Original Research Article

Liming and soil amendments for acidity regulation and nutrients uptake by potato-mungbean-rice cropping pattern in the Old Himalayan Piedmont Plain

ABSTRACT

Soil acidity and lower soil fertility are the key issues that constraint higher crop yield in Old Himalayan Piedmont Plain of Bangladesh. The study evaluated the effect of lime and manure on yield of crops in a cropping pattern, potato-mungbean-transplanted aman (TA) rice. Crop varieties were Cardinal for potato, BARI mung6 for mungbean and Bina dhan7 for TA rice. There were 9 treatment combinations with three lime levels (0, 1 and 2 t dololime ha^{-1}) and three manure treatments (poultry manure, FYM and control) with three replications. The rate of poultry manure was 3 t ha^{-1} and that of FYM was 5 t ha^{-1}. Lime was added to the first crop for entire 2-crop cycles and manures were applied to the first crop of each crop cycle. Application of lime and manure had significant positive effect on the yield of potato and consequently positive residual effects on mungbean and TA rice. An average 45-59% yield benefit over control for the first crop and 41-43% yield benefit for the third crop was observed. Amendment of soil with dololime @ 1 t ha^{-1} coupled with poultry manure @ 3 t ha^{-1} or FYM @ 5 t ha^{-1} could be an efficient practice for achieving higher crop yield due to optimization of soil acidity and nutrient uptake by plants.

Keywords: Cropping pattern, soil acidity; liming; manures; nutrients uptake, crop yields

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1. INTRODUCTION

Soils of northern Bangladesh have varying degrees of soil acidity [1, 2, 3]. Piedmont soils occur in Agro Ecological Zone (AEZ # 1), Old Himalayan Piedmont Plain (OHPP) (398154 ha) and AEZ # 22, Northern and Eastern Piedmont Plains (403758 ha). The AEZ # 1 is extended over Thakurgaon (190300 ha), Panchagarh (112100 ha) and Dinajpur (95800 ha). The soils are light textured, strongly to moderately acidic and low in organic matter content. The available status of phosphorus (P), calcium (Ca) and magnesium (Mg) of the soils are also low. The soils have high contents of aluminum (A), iron (Fe), manganese (Mn) and lower contents of nitrogen (N), P, potassium (K), Ca, Mg, zinc (Zn) and boron (B) [4]. For attaining desired yields as well as maintaining soil fertility of OHPP by fertilizer recommendation [5], resources utilization [6] and avoidance of soil degradation in piedmont areas [7]. Therefore, mitigation of soil acidity sustainably is a key issue for improving crop production in the area. Liming is important to ameliorate soil acidity and improve crop productivity. Lime application to acidic soils is one of the good solutions to address soil acidity problem [8]. Liming is advocated for soils having pH ≤ 5.5 [4]. The optimum soil pH for efficient production of most of the field crops is slightly acidic to slightly alkaline (pH 6.5 – 7.5). Liming of acid soil has been suggested as the most efficient practice to attain and maintain a suitable pH for the growth of a variety of crops. Liming can increase crop yields, as observed in wheat [9, 10, 11], maize [12, 10], mustard [10], soybean [13] and oat [14]. Liming is generally practiced for dry land crops and it is not required for wet land rice cultivation since flooding of rice fields raises soil pH to almost neutrality. Soil acidity limits crop production primarily by impairing root growth, thereby reducing nutrient and water uptake [15]. The concentrations of Al^{3+}, Fe^{3+} or Mn^{2+} are high enough to be toxic to plants in an acid soil. On the other hand, Ca, Mg, Mo and P can be deficient in an acid soil. For these reasons, the majority of crop produce yields less than their potential. A judicious application of lime may help overcome this problem. Liming an acid soil increases the availability of P, Ca, Mg and Mo and renders Fe and Mn insoluble, increases fertilizer effectiveness and decreases plant diseases [16]. But too much addition of lime can decrease the availability of Fe, Mn, Zn and Cu sufficiently to cause deficiencies of those plant nutrients. Thus, judicious application of lime in a soil to bring soil pH to an expected value is essential for maintaining soil health and thus, improving crop productivity.

Soil organic matter (OM) is a key factor in maintaining long-term soil fertility since it is the reservoir of metabolic energy, which drives soil biological processes involved in nutrient availability. A good soil should have at least 2.5% organic matter, but in Bangladesh most of the soils have less than 1.5%, and some soils contain even less than 1% organic matter [4]. Soil fertility and OM content of top soils under high land and medium high land situation has been declined over time [17, 18, 19, 20]. It is believed that the declining productivity of soils is the result of depletion of OM due to increasing cropping intensity, higher rate of organic matter decomposition under the prevailing hot and humid climate, use of lesser quantity of organic manure and little or no use of green manure. The highest depletion of OM has been reported in soils of Meghna River Floodplain (35%) followed by Madhupur Tract (29%), Brahmaputra Floodplain (21%), Old Himalayan Piedmont Plain (18%) and Gangetic Floodplain (15%) [21]. Thus, periodical and moderate application of OM is essential for the soils of Bangladesh.

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The cropping pattern (CP) in Bangladesh is mainly rice based. Wheat, next to rice, is the important cereal crop. Potato is a very good vegetable crop which is consumed all over the year. Mungbean is an important grain legume crop, matures in 60-80 days and can easily be grown as short duration summer pulse crop between wheat or potato and TA rice. The inclusion of a grain legume in CP will supply substantial amount of biomass and N to soil. Legumes in CP with cereals can economize the N use up to 40 kg ha^{-1} [22]. In this situation, brown manure (mungbean) can be an alternative source of OM which can improve soil health and ensure higher crop yield. Farmers usually use fertilizers on single crop basis without considering the whole cropping system. It is possible to increase and obtain satisfactory crop yield in the potato-mungbean-TA rice and wheat-mungbean-TA rice cropping systems in the OHPP by manure and fertilizer management. Thus, the points stated above justify a need for carrying out a study on amendment of piedmont soils with lime, poultry manure and farmyard manure in quest of sustainable crop production. This study was undertaken to make amendment of piedmont soils (AEZ # 1) by liming and manuring (poultry manure and farmyard manure) and to evaluate their effect on crop yield and nutrient uptake in the potato-mungbean-TA rice.

2. MATERIALS AND METHODS

The experiments were carried out at two sites of Agricultural Research Station (ARS), Bangladesh Agricultural Research Institute (BARI), Thakurgaon and farmer's field at Rahimanpur union under Thakurgaon Sadar upazila (located in between 25°40' and 25°59' north latitudes and in between 88°15' and 88°22' east longitudes), Thakurgaon, Bangladesh for consecutive two years, first year and second year. According to General Soil Type classification, both sites fall under non-calcareous brown floodplain soils. Topographically all the fields are high land (HL). Three crops- potato, mungbean and T. aman rice were grown in Potato-Mungbean-T. Aman rice cropping pattern under the field experiments. The crop varieties were Cardinal for potato, BARI Mung6 for mungbean and Binadhan7 for T. Aman rice. The onset and duration of growing seasons were winter (*Rabi* season, middle of October to middle of March), spring (*Kharif-I* season, middle of March-end of May) and monsoon (Kharif-II season, early June – middle October) for potato, mungbean and T. aman respectively.

There were nine treatment combinations comprising of 3 levels of lime (0, 1 and 2 t ha^{-1}) and 2 kinds of manure (poultry and farmyard manure) including no lime and manure treatments. Treatment combinations were L0M0 = Control (no lime, no manure), L0MPM = (no lime, manure as poultry manure), L_0M_{FYM} = (no lime, manure as farmyard manure), L_1M_0 **=** (1 t ha^{-1} lime, no manure), L_1M_{PM} = (1 t ha^{-1} lime, manure as poultry manure), L_1M_{FYM} = (1 t ha^{-1} lime, manure as farmyard manure), L_2M_0 = (2 t ha^{-1} lime, no manure), L_2M_{PM} = (2 t ha^{-1} lime, manure as poultry manure) and L_2M_{FYM} (2 t ha^{-1} lime, manure as farmyard manure). Farmyard manure was used at 5 t ha^{-1} and poultry manure at 3 t ha^{-1}. The dose of urea, Triple Superphosphate (TSP) and Muriate of Potash (MOP) was adjusted taking into the account of the amount of N, P and K supply from manure that was added to the first crop. For all treatments, the fertilizer doses were rationalized for the second and third crops, as outlined in the Fertilizer Recommendation Guide [4]. Micronutrients Zn and B were applied once in 1-crop cycle across the plots to sustain normal plant growth. Micronutrients (Zn, B) were supplied to the first crop only.

The experiments were laid out in a randomized complete block design, with three replications. The unit plot size was 5m x 4m having inter-plot space of 0.75m and inter-block space 1m. The plots were surrounded by 0.3m wide and 10cm high earthen bunds with 10cm deep and 1.0m wide irrigation channel along one side of the plots. The layout of the experiment was kept undisturbed for the 2-crop cycles. The land was prepared thoroughly by ploughing and cross-ploughing with a power tiller. Every ploughing was followed by laddering. Except the first crop, the land was prepared every time by 4 - 5 spadings. The sowing/planting date, plant spacing, seed/seedling rate and harvesting date used for cropping (during both the years of experimentation first year and second year) are stated below:

Parameters	Potato	Mungbean	T. Aman rice
Sowing date	-	March 23-24	June 21-22
Planting date	November 18-19	-	July 14-15
Plant spacing	60 x 20 cm	30 cm×continuous	20 x 15 cm
Seed rate	2500 kg ha^{-1}	30 kg ha^{-1}	-
Seedling rate	-	-	3-4 seedlings $hill^{-1}$
Harvesting date	February 19-20	June 24-25	October 19-20

Dolomite lime was added to the plots before 15 days of sowing/planting. The rates of lime were 1 and 2 t ha^{-1}. Lime was applied to the first crop only with no application to the following crops over two years. Its residual effect was evaluated on the second, third, fourth, fifth and sixth crops. Lime contained 20% Ca and 12% Mg. Two kinds of manure, viz. poultry manure (PM) and farmyard manure (FYM) were used. The rates of manure were 5 t ha^{-1} for FYM and 3 t ha^{-1} for poultry manure. Manure was applied to the first crop only in each crop cycle. Their residual effects were evaluated on the second and third crops. Manure was added 5 days before sowing/transplanting. Nutrient compositions of different manures were as follows:

Manure	Year	N (%)	P (%)	K (%)
Poultry manure	first year	1.86	0.62	0.75
	second year	1.84	0.59	0.73
Farmyard manure	first year	1.20	0.51	0.56
	second year	1.15	0.55	0.62

Fertilizers such as urea, TSP, MOP, gypsum, ZnSO4. 7H2O and boric acid were used as sources of N, P, K, S, Zn and B, respectively. All manures and fertilizers except urea to a full amount were applied to the plots during final land preparation. There were three equal splits of urea application for T. aman rice- land preparation, maximum tillering and panicle initiation stage. Mungbean received full quantities of urea, TSP, MOP and gypsum during land preparation. Half amount of urea and MOP and full amount of TSP, gypsum, ZnSO4 and boric acid were applied at the time of final land preparation. The rest amount of urea and MOP was applied at 30 days after planting at the time of earthing-up followed by irrigation.

The crops were harvested when they attained maturity. Plot-wise yields (main product and by-product) and yield contributing parameters were recorded. Crop yield was expressed as t ha^{-1}. The crop was cut from a $12m^2$ area of the centre of each plot. The grains/seeds were threshed, cleaned, dried and weighed. Grain and straw/stover yields were adjusted to 14% moisture content for rice, 12% moisture content for mungbean, and 80% moisture content for potato tuber and 10% moisture content for potato haulm. Ten representative plants or hills from outside the harvested area within a plot were selected to record the yield contributing characters.

The data collected for different parameters were statistically analyzed to find out the statistical significance of the experimental results. Data analysis was done by computer using MSTAT-C software. Mean values of all the treatments were calculated and analysis of variance for all the parameters was performed by F- test. The significance of the difference between treatment means was evaluated by Duncan's Multiple Range Test (DMRT) [23].

3. RESULTS AND DISCUSSION

3.1. Effects of lime and manure on potato

3.1.1. Effects on tuber yield

The effect of lime and manure on the tuber yield of potato was significant (Table 1). This indicates that the lime effects varied with the kind of manure application. Lime at 1 t ha^{-1} with poultry manure produced significantly higher tuber yield over other treatments in both sites and years. The lowest tuber yield was recorded with the control treatment, with no lime or manure application. The yield increase due to L_1M_{PM} treatment over control was 67.1% for research farm and 50.3% for farmer's plot (Figure 1).

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3.1.2 Effects on haulm yield

The effect of lime and manure on the haulm yield of potato was insignificant. In general, yield response of lime at 1 t ha^{-1} with poultry manure at 3 t ha-1 was higher than that of lime at 1 t ha^{-1} with FYM at 5 t ha^{-1}. Above all, in both sites and years, lime application at 1 t ha^{-1} with poultry manure at 3 t ha^{-1} resulted in highest haulm yield among all the treatments and control treatment (L0M0) produced the lowest haulm yield (Table 1).

Table 1. Interaction effects of lime and manure on the tuber and haulm yields of potato

Lime × manure interaction	Tuber yield (t ha^{-1})				Haulm yield (t ha^{-1})			
	Research farm		Farmer field		Research farm		Farmer field	
	A	B	A	B	A	B	A	B
L_0M_0	22.9	25.3	21.6	19.8	1.32	1.30	1.30	1.32
L_0M_{PM}	28.3	30.7	27.7	23.3	1.57	1.59	1.45	1.42
L_0M_{FYM}	27.5	29.3	27.0	23.1	1.51	1.56	1.46	1.45
L_1M_0	25.0	33.2	27.1	28.8	1.52	1.84	1.55	1.71
L_1M_{PM}	36.7	35.8	33.3	35.8	2.13	2.17	1.83	1.92
L_1M_{FYM}	28.7	35.1	31.5	34.8	1.85	1.89	1.73	1.72
L_2M_0	26.6	33.2	27.4	32.8	1.74	1.84	1.55	1.68
L_2M_{PM}	31.0	35.6	31.7	34.7	1.99	1.80	1.73	1.80
L_2M_{FYM}	28.9	34.4	31.3	34.7	1.87	1.73	1.72	1.81
CV (%)	4.84	4.03	4.13	5.45	6.19	9.54	5.60	5.89
Sig. level	**	NS	NS	**	NS	NS	NS	NS
SE (±)	0.459	0.795	0.684	0.957	0.430	0.673	0.360	0.392

Subscripts of L represent lime rate (t ha^{-1}); Subscripts of M represent kind of manure; PM means poultry manure (3 t ha^{-1}) and FYM means farmyard manure (5 t ha^{-1}); A = First year and B = Second year; CV = Coefficient of variation, **, $P \leq 0.01$; NS = Not significant; SE (±) = Standard error of means.

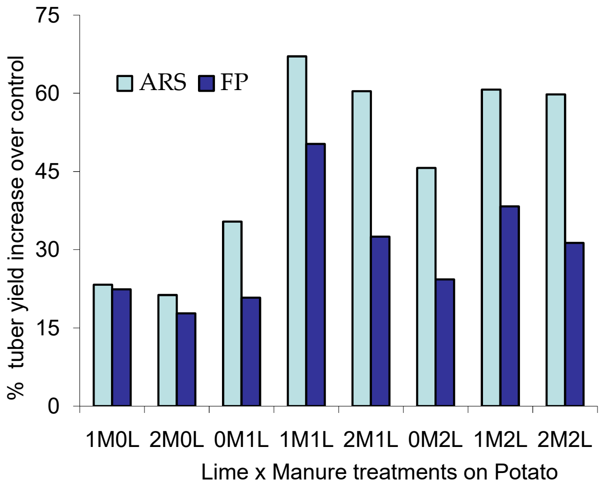

Fig. 1. Effects of lime x manure treatments on % tuber yield increase over control at ARS and farmer plot; results are the average of 2 years; L0, L1 and L2 represent lime dose at 0, 1 & 2 t ha-1, respectively; M1 and M2 represent poultry manure and FYM, respectively.

3.1.2 Effects on tubers hill-1

The effect of lime and manure on the number of tubers hill-1 of potato was significant. Generally, the lime at 1 t ha-1 with poultry manure at 3 t ha-1 produced the highest number of tubers hill-1 over the sites and years. The lowest number of tubers hill-1 was recorded with the control treatment (L0M0) (Table 2).

3.1.3 Effects on tuber weight hill-1

The effect of lime and manure on the tuber weight hill^{-1} (g) of potato was significant (Table 02). The tuber weight hill^{-1} (g) of potato responded differently to the lime and manure treatments. In both locations and years, the lime application at 1 t ha^{-1} with poultry manure at 3 t ha^{-1} produced the highest tuber weight. On the contrary, the lowest tuber weight hill^{-1} (g) was produced by the control treatment (L_0M_0) receiving no lime or manure.

Table 2. Interaction effects of lime and manure on the number of tubers hill^{-1} and tuber weight hill^{-1} of potato

Lime × manure interaction	Tubers hill^{-1}				Tubers weight hill^{-1} (g)			
	Research farm		Farmer field		Research farm		Farmer field	
	A	B	A	B	A	B	A	B
L_0M_0	7.90	8.07	7.43	7.30	368.3	406.7	373.3	366.7
L_0M_{PM}	9.17	8.60	8.13	9.20	420.0	416.7	426.7	446.7
L_0M_{FYM}	9.77	8.30	8.17	9.33	411.7	420.0	441.7	453.3
L_1M_0	9.53	9.50	8.40	10.03	435.0	446.7	456.7	476.7
L_1M_{PM}	10.97	10.80	9.83	10.50	460.0	550.0	528.3	556.7
L_1M_{FYM}	10.63	10.33	9.20	10.20	431.7	513.3	503.3	526.7
L_2M_0	9.83	9.80	8.17	10.10	430.0	440.0	460.0	503.3
L_2M_{PM}	10.77	10.40	9.30	10.07	441.7	516.7	510.0	523.3
L_2M_{FYM}	10.50	10.30	9.10	10.17	428.3	516.7	490.0	520.0
CV (%)	3.41	2.44	3.55	3.05	2.76	2.84	5.08	5.13
Sig. level	**	**	**	**	**	**	NS	**
SE (±)	0.195	0.135	0.177	0.170	6.784	7.688	13.642	14.396

Subscripts of L represent lime rate (t ha^{-1}) ; Subscripts of M represent kind of manure; PM means poultry manure (3 t ha^{-1}) and FYM means farmyard manure (5 t ha^{-1}); A = First year and B = Second year; CV = Coefficient of variation; **, P ≤ 0.01; NS = Not significant; SE (±) = Standard error of means.

3.2 Effects of lime and manure on nutrient uptake by potato

3.2.1 Macronutrients uptake (N, P, K, S)

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There was a significant lime × manure interaction effect on the N, P, K and S uptake by potato (tuber + haulm). This indicates that the lime and manure interacted on the macronutrients uptake by potato (tuber + haulm) (Table 3). For N, the effect of lime at 1 t ha^{-1} with poultry manure at 3 t ha^{-1} was higher than that of lime at 1 t ha^{-1} with FYM at 5 t ha^{-1}. The N uptake (tuber + haulm) depending on the lime-manure treatments ranged from 89.76 - 166.22 kg ha^{-1} in first year and 104.63 - 183.67 kg ha^{-1} in second year. While the P uptake (tuber + haulm) was found to vary from 11.49 - 26.39 kg ha^{-1} in first year and 11.42 - 25.44 kg ha^{-1} in second year. The effect of lime application at 1 t ha^{-1} with poultry manure on P uptake was higher (26.39 and 25.44 kg ha^{-1} in two years, respectively) than that of lime application at 2 t ha^{-1} with poultry manure (22.90 & 24.11 kg P ha^{-1} in two years, respectively). The K uptake (tuber + haulm) ranged from 112.96 - 225.55 kg ha^{-1} in first year and 166.83 - 224.25 kg ha^{-1} in second year. The effect of lime at 1 t ha^{-1} with poultry manure was remarkably higher (255.55 kg ha^{-1} and 224.25 kg ha^{-1}) compared to lime application at 1 t ha^{-1} with farmyard manure (182.53 kg ha^{-1} K uptake in first year and 208.10 kg ha^{-1} K uptake in second year). The S uptake (tuber + haulm) varied from 14.10 to 26.42 kg ha^{-1} in first year and 17.43 to 31.55 kg ha^{-1} in second year over the lime-manure treatments. The magnitude of S uptake was found 26.42 kg ha^{-1} for L_1M_{PM}, 23.14, kg ha^{-1} for L_2M_{PM}, 20.88 kg ha^{-1} for L_1M_{FYM} and 20.83 kg ha^{-1} for L_2M_{FYM} in first year and the S uptake values in second year were 31.55 kg ha^{-1} for L_1M_{PM}, 29.42 kg ha^{-1} for L_2M_{PM}, 28.75 kg ha^{-1} for L_1M_{FYM} and 27.50 kg ha^{-1} for L_2M_{FYM} (Table 3)

3.2.2 Micronutrients uptake (Zn and B)

There was a significant lime-manure interaction on the Zn and B uptake by potato (Table 3). This indicates that the lime and manure treatments interacted on the Zn and Br uptake by potato. The highest Zn uptake (tuber + haulm) was recorded as 0.686 kg ha^{-1} in first year and 0.688 kg ha^{-1} in second year due to L_1M_{PM} treatment which was significantly higher than that recorded with L_1M_{FYM} and L_2M_{PM} treatments. The Zn uptake across the nine treatments varied from 0.308 - 0.686 kg ha^{-1} in first year and 0.311 - 0.688 kg ha^{-1} in second year. For B, the effect of lime at 1 t ha^{-1} with poultry manure at 3 t ha^{-1} was significantly higher than that of lime 1 t ha^{-1} with farmyard manure at 5 t ha^{-1}. The B uptake (tuber + haulm) over the nine treatment combinations was found to vary from 0.142-0.317 kg ha^{-1} in first year and 0.146- 0.317 kg ha^{-1} in second year (Table 3).

Table 3. Interaction effects of lime and manure on nutrient uptake (kg ha^{-1}) by potato (tuber and haulm) in the potato-mungbean-T. aman rice pattern at ARS (BARI) farm, Thakurgaon

Lime × manure interaction	First year						Second year					
	N	P	K	S	Zn	B	N	P	K	S	Zn	B
L_0M_0	89.76	11.49	112.96	14.11	0.308	0.142	104.63	11.42	116.83	17.43	0.311	0.146
L_0M_{PM}	120.20	18.13	161.58	17.90	0.465	0.213	142.65	18.69	169.38	22.47	0.477	0.222
L_0M_{FYM}	114.78	16.34	155.89	17.08	0.443	0.204	138.98	16.73	165.32	21.67	0.463	0.216
L_1M_0	112.31	17.25	147.76	16.85	0.464	0.195	161.82	21.51	187.84	25.71	0.567	0.246
L_1M_{PM}	166.22	26.39	225.55	26.42	0.686	0.317	183.67	25.44	224.25	31.55	0.688	0.317
L_1M_{FYM}	134.99	20.89	182.53	20.88	0.566	0.258	176.37	23.72	208.10	28.75	0.601	0.293
L_2M_0	123.79	18.80	164.35	18.43	0.517	0.216	166.48	21.65	191.61	26.06	0.569	0.250
L_2M_{PM}	146.08	22.90	197.92	23.14	0.619	0.283	181.04	24.11	209.28	29.42	0.597	0.298
L_2M_{FYM}	135.02	20.76	182.13	20.83	0.571	0.259	174.43	22.58	200.60	27.50	0.568	0.285
CV (%)	3.57	4.41	3.62	3.24	4.25	3.30	1.69	2.66	2.78	2.71	6.01	2.64
Sig. level	**	**	**	**	**	**	**	**	**	**	**	**
S.E. (±)	2.6191	0.4895	3.5532	0.3654	0.1266	0.0441	1.5501	0.3175	2.9836	0.4010	0.1867	0.0385

CV = Coefficient of variation; **, P ≤ 0.01; S.E. = Standard error

3. 2 Residual effects of lime and manure on mungbean

3.2.1 Effects on seed yield and stover yield

There was a significant interaction effect of lime and manure on the seed yield and stover yield of mungbean, as recorded in two sites and two years. Seed and stover yields are shown in Table 4. L_1M_{PM} treatment was superior to all other treatments and control treatment (L_0M_0) was inferior in terms of seed yield and stover yield of mungbean. The highest seed yield recorded with L_1M_{PM} treatment showed 139% increase over control in research farm and 145% increase in farmer field (Figure 2).

Table 4. Interaction effects of lime and manure on the grain and stover yields (t ha^{-1}) of mungbean

Lime × manure interaction	Seed yield (t ha^{-1})				Stover yield (t ha^{-1})			
	Research farm		Farmer field		Research farm		Farmer field	
	A	B	A	B	A	B	A	B
L_0M_0	0.80	0.75	0.75	0.73	1.55	1.50	1.48	1.45
L_0M_{PM}	1.20	1.15	1.15	1.13	2.00	1.95	1.93	1.90
L_0M_{FYM}	1.10	1.05	1.07	1.03	1.88	1.85	1.85	1.82
L_1M_0	1.05	1.00	1.00	0.97	1.80	1.75	1.77	1.72
L_1M_{PM}	1.71	1.68	1.65	1.63	2.83	2.76	2.75	2.73
L_1M_{FYM}	1.65	1.62	1.64	1.61	2.60	2.55	2.53	2.48
L_2M_0	1.58	1.56	1.53	1.52	2.43	2.52	2.35	2.28
L_2M_{PM}	1.52	1.45	1.47	1.45	2.33	2.28	2.28	2.25
L_2M_{FYM}	1.43	1.38	1.37	1.33	2.30	2.23	2.25	2.20
CV (%)	6.19	5.94	6.82	6.84	4.74	6.02	4.99	4.77
Sig. level	**	**	**	**	**	**	**	**
SE (±)	0.0488	0.0451	0.0516	0.0509	0.0600	0.0749	0.0615	0.0576

Subscripts of L represent lime rate (t ha-1); Subscripts of M represent kind of manure; PM means poultry manure (3 t ha^{-1}) and FYM means farmyard manure (5 t ha^{-1}); A = First year and B = Second year; CV = Coefficient of variation; ** P ≤ 0.01; SE (±) = Standard error of means.

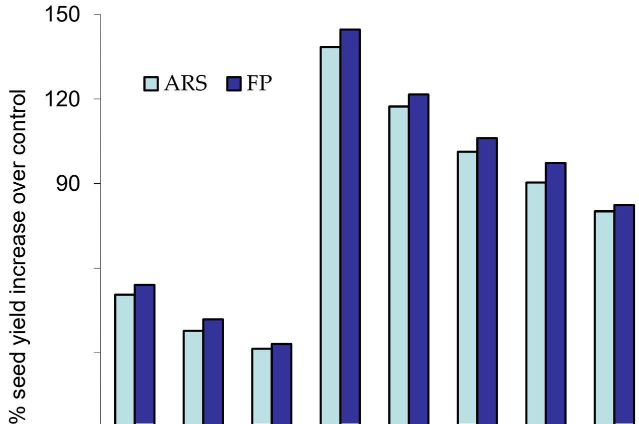

Fig. 2. Residual effects of lime x manure treatments on % seed yield (mungbean) increase over control; results are the average of 2 years; L0, L1 and L2 represent lime dose at 0, 1 & 2 t ha^{-1}, respectively; M1 and M2 represent poultry manure and FYM, respectively.

3.2.2 Effects on pods plant^{-1} and seeds pod^{-1}

The interaction effect of lime and manure on the number of pods plant^{-1} and seeds pod^{-1} of mungbean was significant. Pods per plant and seeds per pod are shown in Table 5. Lime at 1 t ha^{-1} with poultry manure (L_1M_{PM}) produced the highest number of pods plant^{-1} as well as seeds pod^{-1} and the lowest number of pods plant^{-1} and seeds pod^{-1} were recorded with the control treatment (L0M0) across the sites and years (Table 5).

Table 5. Interaction effects of lime and manure on the number of pods plant^{-1} and seeds pod^{-1} of mungbean

Lime × manure interaction	Pods plant^{-1}				Seeds pod^{-1}			
	Research farm		Farmer field		Research farm		Farmer field	
	A	B	A	B	A	B	A	B
L_0M_0	9.23	8.60	9.00	8.87	8.53	8.30	8.20	8.10
L_0M_{PM}	11.50	11.20	11.27	11.10	10.20	10.00	9.93	9.73
L_0M_{FYM}	11.40	11.10	11.17	11.00	9.66	9.40	9.40	9.27
L_1M_0	9.86	9.56	9.60	9.47	9.50	9.30	9.23	9.07
L_1M_{PM}	18.40	18.43	18.07	17.87	13.00	12.60	12.60	12.33
L_1M_{FYM}	15.60	15.36	15.23	15.03	11.80	11.60	11.53	11.40
L_2M_0	11.80	11.50	11.53	11.27	10.20	10.00	9.80	9.53
L_2M_{PM}	13.56	13.26	13.17	12.90	11.13	10.93	10.73	10.43
L_2M_{FYM}	12.13	11.83	11.73	11.47	10.60	10.36	10.27	10.00
CV (%)	8.24	8.06	8.43	8.63	4.51	4.49	5.25	4.93
Sig. level	**	**	**	**	**	**	*	**
SE (±)	0.6002	0.5732	0.5991	0.6032	0.2737	0.2667	0.3086	0.2844

Subscripts of L represent lime rate (t ha-1); Subscripts of M represent kind of manure; PM means poultry manure (3 t ha-1) and FYM means farmyard manure (5 t ha-1); A = First year and B = Second year; CV = Coefficient of variation; ** P ≤ 0.01; SE (±) = Standard error of means.

3.2.2 Effects on 1000-seed weight

There was a significant lime - manure interaction effect on the 1000-seed weight of mungbean. In both sites and years, application of lime 1 t ha^{-1} with poultry manure (L_1M_{PM}) produced the highest 1000-seed weight. In all cases, the lowest 1000-seed weight was recorded with the control treatment (L_0M_0) over the sites and years (Table 6).

Table 6. Interaction effects of lime and manure on 1000-seed weight of mungbean

Lime × manure interaction	1000-seed weight (g)			
	Research farm		Farmer field	
	First year	Second year	First year	Second year
L_0M_0	35.0	34.7	34.6	34.3
L_0M_{PM}	41.1	40.7	40.5	40.2
L_0M_{FYM}	39.5	39.2	39.2	39.1
L_1M_0	37.3	36.9	36.9	36.7
L_1M_{PM}	46.9	46.5	46.4	46.2
L_1M_{FYM}	43.4	43.1	43.1	42.8
L_2M_0	38.5	38.2	38.1	37.8
L_2M_{PM}	41.8	41.6	41.4	40.9
L_2M_{FYM}	40.9	40.5	40.4	39.9
CV (%)	2.53	2.55	2.69	3.22
Sig. level	**	**	**	**
SE (±)	0.5905	0.5917	0.6219	0.7391

Subscripts of L represent lime rate (t ha-1); Subscripts of M represent kind of manure; PM means poultry manure (3 t ha-1) and FYM means farmyard manure (5 t ha-1); A = First year and B = Second year; CV = Coefficient of variation; ** P ≤ 0.01; SE (±) = Standard error of means.

3.3 Effects on nutrient uptake by mungbean

3.3.1 Macronutrients uptake (N, P, K, S)

There was a significant lime × manure interaction effect on the N, P, K and S uptake (seed + stover) by mungbean (Table 7). This indicates that the lime and manure treatments interacted on the macronutrients uptake by mungbean. For N, lime 1 t ha^{-1} with poultry manure at 3 t ha^{-1} resulted in higher N uptake compared to lime application at 1 t ha^{-1} with farmyard manure at 5 t ha^{-1}. The N uptake (seed + stover) varied from 57.34 - 148.17 kg ha^{-1} in first year and 62.73 - 165.61 kg ha^{-1} in second year. While the P uptake (seed + stover) varied from 10.22 - 28.49 kg ha^{-1} in first year and 11.15 - 31.88 kg ha^{-1} in second year. Generally, the effect of lime 1 t ha^{-1} with poultry manure (3 t ha^{-1}) was higher than that of lime 1 t ha^{-1} with farmyard manure (5 t ha^{-1}) and also lime 2 t ha^{-1} with poultry manure (3 t ha^{-1}). The K uptake (seed + stover) was found to vary from 49.23 - 106.68 kg ha^{-1} in first year and 21.52 - 92.80 kg ha^{-1} in second year. Overall results indicate that lime application at 1 t ha^{-1} with poultry manure at 3 t ha^{-1} demonstrated higher K uptake in comparison with the K uptake due to lime application at 1 t ha^{-1} with farmyard manure or lime application at 2 t ha^{-1} with poultry manure. The S uptake (seed + stover) was found to vary from 5.02 - 14.04 kg ha^{-1} in first year and 4.81 - 13.60 kg ha^{-1} in second year (Table 4.1.21). Overall the effect of lime at 1 t ha^{-1} with poultry manure (L_1M_{PM}) was markedly higher than that of lime 1 t ha^{-1} with farmyard manure (L_1M_{FYM}) (Table 7).

3.3.1 Micronutrients uptake (Zn, B)

There was a significant lime × manure interaction on the Zn and B uptake by mungbean (seed + stover) (Table 7). This endorses that the lime and manure treatments had interacting effect on the micronutrients uptake by mungbean. The Zn uptake (seed + stover) over the nine treatments ranged from 0.065 - 0.194 kg ha^{-1} in first year and 0.083 - 0.177 kg ha^{-1} in second year. In first year the highest Zn uptake (0.194 kg ha^{-1}) was obtained from L_1M_{PM}, next to it was 0.175 kg ha^{-1} due to L_1M_{FYM} and 0.165 kg ha^{-1} due to from $L_2M_{PM.}$ In second year, the highest Zn uptake was noted with L_1M_{PM} showing 0.177 kg ha^{-1} Zn uptake, followed by L_2M_{PM} (0.165 kg ha^{-1}) and L_1M_{FYM} (0.194 kg ha^{-1}). While the B uptake (seed + stover) ranged from 0.073 - 0.194 kg ha^{-1} in first year and 0.070 - 0.172 kg ha^{-1} in second year across the nine lime – manure treatment combinations. In first year the highest B uptake was obtained from L_1M_{PM} (0.194 kg ha^{-1}), the next was from L_1M_{FYM} (0.177 kg ha^{-1}) and then from L_2M_{PM} (0.162 kg ha^{-1}). In second year, the highest B uptake was recorded with L_1M_{FYM} (0.173 kg ha^{-1}), the next with L_2M_{PM} (0.157 kg ha^{-1}) and then with L_2M_{FYM} (0.151 kg ha^{-1}) (Table 7).

Table 7. Residual effects of lime × manure interaction on nutrient uptake (kg ha^{-1}) by mungbean (seed and stover) in the potato-mungbean-T. aman rice cropping pattern at ARS (BARI) farm, Thakurgaon

Lime × manure interaction	First year						Second year					
	N	P	K	S	Zn	B	N	P	K	S	Zn	B
L_0M_0	57.43	10.22	49.23	5.02	0.065	0.075	62.73	11.15	21.52	4.81	0.083	0.070
L_0M_{PM}	92.71	16.68	69.49	8.36	0.114	0.118	101.74	18.43	54.12	7.95	0.106	0.113
L_0M_{FYM}	84.45	15.00	64.53	7.33	0.105	0.107	93.44	16.58	59.81	7.13	0.104	0.105
L_1M_0	85.23	16.31	64.25	8.17	0.108	0.107	94.31	18.25	57.02	7.70	0.136	0.104
L_1M_{PM}	148.18	28.49	106.68	14.04	0.194	0.194	165.61	31.88	77.17	13.60	0.177	0.147
L_1M_{FYM}	139.21	26.54	98.90	12.84	0.175	0.177	154.58	29.48	92.80	12.48	0.163	0.173
L_2M_0	123.99	23.68	89.96	11.81	0.151	0.147	141.94	27.30	89.19	11.82	0.155	0.149
L_2M_{PM}	128.74	24.80	90.45	11.85	0.165	0.162	141.01	27.50	80.84	11.42	0.154	0.157
L_2M_{FYM}	121.89	23.48	86.47	11.18	0.154	0.156	133.70	25.75	77.64	10.78	0.132	0.151
CV (%)	5.01	4.77	4.60	4.66	4.89	4.56	5.11	5.49	8.14	5.32	8.63	7.62
Significant level	**	**	**	**	**	**	**	**	**	**	**	**
S.E. (±)	3.1541	0.5669	2.1224	0.2707	0.0386	0.0364	3.5712	0.7262	2.3595	0.2994	0.0399	0.0345

CV = Coefficient of variation; **, P ≤ 0.01; S.E. = Standard error.

3.4 Residual effects of lime and manure on T. aman rice

3.4.1 Effects on grain yield and straw yield

There was a significant lime × manure interaction effect on the grain yield and straw yield of T. aman rice (Table 8). In both sites and years, the lowest grain yield and straw yield were recorded with the control treatment (L0M0). Overall results indicated that lime application at 1 t ha-1 with poultry manure (L1MPM) produced the best grain yield as well as straw yield and Next to it was L1MFYM treatment which gave better grain yield as well as straw yield over the sites and years (Figure 3). Calculating the average of 2 years' results in both sites, the L1MPM treatment gave 40.6% yield benefit over control at research farm and 43.1% benefit at farmer's plot in case of grain yield of T. aman rice (Figure 04).

Table 8. Interaction effects of lime and manure on the grain and straw yields of T. aman rice

Lime × manure interaction	Grain yield (t ha^{-1})				Straw yield (t ha^{-1})			
	Research farm		Farmer field		Research farm		Farmer field	
	A	B	A	B	A	B	A	B
L_0M_0	4.10	4.07	3.93	3.87	6.17	6.10	5.98	5.93
L_0M_{PM}	4.40	4.33	4.25	4.18	6.67	6.60	6.43	6.37
L_0M_{FYM}	4.57	4.50	4.40	4.35	6.87	6.80	6.68	6.67
L_1M_0	4.75	4.68	4.83	4.73	6.82	6.78	7.27	7.13
L_1M_{PM}	5.80	5.70	5.63	5.53	8.78	8.62	8.47	8.42
L_1M_{FYM}	5.42	5.35	5.20	5.13	8.30	8.27	7.83	7.77
L_2M_0	5.23	5.20	4.80	4.73	7.90	7.83	7.23	6.57
L_2M_{PM}	5.15	5.03	4.63	4.57	7.77	7.67	6.98	7.13
L_2M_{FYM}	4.93	4.90	4.43	4.37	7.40	7.33	6.67	6.88
CV (%)	3.82	3.92	5.12	4.53	3.84	3.63	5.17	4.75
Sig. level	**	**	**	**	**	**	**	**
SE (±)	0.1087	0.1101	0.1384	0.1204	0.1641	0.1535	0.2108	0.1916

Subscripts of L represent lime rate (t ha-1); Subscripts of M represent kind of manure; PM means poultry manure (3 t ha-1) and FYM means farmyard manure (5 t ha-1); A = First year and B = Second year; CV = Coefficient of variation; ** P ≤ 0.01; SE (±) = Standard error of means.

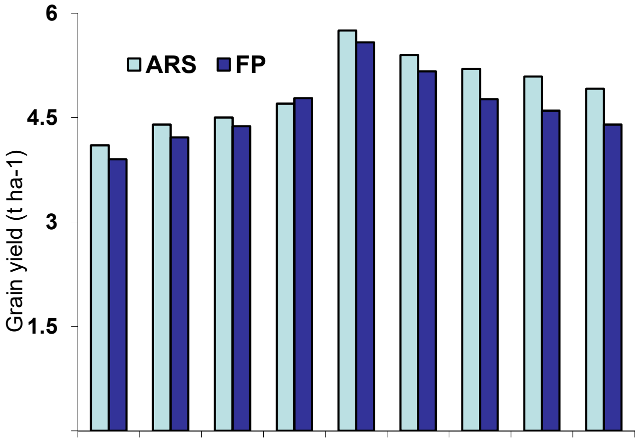

Fig. 3. Residual effects of lime x manure treatments on grain yield of T. aman rice at ARS and farmer's plot in Thakurgaon; results are the average of 2 years; L0, L1 and L2 represent lime dose at 0, 1 & 2 t ha^{-1}, respectively; M1 and M2 represent poultry manure and FYM, respectively.

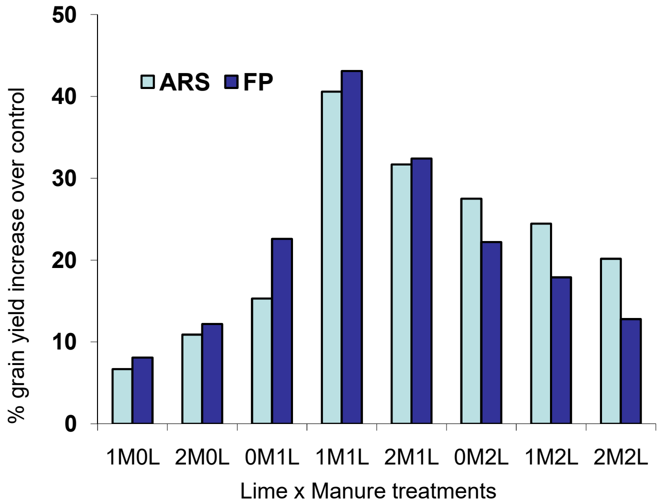

Fig. 4. Residual effects of lime x manure treatments on % grain yield (T. aman) increase over control at ARS and farmer's plot in Thakurgaon; results are the average of 2 years; L0, L1 and L2 represent lime dose at 0, 1 & 2 t ha-1, respectively; M1 and M2 represent poultry manure and FYM, respectively.

3.4.2 Effects on plant height and tillers hill^{-1}

The lime × manure interaction on the plant height and tillers hill^{-1} of T. aman rice was significant. In both sites and years, lime at 1 t ha^{-1} with poultry manure (L_1M_{PM}) produced the highest plant height as well as tillers hill^{-1} over other treatments and the lowest plant height as well as tillers hill^{-1} was noted with the control treatment (L_0M_0) (Table 9).

Table 9. Interaction effects of lime and manure on the plant height and tillers hill^{-1} of T.aman rice

Lime × manure	Plant height (cm)		Tillers hill^{-1}	
	Research farm	Farmer field	Research farm	Farmer field

interaction	A	B	A	B	A	B	A	B
L_0M_0	84.5	84.4	81.9	80.3	8.66	8.46	7.83	7.70
L_0M_{PM}	91.0	91.7	89.6	85.8	9.06	8.87	8.63	8.50
L_0M_{FYM}	94.3	93.0	93.3	89.7	10.16	9.93	9.60	9.47
L_1M_0	98.7	96.4	95.5	92.7	10.33	10.47	9.93	9.73
L_1M_{PM}	104.5	103.0	103.6	101.9	12.46	12.27	12.20	12.00
L_1M_{FYM}	100.4	99.0	97.3	98.5	11.63	11.57	10.60	10.47
L_2M_0	97.5	96.4	94.3	95.9	11.20	11.03	9.80	9.70
L_2M_{PM}	97.0	96.0	94.1	95.1	11.06	10.90	9.20	9.07
L_2M_{FYM}	96.0	95.0	92.1	92.6	10.86	10.67	9.10	8.93
CV (%)	2.60	2.66	2.81	2.53	4.48	3.71	5.80	4.58
Sig. level	**	*	**	**	**	**	**	**
SE (±)	1.4417	1.4571	1.5171	1.3529	0.2745	0.2241	0.3235	0.2515

Subscripts of L represent lime rate (t ha^{-1}); Subscripts of M represent kind of manure PM means poultry manure (3 t ha^{-1}) and FYM means farmyard manure (5 t ha^{-1}); A = First year and B = Second year; CV = Coefficient of variation; ** $P \leq 0.01$; * $P \leq 0.05$; SE (±) = Standard error of means.

3.4.3 Effects on panicle length and grains panicle^{-1}

There was a significant lime × manure interaction on panicle length and the number of grains panicle^{-1} of T. aman rice. In both locations and years, the lowest panicle length and number of grains panicle^{-1} was noted with control treatment (L0M0) and lime at 1 t ha^{-1} with poultry manure (L1MPM) produced the highest panicle length and number of grains panicle^{-1} of T. aman rice over other treatments (Table 10).

Table 10. Interaction effects of lime and manure on the panicle length and grains panicle^{-1} of T. aman rice

Lime × manure interaction	Panicle length (cm)				Grains panicle^{-1}			
	Research farm		Farmer's field		Research farm		Farmer field	
	A	B	A	B	A	B	A	B
L_0M_0	20.7	20.2	19.3	19.1	78.5	77.4	79.9	79.6
L_0M_{PM}	22.5	22.3	21.4	21.2	85.7	83.7	88.0	87.5
L_0M_{FYM}	23.2	23.0	21.3	21.2	90.5	89.3	91.5	91.1
L_1M_0	23.5	23.2	22.0	21.8	95.2	94.8	97.0	96.4
L_1M_{PM}	25.6	25.3	24.7	24.5	113.3	110.5	107.6	106.9
L_1M_{FYM}	24.2	23.9	23.2	23.0	102.0	100.3	99.5	99.0
L_2M_0	23.7	23.6	22.5	22.2	98.5	97.9	96.0	95.8
L_2M_{PM}	23.4	23.2	22.0	21.9	97.1	96.o	93.4	93.1
L_2M_{FYM}	22.7	22.4	22.1	21.9	94.6	94.0	91.9	91.6
CV (%)	3.31	3.43	4.13	3.62	3.16	2.34	3.51	2.88
Sig. level	**	**	*	*	**	*	**	**
SE (±)	0.4448	0.4559	0.5249	0.4564	1.7316	1.2676	1.9043	1.5547

Subscripts of L represent lime rate (t ha^{-1}); Subscripts of M represent kind of manure PM means poultry manure (3 t ha^{-1}) and FYM means farmyard manure (5 t ha^{-1}); A = First year and B = Second year; CV = Coefficient of variation; ** $P \leq 0.01$; * $P \leq 0.05$; SE (±) = Standard error of means.

3.5 Effects on nutrient uptake by T. Aman rice

3.5.1 Macronutrients uptake (N, P, K, S)

The interaction effect of lime and manure on the N, P, K and S uptake by T. aman rice (grain + straw) was significantly affected by the treatments (Table 11). At ARS (BARI) farm, the N uptake (grain + straw) ranged from 78.21 - 152.90 kg ha^{-1} in first year and 62.30 - 121.81 kg ha^{-1} in second year. Results indicate that lime at 1 t ha^{-1} with poultry manure at 3 t ha^{-1} (L_1M_{PM}) performed better compared to lime at 1 t ha^{-1} with farmyard manure at 5 t ha^{-1} (L_1M_{FYM}) and lime at 2 t ha^{-1} with poultry manure at 3 t ha^{-1} (L_2M_{PM}).While the P uptake ranged from 11.55 - 22.06 kg ha^{-1} in first year and 11.55 - 21.96

kg ha^{-1} in second year over the nine lime – manure treatment combinations. The highest P uptake (22.06 and 21.96 kg ha^{-1} in two years, respectively) was recorded with L_1M_{PM}, the next highest (19.72 and 19.666 kg ha^{-1} in two years, respectively) with L_1M_{FYM} and the third highest (19.13 and 18.84 kg ha^{-1} in two years, respectively) was with $L_2M_{PM.}$ However, as observed in first year, the K uptake ranged from 92.82 - 225.39 kg ha^{-1} and in 2010-1 this range was 50.41 - 121.07 kg ha^{-1} over the nine lime- manure treatment combinations. The highest K uptake was recorded from the treatment combination of lime at 1 t ha^{-1} with poultry manure at 3 t ha^{-1} (L_1M_{PM}) and the lowest from the control (L_0). The S uptake ranged from 10.20 - 20.51 kg ha^{-1} in first year and 10.00 - 20.15 kg ha^{-1} in second year. The highest S uptake of 20.51 and 20.15 kg ha^{-1} was obtained with L_1M_{PM} treatment followed by 16.27 and 15.98 kg ha^{-1} with $L_1M_{FYM,}$ then 18.18 and 17.69 kg ha^{-1} by L_2M_{PM} and the lowest S uptake of 10.20 and 10.00 kg ha^{-1}) was observed with the control in first year and second year, respectively (Table 11).

3.5.2 Micronutrients uptake (Zn and B)

There was a significant lime x manure interaction on the Zn and B uptake by T. aman rice (grain + straw) (Table 11). As recorded in first year, the Zn uptake varied from 0.424 - 0.696 kg ha^{-1} and in second year, it ranged from 0.423 to 0.688 kg ha^{-1}. Generally, effect of lime at 1 t ha^{-1} with poultry manure (L_1M_{PM}) was higher than that of lime at 1 t ha^{-1} with farmyard manure (L_1M_{FYM}) and lime at 2 t ha^{-1} with poultry manure (L_2M_{PM}). While the B uptake (grain + straw) varied from 0.132 - 0.250 kg ha^{-1} in first year and 0.129 - 0.245 kg ha^{-1} in second year. The highest B uptake of 0.250 and 0.245 kg ha^{-1} was recorded with L_1M_{PM}, next to it was 0.225 & 0.222 kg ha^{-1} with L_1M_{FYM} and then 0.217 & 0.212 kg ha^{-1} was obtained with L_2M_{PM} in two years, respectively. The uptake results were principally influenced by yield results.

Table 11. Residual effects of lime × manure interaction on nutrient uptake (kg ha^{-1}) by T. aman rice (grain and straw) in the potato–mungbean-T. aman rice pattern at ARS (BARI) farm, Thakurgaon

Lime × manure interaction	First year						Second year					
	N	P	K	S	Zn	B	N	P	K	S	Zn	B
L_0M_0	78.21	11.55	92.82	10.20	0.424	0.132	62.30	11.55	50.41	10.00	0.423	0.129
L_0M_{PM}	97.12	13.87	150.39	12.92	0.481	0.173	78.01	13.79	80.24	12.59	0.477	0.169
L_0M_{FYM}	97.94	13.87	152.59	12.94	0.479	0.172	78.84	13.80	81.20	12.65	0.477	0.169
L_1M_0	106.55	14.90	167.50	15.25	0.515	0.169	84.01	15.03	90.90	15.09	0.514	0.166
L_1M_{PM}	152.90	22.06	225.39	20.51	0.696	0.250	121.81	21.96	121.07	20.15	0.688	0.245
L_1M_{FYM}	139.95	19.72	210.10	18.86	0.642	0.225	111.79	19.66	113.81	18.59	0.640	0.222
L_2M_0	118.76	16.45	194.46	17.33	0.574	0.198	93.33	16.55	105.18	17.07	0.571	0.194
L_2M_{PM}	134.72	19.13	198.44	18.18	0.611	0.217	102.64	18.84	106.82	17.69	0.601	0.212
L_2M_{FYM}	123.99	17.79	186.24	17.00	0.568	0.196	98.51	17.82	100.49	16.69	0.566	0.193
CV (%)	3.70	3.61	3.93	3.68	3.72	3.82	4.20	3.82	3.76	3.73	3.74	3.66
Significant level	**	**	**	**	**	**	**	**	**	**	**	**
S.E. (±)	2.4926	0.3455	3.9822	0.3377	0.1192	0.0424	2.2396	0.3651	2.0478	0.3363	0.1190	0.0399

CV = Coefficient of variation; **, $P \leq 0.01$; S.E. = Standard error.

4. CONCLUSION

Application of lime and manure increased yields of crops under this study. Averaged over two years and two study sites, addition of lime at 1 t ha^{-1} resulted in an increase of potato yield by 29.1% as direct effect and 51.7% for mungbean and 23.2% for T. aman rice as residual effects. Such yield benefits due to 2 t ha^{-1} was 25.5% as direct effect and 47.9% for mungbean and 13.8 for T. aman rice as residual effects. This result reveals that one-time addition may benefit the crops for at least two years (beyond two years period was not investigated in the present study). Further research is needed to ascertain which factor is more important or dominant. While addition of manure had marked positive effect on crop yield. Between two manures, the influence of PM was higher than that of FYM. The tuber yield of potato was positively correlated with the tubers hill^{-1} and weight of tubers hill^{-1}. Poultry manure gave significantly higher seed yield compared to FYM when the soil was amended with lime 1 t ha^{-1}, but the yield was not statistically different in lime control plots. This indicates a positive interaction between manure and lime applications. Superiority of poultry manure over farmyard manure in terms of their effect on mungbean yield was a pH effect induced by liming. Decomposition rate of manure was faster when soil pH increases after liming. Results indicated that both lime and manure applications had significant influence on soil fertility and crop yield improvement. In the cropping patterns potato-mungbean-rice, the crop yield did not increase with 2 t ha^{-1} lime rate over 1 t ha^{-1} rate. Thus, the dololime application at 1 t ha^{-1} along with manure addition (FYM at 5 t ha^{-1} or PM at 3 t ha^{-1}) can be regarded as the best amendment for sustainable soil fertility and crop yield in the Old Himalayan Piedmont Plain soils of north eastern Bangladesh.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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