.19	12.24	12.27	12.32	
SEm±	M=0.015		P= 0.017 MxP=0.034		
CD (P=0.05)	M=0.045		P= 0.049 MxP=NS		

Table 2: Effect of liming materials and phosphorus on protein and oil yield of soybean (pooled mean of 2 year)

Protein content (%)					
Main Plot	**Sub plot**				**Mean**
Liming materials	**Phosphorus levels**				
	P_0	**P_{40}**	**P_{60}**	**P_{80}**	
M_0	28.61	35.64	36.46	37.86	34.64
M_1	35.14	36.16	37.09	37.97	36.59
M_2	35.18	36.57	37.40	38.15	36.83
M_3	35.68	37.03	38.22	39.14	37.52
Mean	33.65	36.35	37.29	38.28	
SEm±	M=0.25		P=0.22 MxP=0.44		
CD (P=0.05)	M=0.76		P=0.62 MxP=1.24		
Protein yield (kg ha^{-1})					
M_0	431.41	610.72	657.56	695.44	598.78
M_1	562.54	642.02	668.62	726.62	649.95
M_2	572.03	657.02	735.03	802.20	691.57
M_3	592.63	677.46	799.21	859.77	732.27
Mean	539.65	646.81	715.11	771.01	
SEm±	M=8.13		P=6.13 MxP=12.26		
CD (P=0.05)	M=25.04		P=17.42 MxP=34.85		
Oil content (%)					
M_0	15.95	17.30	17.71	18.68	17.41
M_1	16.37	18.52	18.82	19.49	18.30
M_2	16.96	17.76	18.47	19.30	18.12
M_3	17.38	18.41	19.12	20.11	18.76
Mean	16.67	18.00	18.53	19.40	
SEm±	M=0.16		P=0.13 MxP=0.26		
CD (P=0.05)	M=0.50		P=0.37 MxP=NS		
Oil yield (kg ha^{-1})					
M_0	224.59	278.91	301.28	324.20	282.25
M_1	245.54	310.31	320.88	353.52	307.56
M_2	259.23	300.38	342.79	384.72	321.78
M_3	270.03	317.33	378.21	419.33	346.23
Mean	249.85	301.73	335.79	370.44	
SEm±	M=4.85		P=3.07 MxP=6.13		
CD (P=0.05)	M=14.49		P= 8.72 MxP=17.44		

Table 3: Effect of liming materials and phosphorus on nutrient uptake by soybean (pooled mean of 2 year)

Nitrogen uptake (kg ha^{-1})					
Main Plot	**Sub plot**				**Mean**
Liming materials	**Phosphorus levels**				
	P_0	**P_{40}**	**P_{60}**	**P_{80}**	
M_0	103.41	141.03	153.47	163.90	140.45
M_1	127.12	149.65	165.29	184.43	156.62
M_2	133.18	154.59	178.01	194.66	165.11
M_3	136.42	159.26	192.87	209.50	174.51
Mean	125.03	151.13	172.41	188.12	
SEm±	M=1.46		P= 1.06 MxP=2.13		
CD (P=0.05)	M=4.46		P= 3.03 MxP=6.06		
Phosphorus uptake (kg ha^{-1})					
M_0	4.60	9.35	10.91	11.82	9.17
M_1	6.90	11.75	13.20	15.01	11.72
M_2	6.23	11.16	13.07	14.50	11.24
M_3	7.85	12.83	15.03	16.82	13.13
Mean	6.40	11.27	13.05	14.54	
SEm±	M=0.08		P= 0.08 MxP=0.16		
CD (P=0.05)	M=0.25		P=0.23 MxP=0.46		
Potassium uptake (kg ha^{-1})					
M_0	55.31	67.67	76.49	82.57	70.51
M_1	61.01	77.24	85.03	92.98	79.07
M_2	64.53	77.12	88.22	97.89	81.94
M_3	67.46	80.23	93.04	103.35	86.02
Mean	62.08	75.57	85.70	94.20	
SEm±	M=0.55		P= 0.49 MxP=0.98		
CD (P=0.05)	M=1.68		P=1.39 MxP=2.77		
Sulphur uptake (kg ha^{-1})					
M_0	5.00	6.64	7.48	8.60	6.93
M_1	5.93	7.43	8.13	9.39	7.72
M_2	5.99	7.47	9.14	10.23	8.21
M_3	6.61	8.44	9.50	11.32	8.97
Mean	5.88	7.50	8.56	9.89	
SEm±	M=0.06		P= 0.09 MxP=0.18		
CD (P=0.05)	M=0.20		P= 0.26 MxP=0.53		
Calcium uptake (kg ha^{-1})					
M_0	13.53	16.82	18.88	20.11	17.34
M_1	15.15	18.54	20.08	22.14	18.98
M_2	16.30	18.73	21.34	24.25	20.16
M_3	19.06	20.15	23.82	25.97	22.25
Mean	16.01	18.56	21.03	23.12	
SEm±	M=0.13		P= 0.18 MxP=0.36		
CD (P=0.05)	M=0.39		P= 0.51 MxP=1.02		

Table 4: Effect of liming materials and phosphorus on soil properties after harvest of soybean (pooled mean of 2 year)

pH					
Main Plot	**Sub plot**				**Mean**
Liming materials	**Phosphorus levels**				
	P_0	**P_{40}**	**P_{60}**	**P_{80}**	**5.11**
M_0	5.02	5.08	5.14	5.18	5.32
M_1	5.37	5.33	5.29	5.30	5.26
M_2	5.30	5.26	5.20	5.29	5.34
M_3	5.41	5.34	5.29	5.32	5.11
Mean	5.28	5.25	5.23	5.27	
SEm±	M=0.02		P= 0.02 MxP=0.04		
CD (P=0.05)	M=0.05		P= NS MxP=NS		
Organic carbon %					
M_0	0.95	1.03	1.13	1.18	1.07
M_1	0.93	1.07	1.12	1.31	1.11
M_2	0.93	1.07	1.09	1.20	1.07
M_3	1.03	1.18	1.21	1.28	1.18
Mean	0.96	1.09	1.14	1.24	
SEm±	M=0.08		P= 0.02 MxP=0.04		
CD (P=0.05)	M=0.25		P=0.05 MxP=NS		
P kg ha^{-1}					

M_0	9.01	11.68	12.53	13.42	11.66
M_1	9.69	11.22	12.31	13.41	11.66
M_2	10.40	11.57	13.78	15.57	12.83
M_3	10.58	11.97	13.58	16.07	13.05
Mean	9.92	11.61	13.05	14.62	
SEm±	M=0.02		P= 0.18 MxP=0.37		
CD (P=0.05)	M=0.08		P=0.52 MxP=1.04		
Exch. Ca^{2+} [cmol(p^+)kg^{-1}]					
M_0	1.90	1.94	2.02	1.99	1.96
M_1	2.08	2.12	2.16	2.16	2.13
M_2	2.22	2.18	2.13	2.21	2.19
M_3	2.36	2.33	2.35	2.33	2.34
Mean	2.14	2.14	2.17	2.17	
SEm±	M=0.03		P= 0.03 MxP=0.07		
CD (P=0.05)	M=0.09		P=NS MxP= NS		
Exch. Mg^{2+} [cmol(p^+)kg^{-1}]					
M_0	0.71	0.71	0.75	0.70	0.72
M_1	0.88	0.89	0.87	0.86	0.88
M_2	0.89	0.88	0.87	0.90	0.89
M_3	0.93	0.94	0.93	0.89	0.92
Mean	0.85	0.86	0.86	0.84	
SEm±	M=0.02		P= 0.02 MxP=0.03		
CD (P=0.05)	M=0.06		P= NS MxP=NS		

Liming materials	Phosphorus levels	
M_0 = No liming material	P_0 = 0 kg ha^{-1}	WA= Wood Ash
M_1= WA @ 0.4 LR	P_{40} = 40 kg ha^{-1}	PMS= Paper mill sludge
M_2= PMS@ 0.4 LR	P_{60} = 60 kg ha^{-1}	CS= Calcium Silicate
M_3 = CS @ 0.4 LR	P_{80} = 80 kg ha^{-1}	

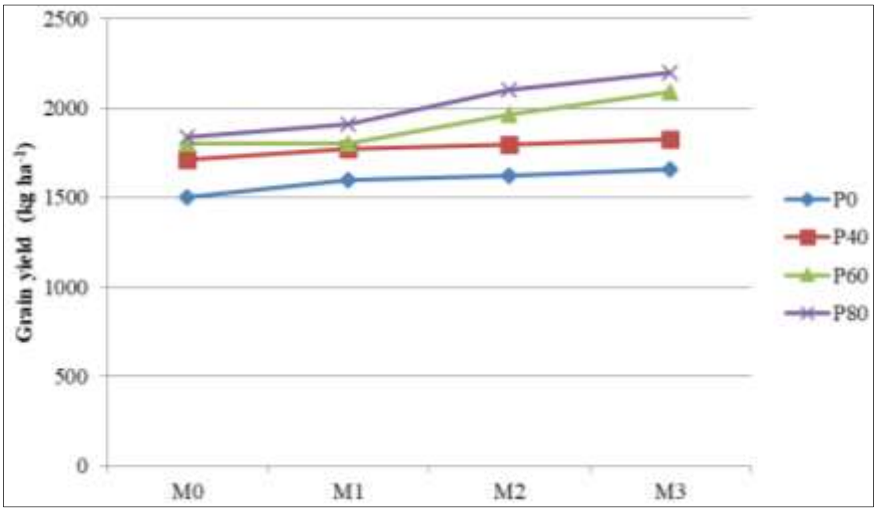

Fig 1: Effect of liming materials and phosphorus on grain yield kg ha^{-1}

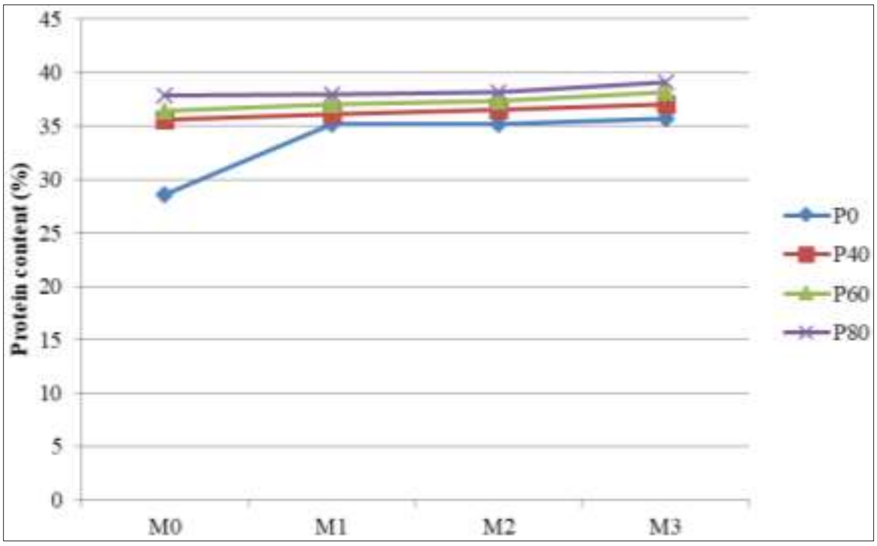

Fig 2: Effect of liming materials and phosphorus on protein content (%)

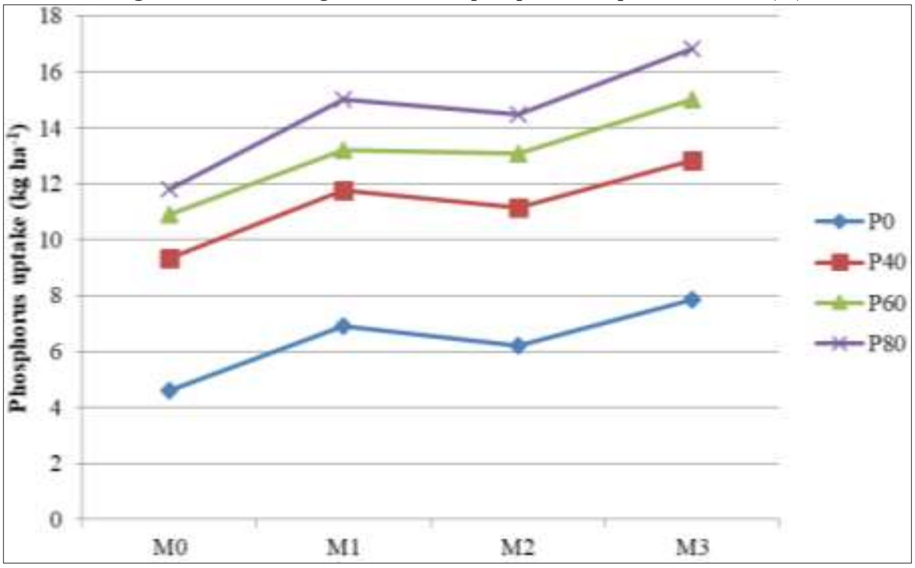

Fig 3: Effect of liming materials and phosphorus on phosphorus uptake by soybean (kg ha-1)

Conclusion

The above results indicate that the optimum yield of soybean in acid soils of Nagaland could be achieved with the application of calcium silicate (CS) @ 0.4 LR along with 80 kg P_2O_5 ha^{-1}. This treatment also increased pH, organic carbon content, available P, exchangeable Ca and Mg of post-harvest soil.

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