

Amendments of acidic soil with lime and manure for enhancing fertility, nutrient uptake and yield of wheat-mungbean-T. aman in Old Himalayan Piedmont Plain

ABSTRACT

Soil acidic conditions and the decline in soil fertility status are among the critical factors that constraint higher crop productivity in the Old Himalayan Piedmont Plain (OHPP), Bangladesh. The study was conducted to and soil properties evaluate the effect of lime and manure on crops. Experiments were conducted at Agricultural Research Station (ARS), Bangladesh Agricultural Research Institute (BARI) farm and farmer field over two consecutive years with a cropping pattern [wheat-mungbean-transplanted (T.) aman rice]. The varieties used were Bijoy for wheat, BARI mung6 for mungbean and Bina dhan7 for T. aman rice. There were nine treatment combinations with three lime levels (0, 1 and 2 ton dololime ha⁻¹) and three manure treatments (poultry manure, farmyard manure and no manure) with three replications. The rate of poultry manure was 3 t ha⁻¹ and that of FYM was 5 t ha⁻¹. Nutrients from manure sources were supplemented with chemical fertilizers to adjust recommended dose. Lime was added to the first crop for entire two crop cycles and manures were applied to the first crop of each crop cycle. Soil p^H increased by 0.5-1.11 units, the higher values were observed with higher rates of lime application. Soil organic matter (SOM) increased slightly due to manure treatment. Soil P availability increased, Zn and B availability decreased, but the K and S availability remained almost unchanged after liming. Application of lime and manure had significant positive effect on the yield of wheat, and their positive residual effects on mungbean and T. aman rice. The effect of 1 t lime ha⁻¹ was comparable with that of 2 t lime ha⁻¹. Between two manures, poultry manure performed better than FYM on crop yields. The trend of nutrient uptake (N, P, K, S, Zn and B uptake) followed the trend of crop yield. The treatment combinations with 1 t lime and 3 t poultry manure ha⁻¹ produced an average 35-55% yield benefit over control for the first crop (wheat) and 41-43% yield benefit for the third crop (T. aman rice). This study suggests that dololime @ 1 t ha⁻¹ coupled with poultry manure @ 3 t ha⁻¹ or FYM @ 5 t ha⁻¹ would be an efficient practice for better soil acidic condition, soil fertility and productivity of crops in the OHPP.

Keywords: Piedmont soils, Cropping pattern (wheat-mungbean-monsoon rice), Soil acidity, Lime, Manure, Nutrients uptake, Yields and Crop productivity.

1. INTRODUCTION

Soil acidity is an important issue in the context of sustenance of soil fertility and crop productivity. Acidity produces adverse effect on crops directly through acidic reaction and indirectly through affecting nutrient availability. More than 30% land in Bangladesh has soil acidity where crop production is constrained [1]. Old Himalayan Piedmont Plain (Agroecological zone, AEZ #1), among others, has moderately to strong acid soils. Acid soils possess toxic concentration of Al³⁺, Fe³⁺ and Mn²⁺, deficient in P concentration and lower availability of bases which in turn cause decrease in crop yield. Common crops such as potato, paddy, wheat, mungbean, in piedmont areas adversely affected by soil acidity [2]. Legumes are highly affected due to soil acidity [3, 4]. Soil acidity is caused by use of chemical fertilizers, especially NH⁴⁺

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and urea-N fertilizers that produces H^+ during nitrification, removal of basic cations (Ca^{2+} , Mg^{2+} , Na^+ , K^+) and NH_4^+ by crops in exchange for H^+ , leaching of basic cations being replaced first by H^+ and subsequently by Al^{3+} and decomposition of organic residues [5]. Occasionally liming is done to modify soil p^H and correct acidity of soils. Lime application in soil reduces the toxic effect of Al, Fe and Mn, and consequently increases the availability of P, Mo, Ca and Mg elements [6-8]. Mineralization of organic N and atmospheric fixation of N stimulates through liming. In addition, lime and organic manure improves soil physical conditions such as soil structure and water holding capacity. Lime is generally applied as calcite ($CaCO_3$) and dolomite ($CaCO_3.MgCO_3$) and the levels being 0.25-6 t ha^{-1} [9-11]. For the amelioration of acid soils in piedmont areas of Bangladesh, application of lime has been studied in different crops to improve productivity and avoid land degradation [2,12-14]. Efficient management of fertilizers through cropping pattern-based recommendation practices is essential to minimize land degradation, maintain soil aggregate stability, availability of water and nutrients; and resource utilization in piedmont areas [15-19]. Nonetheless liming is generally practiced for dry land crops, such as maize, wheat, grain legumes, oil seeds etc., where soil acidity is higher. But liming is not suggested for wetland paddy cultivation since flooding of rice fields raises the p^H to almost neutrality. Where legumes in general, have been found much more responsive to liming than other plants. A major reason is the increased availability of Mo in soils and its role in N_2 fixation. Hence, liming for acid soils have been recommended to obtain and maintain a desirable p^H for the growth of different dryland crops [20,21]. Lime and organic manure application affect yield contributing characters of crops, this in turn increase crop yields, as observed in wheat [22-24] and maize [25,26]. In particular, field trials in three northern districts of Bangladesh identified that lime application in the wheat-rice and maize-rice cropping patterns increased crop productivity [24, 26].

Crop productivity and sustainability of soil fertility depends on SOM greatly. SOM usually drives biological processes of soils that are responsible for availability of nutrients; it is the reservoir of metabolic energy as well. Application of cropping pattern based organic manure has become essential due to intensive agricultural practices and fertility decline throughout the country. During the years from 1967-1995, the depletion of SOM was from 15-35% [27]. Rather recently, 51% (7.2 Mha) and 30% (4.1 Mha) of land area consists of medium (1.71-3.4%) and low (1.1-1.7%) level/range of OM respectively reported by Soil Resource Development Institute, Bangladesh [28]. The advent of green revolution in Bangladesh, during last several decades with high yielding varieties, chemical fertilizers, pesticides and irrigation-based agriculture, caused certain decline in soil fertility and crop productivity [29,30]. But intensive farming affecting soils have not studied based on cropping pattern. Neither soil nutrients high-resolution characterization has also not conducted widely to know spatio-temporal variability of soil properties; and for implementation of management decisions that could ensure sustainability and productivity [31-33]. Moreover, crop residues and cowdung are widely used as fuel and fodder and not returned to the soils, residues retention is very low [34]. Hence, decreased SOM leads to the degradation of soil physio-chemical properties including water-holding capacity and nutrient retention capacity leading to the lower release of nutrients from mineralization of SOM in Bangladesh [35]. Therefore, application of organic manure is essential in rice and wheat-based farming systems of Bangladesh. Moreover, choice of crops and cropping pattern can be an important factor for maintaining fertility of soils in Bangladesh. Intercropping of grain legumes with cereals is good for higher productivity and for improving SOM status. OM status of the soil can be raised up to 1.43% by intercropping of mungbean with Aus (spring) rice [36]. Thus, legumes in cereal based cropping patterns can improve the soil health and consequently crop productivity. All these reasons pertain the need to investigate further wheat, mungbean and T. aman (monsoon) rice in acid soil of piedmont area with lime, manure and supplemented by recommended doses of fertilizers.

Positive influence of lime, poultry manure and FYM on yield contributing characters of wheat, mungbean and T. Aman, soil acidity, plant nutrients uptake, soil fertility and consequently higher crop productivity were the hypothesis for the set of experiments over two years under this study. Although several studies have been done with respect to lime, poultry manure and FYM application in some major crops, but studies involving cropping pattern over several crop seasons is almost non-existence and not studied including adequate number of crop and soil variables in the Old Himalayan Piedmont plain areas. Therefore, it justifies undertaking a study to investigate the effect of lime, poultry manure and farmyard manure application supplemented with fertilizers on soil and crops in the Old Himalayan Piedmont Plain (AEZ #1) to improve soil acidic condition, fertility, plant nutrients uptake for crop productivity and yields.

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2. MATERIAL AND METHODS

2.1 Study locations, climate and cropping season

The experiments were carried out at two sites in Thakurgaon Sadar Upazila, Thakurgaon district, Bangladesh for consecutive two years, Year 1 (2011-2012) and Year 2 (2013-2014). Field trials were done in the ARS field, BARI and farmer field at Rahimanpur, Thakurgaon Sadar. The ARS field, BARI lies at the 26°02'28.7" North Latitude and 88°27'06.2" East Longitude and the farmer field at the 26°03'35.5" North Latitude and 88°23'53.7" East Longitude. The soil of ARS belongs to Ranisankail Soil Series and the farmer field to Baliadangi Soil Series under AEZ#1. According to General Soil Type classification, both sites fall under Non-calcareous Brown Floodplain high land areas. The mean (average of 3 years) annual rainfall of the area is 66.97 mm and the mean annual evaporation is about 1337 mm. Being in the west-northern part of Bangladesh (towards the Himalayas), this study area has a prolonged winter as compared to the other regions of the country. In the month of January (the coldest month of a year), the mean minimum temperature was 13.7°C. There are three major cropping seasons in Bangladesh Rabi (summer), Kharif-I (spring) and Kharif-II (monsoon). The onset and duration of these seasons vary in different regions of the country. Generally, Rabi season extends from the middle of October to the middle of March, Kharif-I season from the middle of March to the end of May and Kharif-II season from the early June to the middle of October. In this study, mungbean was grown in the Kharif-I season, T. aman in Kharif-II and wheat in Rabi season.

2.2 Crops and cropping patterns

A cropping pattern viz. Wheat-Mungbean-T. Aman rice was used for setting of field experiments. Mungbean was not commonly grown in the area. So, attempt was taken to fit mungbean to the cropping pattern and to popularize the crop among the farmers. The crop varieties were Bijoy for wheat, BARI Mung6 for mungbean and Binadhan7 for T. Aman rice.

2.3 Experiments Treatments

There were nine treatment comprising 3 levels of lime (0, 1 and 2 t ha⁻¹) and 2 kinds of manure (Poultry Manure and Farmyard Manure) plus 1- no manure, as shown below.

- o L₀M₀ Control (no lime, no manure)
- o L₀M_{PM} (no lime, manure as poultry manure)
- o L₀M_{FYM} (no lime, manure as farmyard manure)
- o L₁M₀ (1 t ha⁻¹ lime, no manure)
- o L₁M_{PM} (1 t ha⁻¹ lime, manure as poultry manure)
- o L₁M_{FYM} (1 t ha⁻¹ lime, manure as farmyard manure)
- o L₂M₀ (2 t ha⁻¹ lime, no manure)
- o L₂M_{PM} (2 t ha⁻¹ lime, manure as poultry manure)
- o L₂M_{FYM} (2 t ha⁻¹ lime, manure as farmyard manure)

FYM was used at 5 t ha⁻¹ and poultry manure at 3 t ha⁻¹. The dose of Urea, Triple super phosphate (TSP) and Murate of potash (MoP) was adjusted taking into the account of the amount of Nitrogen (N), Phosphorus (P) and Potassium (K) supply from manure that added to the first crop. Fertilizer doses were rationalized for the second and third crops, as outlined in the Fertilizer Recommendation Guide (FRG, 2012). Micronutrients Zinc (Zn) and Boron (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 in each pattern.

2.4 Experimental design

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 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.

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2.5 Land preparation and sowing/planting of crops

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 spading. The sowing/planting date, plant spacing, seed/seedling rate and harvesting date used are stated below:

Parameters	Wheat	Mungbean	T. Aman rice
Sowing date	November 19-20	March 24-25	June 15-16
Planting date	-	-	July 15-16
Plant spacing	20cmxcontinuous	30 cmxcontinuous	20 cm x 15 cm
Seed rate	120 kg ha ⁻¹	30 kg ha ⁻¹	-
Seedling rate	-	-	3-4 seedlings hill ⁻¹
Harvesting date	March 23-24	June 25-26	October 20-21

2.6 Lime and manure (poultry and FYM) application

Dolomite lime was added to the plots before 15 days of sowing/planting. The rates of lime were 1 and 2 t ha⁻¹ respectively. 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 rate of manure was 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 are shown below.

Manure	Year	N (%)	P (%)	K (%)
Poultry manure	Year 1	1.86	0.62	0.75
	Year 2	1.84	0.59	0.73
Farmyard manure	Year 1	1.20	0.51	0.56
	Year 2	1.15	0.55	0.62

2.7 Fertilizer application

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, i.e. land preparation, maximum tillering and panicle initiation stage. For wheat, 50% urea was applied during land preparation, 25% at crown root initiation stage and the rest 25% at booting stage. Mungbean received full quantities of urea, TSP, MoP and gypsum during land preparation.

2.8 Intercultural operations

During growing period of the crops, all necessary agronomic cares were taken for ensuring and maintaining normal growth and development of the crops. Weeding, irrigation, earthing-up, insecticide and fungicide spray were done, whenever required as standards.

2.9 Harvesting

The crops were harvested plot-wise (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 12m² area of the center 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 wheat and mungbean. Ten representative plants or hills from outside the harvested area within a plot were selected to record the yield contributing characters.

2.10 Chemical analysis of soil sample, plants/grain and manure

Extended methodologies and techniques that were used for analysis of soil and plant samples analysis were described in Appendix Table 1 (A,B). Initial status of experimental site soil properties was also included in Appendix 2 (C, D,E).

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2.11 Statistical analysis

The data collected for different parameters were statistically analyzed to find out the statistical significance of the experimental results. 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) [37]. Data analysis was done by computer using MSTAT-C software [38].

3. RESULTS AND DISCUSSION

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3.1. Effects of lime and manure on wheat-mungbean-T. aman rice pattern

The experiments were set up with wheat as the first crop, mungbean as the second crop and T. aman rice as the third crop in each cropping year and it continued up to the second crop year. Data on the grain/seed and straw/stover yields, and the yield contributing characters were recorded. Nutrient uptake by the crops and changes in soil properties was also observed. Nutrient uptakes by the three crops were calculated from the nutrient concentration results. Nitrogen, phosphorus, potassium, sulphur, zinc and boron concentrations of grain/seed and straw/stover were also determined (Supplementary materials, Table 1-3).

3.1.1 Effects on wheat grain and straw yield

The interaction effect of lime and manure on the grain and straw yield of wheat was significant (Table 1) in research and farmer field experiment. In both cropping years (Year 1 and 2), the highest grain yield (5.03 and 5.21 t ha⁻¹) was obtained from the treatment L₁M_{PM}. The next highest yielding treatments were L₁M_{FYM} and L₂M₀ followed by the treatments L₂M_{PM} and L₂M_{FYM}. The result indicated that the 1 t ha⁻¹ lime with poultry manure (L₁M_{PM}) treatment gave better yield compared to 2 t ha⁻¹ lime with poultry manure (L₂M_{PM}) treatment. While in farmer field experiment, the highest grain yield (4.92 t ha⁻¹ and 4.97 t ha⁻¹) was obtained from the treatment L₁M_{PM}. The next highest yielding treatments were L₁M_{FYM}, L₂M₀, L₂M_{PM} and L₂M_{FYM}. Results indicated that the 1 t ha⁻¹ lime with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) treatment gave better yield compared to 2 t ha⁻¹ lime with poultry manure (L₂M_{PM}) treatment. Considering two-year average yield, it varied from 3.80–5.12 t ha⁻¹ at ARS farm and 3.19–4.95 t ha⁻¹ at farmer field. The L₁M_{PM} treatment gave 34.7% yield benefit over control at research farm and 55.0% benefit at farmer field (Fig. 1). While the highest straw yield was observed in L₁M_{PM} treatment (5.53 and 5.73 t ha⁻¹; and 5.40 and 5.43 t ha⁻¹), the next highest straw yield was observed in L₁M_{FYM} treatment (5.00 and 5.15 t ha⁻¹; and 4.98 and 5.03 t ha⁻¹).

Table 1. Interaction effects of lime and manure on the grain and straw yields of wheat in the wheat-mungbean-T. aman rice pattern

Lime × Manure interaction	Grain yield (t ha ⁻¹)				Straw yield (t ha ⁻¹)			
	Research farm		Farmer field		Research farm		Farmer field	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
L ₀ M ₀	3.76	3.83	3.10	3.27	4.16	4.27	3.90	4.02
L ₀ M _{PM}	4.06	4.12	3.47	3.58	4.43	4.45	4.17	4.22
L ₀ M _{FYM}	4.16	4.25	3.65	3.77	4.55	4.60	4.43	4.50
L ₁ M ₀	4.28	4.38	4.05	4.12	4.70	4.80	4.55	4.62
L ₁ M _{PM}	5.03	5.21	4.92	4.97	5.53	5.73	5.40	5.43
L ₁ M _{FYM}	4.63	4.77	4.60	4.48	5.00	5.15	4.98	5.03
L ₂ M ₀	4.43	4.31	4.40	4.40	4.83	4.68	4.83	4.87

L ₂ M _{PM}	4.30	4.25	4.28	4.28	4.70	4.67	4.72	4.77
L ₂ M _{FYM}	4.20	4.23	4.15	4.15	4.60	4.62	4.57	4.70
CV (%)	4.12	4.14	3.66	5.43	4.15	5.03	3.74	4.61
Sig. level	**	**	**	**	**	**	**	**
SE (±)	0.1028	0.1040	0.0860	0.1289	0.1130	0.1387	0.0998	0.1246

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

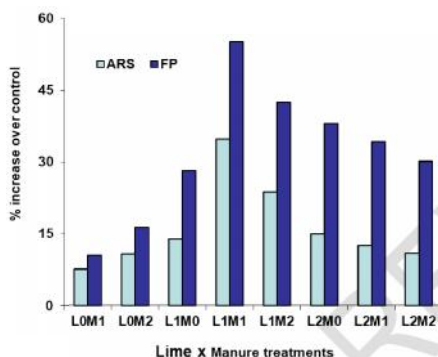


Fig.1. Effects of lime and manure treatments on % grain yield (wheat) increase over control at ARS and farmer plot; results are the average of 2 years. L₀, L₁ and L₂ represent lime dose at 0, 1 and 2 $t\ ha^{-1}$, respectively; M₁ and M₂ represent poultry manure and FYM, respectively.

3.1.2 Effects on wheat plant height and tillers plant⁻¹

The interaction effect of lime and manure on plant height and tillers plant⁻¹ of wheat was significant (Table 2). The plant height ranged from 86.40-100.36 cm and 84.70-104.13 cm at ARS farm; and 78.43-94.26 cm and 83.06-98.36 cm at farmer field. The highest plant height was obtained in L₁M_{PM} treatment (100.36 and 104.13 cm and 94.26 and 98.36). The next highest plant height was observed in L₁M_{FYM} treatment. While in ARS, BARI farm, the maximum number of tillers plant⁻¹ (7.80 and 5.16 in two consecutive years) was resulted from treatment L₁M_{PM} which was statistically identical with L₁M_{FYM} (7.06 and 4.63) treatment. In farmer field, the maximum number of tillers plant⁻¹ was observed in treatment L₁M_{PM} (4.86 and 4.96) which was statistically similar with L₁M_{FYM} and L₂M₀ treatments.

Table 2. Interaction effects of lime and manure on the plant height and tillers plant⁻¹ of wheat in the wheat-mungbean-T. aman rice pattern

Lime × Manure interaction	Plant height (cm)				Tillers plant ⁻¹			
	Research farm		Farmer's field		Research farm		Farmer's field	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
L ₀ M ₀	86.40	84.70	78.43	83.06	5.56	3.66	3.43	3.46
L ₀ M _{PM}	91.10	89.56	81.40	86.70	5.86	3.96	3.93	3.76
L ₀ M _{FYM}	93.66	93.26	85.10	90.70	6.33	4.23	4.13	4.03
L ₁ M ₀	94.83	95.93	86.23	94.40	6.40	4.40	4.30	4.33
L ₁ M _{PM}	100.36	104.13	94.26	98.36	7.80	5.16	4.86	4.96
L ₁ M _{FYM}	96.83	97.13	91.20	95.03	7.06	5.63	4.70	4.80
L ₂ M ₀	93.40	94.60	89.53	94.06	6.80	4.50	4.60	4.66
L ₂ M _{PM}	95.76	94.10	87.56	92.60	6.30	4.40	4.53	4.56

L ₂ M _{FYM}	94.06	92.56	87.03	92.46	5.96	4.23	4.43	4.46
CV (%)	2.44	2.47	3.13	1.80	7.64	5.42	3.75	4.11
Sig. level	*	**	**	**	**	**	**	**
SE (±)	1.3271	1.3399	1.5672	0.9554	0.2848	0.0787	0.0937	0.1029

*Subscripts of L represent lime rate (t ha⁻¹), M represent kind of manure; PM means poultry manure (3 t ha⁻¹) and FYM means farmyard manure (5 t ha⁻¹); CV = Coefficient of variation; ** P ≤ 0.01, ; * P ≤ 0.05; SE (±) = Standard error of means.

3.1.3 Effects on wheat grains spike⁻¹ and 1000- grain weight

The lime and manure interaction was found significant on the number of grains spike⁻¹ and 1000-grain weight of wheat (Table 3). Grains spike⁻¹ varied with different treatment combinations showing a range of 38.4-51.5 and 31.6-46.6 in research farm; and 28.4-44.3 and 29.3-45.2 in farmer's field in two years, respectively. In both sites, the maximum number of grains spike⁻¹ (51.5 and 46.6 in two consecutive years) was recorded with L₁M_{PM} which was statistically similar with L₁M_{FYM}. The poultry manure accompanied with lime at 1 t ha⁻¹ treatment had superior effect over other treatments. While the 1000-grain weight across the nine treatment combinations was 43.0 - 53.0 g in Year 1 and 38.7 - 56.1 g in Year 2 at site-1 and 35.7 - 53.2 g in Year 1 and 38.0 - 54.6 g in Year 2 at site-2. In both sites, the highest 1000-grain weight was recorded with L₁M_{PM} treatment in both study sites.

Table 3. Interaction effects of lime and manure on the grains spike⁻¹ and 1000-grain weight of wheat in the wheat-mungbean-T. aman rice pattern

Lime × Manure interaction	Grains spike ⁻¹				1000-grain weight (g)			
	Research farm		Farmer's field		Research farm		Farmer's field	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
L ₀ M ₀	38.4	31.6	28.4	29.3	43.4	38.7	35.7	38.0
L ₀ M _{PM}	41.5	35.1	32.5	35.1	45.8	43.0	39.1	41.6
L ₀ M _{FYM}	42.9	37.5	36.5	36.0	48.3	45.5	42.3	45.5
L ₁ M ₀	48.0	38.7	40.1	39.0	49.3	48.1	47.2	47.7
L ₁ M _{PM}	51.5	46.6	44.3	45.2	53.0	56.1	53.2	54.6
L ₁ M _{FYM}	49.3	44.5	43.0	41.8	50.8	50.8	50.6	51.8
L ₂ M ₀	47.6	42.5	41.7	40.0	49.7	50.3	51.3	51.0
L ₂ M _{PM}	47.4	39.1	40.9	38.7	48.5	48.8	50.9	48.9
L ₂ M _{FYM}	44.0	37.2	40.1	36.8	47.0	47.4	48.6	48.1
CV (%)	3.91	3.80	4.76	4.14	4.36	3.32	3.64	3.37
Sig. level	**	**	**	**	*	**	**	**
SE (±)	1.0285	0.8611	1.0603	0.9079	1.2189	0.9124	0.9790	0.9250

*Subscripts of L represent lime rate (t ha⁻¹); M represent kind of manure; PM means poultry manure (3 t ha⁻¹) and FYM means farmyard manure (5 t ha⁻¹); CV = Coefficient of variation; ** P ≤ 0.01, ; * P ≤ 0.05; SE (±) = Standard error of means.

3.2 Effects on nutrient uptake by wheat

The grain and straw samples of wheat from ARS farm were analyzed for N, P, K, S, Zn and B concentrations. Nutrient uptake is calculated from the yield and nutrient concentration data. Total uptake of a nutrient is calculated as the sum of grain uptake and straw uptake of that nutrient.

Lime and manure interacted significantly on the N, P, K, S, Zn and B uptake by wheat. Influence of lime at 1 t ha⁻¹ with poultry manure (L₁M_{PM}) was higher than that of lime at 1 t ha⁻¹ with farmyard manure (L₁M_{FYM}). The N uptake over the nine treatment combinations varied from 59.42-106.99 kg ha⁻¹ in year 1 and 59.66-109.53 kg ha⁻¹ in year 2 (Appendix Table 3). The P uptake (grain + straw) ranged from 17.47-31.15 kg ha⁻¹ in Year 1 and 17.49-31.78 kg ha⁻¹ in Year 2 over the nine treatment combinations. Lime at 1 t ha⁻¹ with poultry manure 3 t ha⁻¹ (L₁M_{PM}) produced higher P uptake (31.15 and 31.78 kg ha⁻¹), next to it was L₁M_{FYM} (27.61 and 28.41 kg ha⁻¹); and then L₂M_{PM} produced P uptake of 31.15 and 31.78 kg ha⁻¹. The K uptake values were 73.43-123.23 kg ha⁻¹ and 75.77-126.49 kg ha⁻¹, for the consecutive two years. The highest K uptake was recorded by L₁M_{PM} which was statistically superior over other eight treatment combinations. The S uptake ranged from 14.73-24.38 kg ha⁻¹ in Year 1 and 14.60-24.75 kg ha⁻¹ in Year 2. The effect of Lime at 1 t ha⁻¹ with poultry manure (L₁M_{PM}) was higher than that of lime at 1 t ha⁻¹ with farmyard manure (L₁M_{FYM}). The Zn uptake over two years ranged from 0.267-0.386 kg ha⁻¹ in Year 1 and 0.275 - 0.398 kg ha⁻¹ in Year 2. The highest Zn uptake was recorded with lime at 1 t ha⁻¹ with poultry manure (L₁M_{PM}) which was higher than that of lime at 1 t ha⁻¹ with farmyard manure (L₁M_{FYM}) and L₂M_{PM}. The B uptake varied from 0.139 - 0.216 kg ha⁻¹ in Year 1 and 0.151 - 0.251 kg ha⁻¹ in Year 2. Lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) had better effect on B uptake compared to lime 1 t ha⁻¹ with farmyard manure at 5 t ha⁻¹ (L₁M_{FYM}).

3.3. Residual effects of lime and manure on mungbean

Direct effects of lime and manure were evaluated on the first crop (wheat) and their residual effects were evaluated on the second crop (mungbean) and on the third crop (T. aman rice).

3.3.1 Effects on seed and stover yield of mungbean

There was a significant lime and manure interaction on the seed and stover yield of mungbean. Depending on the treatment combinations, the seed yield ranged from 0.70-1.76 t ha⁻¹ in Year 1 and 0.72-1.78 t ha⁻¹ in Year 2 for ARS farm and 0.72-1.77 t ha⁻¹ in Year 1 and 0.70-1.73 t ha⁻¹ in Year 2 for farmer's field (Table 4). The highest seed yield was obtained from L₁M_{PM} treatment (1.64 t ha⁻¹) which was superior over all other treatments in Year 1. In case of Year 2, the L₁M_{PM} treatment showed the highest seed yield (1.63 t ha⁻¹). In farmer field, the L₁M_{PM} treatment showed the highest seed yield (1.63 and 1.61 t ha⁻¹). The seed yield, as calculated average of 2 years' result, ranged from 0.71-1.77 t ha⁻¹ at ARS farm and 0.71-1.75 t ha⁻¹ at farmer's field, the highest yield being recorded with L₁M_{PM} treatment. The L₁M_{PM} treatment showed 149% yield increase compared to control at research farm and 147% yield increase at farmer field (Fig. 2). While the stover yield of mungbean ranged from 1.45-2.72 t ha⁻¹ in Year 1 and 1.47-2.73 t ha⁻¹ in Year 2 for ARS farm, and 1.42-2.65 t ha⁻¹ in Year 1 and 1.38-2.60 t ha⁻¹ in Year 2 for farmer field. In ARS farm, the highest stover yield of 2.72 t ha⁻¹ was obtained from L₁M_{PM} treatment, which was superior over all other treatments in Year 1. In case of Year 2, the L₁M_{PM} treatment showed the highest stover yield 2.73 t ha⁻¹. In farmer's field, the L₁M_{PM} showed also the highest stover yield (2.65 and 2.60 t ha⁻¹).

Table 4. Interaction effects of lime and manure on the grain and stover yields of mungbean in the wheat-mungbean-T. aman rice pattern

Lime × Manure interaction	Seed yield (t ha ⁻¹)				Stover yield (t ha ⁻¹)			
	Research farm		Farmer's field		Research farm		Farmer's field	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
L ₀ M ₀	0.70	0.72	0.72	0.70	1.45	1.47	1.42	1.38
L ₀ M _{PM}	1.10	1.12	1.10	1.08	1.90	1.92	1.87	1.83
L ₀ M _{FYM}	1.00	1.02	1.02	1.00	1.80	1.82	1.77	1.73
L ₁ M ₀	0.95	0.97	0.95	0.98	1.70	1.72	1.67	1.62
L ₁ M _{PM}	1.76	1.78	1.77	1.73	2.72	2.73	2.65	2.60
L ₁ M _{FYM}	1.63	1.61	1.62	1.60	2.50	2.52	2.47	2.43
L ₂ M ₀	1.48	1.50	1.48	1.45	2.47	2.48	2.38	2.35

L ₂ M _{PM}	1.40	1.42	1.43	1.40	2.23	2.25	2.20	2.15
L ₂ M _{FYM}	1.33	1.35	1.30	1.25	2.20	2.22	2.13	2.10
CV (%)	6.20	6.12	7.12	6.38	6.19	6.14	4.92	5.69
Sig. level	**	**	**	**	**	**	**	**
SE (±)	0.0452	0.0452	0.0520	0.1203	0.0753	0.0753	0.0585	0.0664

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

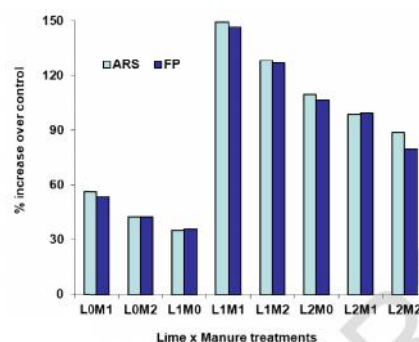


Fig. 2. Residual effects of lime and manure treatments on % seed yield (mungbean) increase over control at ARS and farmer plot; results are the average of 2 years. L0, L1 and L2 represent lime dose at 0, 1 and 2 t ha⁻¹, respectively; M1 and M2 represent poultry manure and FYM, respectively.

3.3.2 Effects on mungbean pods plant⁻¹ and seeds pod⁻¹

There was a significant lime and manure interaction on the number of pods plant⁻¹ and seeds pod⁻¹ of mungbean (Table 5). At ARS, BARI farm, the pods plant⁻¹ ranged from 8.30-18.13 in Year 1 and 8.43-18.27 in Year 2. At farmer field, the number of pods plant⁻¹ varied from 8.73-17.67 in Year 1 and from 8.60-17.33 in Year 2. While at ARS, BARI farm, the number of seeds pod⁻¹ ranged from 8.03-12.33 in Year 1 and 8.10-12.40 in Year 2. At farmer field, the seeds pod⁻¹ varied from 7.97-12.13 in Year 1 and 7.83-11.93 in Year 2.

Table 5. Interaction effects of lime and manure on the pods plant⁻¹ and seeds pod⁻¹ of mungbean in the wheat-mungbean-T. aman rice pattern

Lime × Manure interaction	Pods plant ⁻¹ (no.)				Seeds pod ⁻¹ (no.)			
	Research farm		Farmer's field		Research farm		Farmer's field	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
L ₀ M ₀	8.30	8.43	8.73	8.60	8.03	8.10	7.97	7.83
L ₀ M _{PM}	10.93	11.07	10.83	10.50	9.70	9.77	9.57	9.43
L ₀ M _{FYM}	10.80	10.93	10.80	10.63	9.10	9.17	9.13	9.00
L ₁ M ₀	9.26	9.40	9.33	9.13	9.00	9.06	8.93	8.73
L ₁ M _{PM}	18.13	18.27	17.67	17.33	12.33	12.40	12.13	11.93
L ₁ M _{FYM}	15.06	15.20	14.90	14.63	11.30	11.37	11.27	11.07
L ₂ M ₀	11.20	11.33	11.13	10.93	9.70	9.77	9.33	9.13
L ₂ M _{PM}	12.96	13.10	12.67	12.47	10.66	10.77	10.23	10.07
L ₂ M _{FYM}	11.53	11.67	11.20	11.07	10.06	10.17	9.83	9.67

CV (%)	8.20	8.11	8.72	8.78	4.60	4.54	4.95	5.29
Sig. level	**	**	*	*	**	**	**	**
SE (\pm)	0.5694	0.5694	0.5998	0.5931	0.2653	0.2638	0.2806	0.2946

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

3.3.3 Effects on mungbean 1000-seed weight

There was a significant lime and manure interaction on the 1000-seed weight of mungbean (Table 6). At ARS (BARI) farm, the 1000-seed weight of mungbean ranged from 34.06-46.00g in Year 1 and 34.10-46.03g in Year 2. At farmer field, the 1000-seed weight (g) varied from 34.17-45.90g in Year 1 and from 34.00-45.40g in Year 2.

Table 6. Interaction effects of lime and manure on the 1000-seed weight of mungbean in the wheat-mungbean-T. aman rice pattern

Lime \times Manure interaction	1000-seed weight (g)			
	Research farm		Farmer's field	
	Year 1	Year 2	Year 1	Year 2
L_0M_0	34.06	34.10	34.17	34.00
L_0M_{PM}	40.30	40.33	40.07	39.77
L_0M_{FYM}	38.60	38.63	38.90	38.40
L_1M_0	36.46	36.50	36.40	36.13
L_1M_{PM}	46.00	46.03	45.90	45.40
L_1M_{FYM}	42.56	42.60	42.60	42.27
L_2M_0	37.76	37.80	37.23	36.90
L_2M_{PM}	41.16	41.20	40.50	40.17
L_2M_{FYM}	40.03	40.07	39.33	38.83
CV (%)	2.56	2.55	2.96	3.14
Sig. level	**	**	**	**
SE (\pm)	0.5851	0.5851	0.6750	0.7093

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

3.4 Effects on nutrient uptake by mungbean

The seed and stover samples of mungbean from ARS farm were analyzed for N, P, K, S, Zn and B concentrations. The uptake calculation was made using the yield and nutrient concentration data of seed and stover.

There was significant lime and manure interactions effects on the N, P, K, S, Zn and B uptake by mungbean (Appendix Table 4). The N uptake (seed + stover) ranged from 34.56 - 100.71 kg ha^{-1} in Year 1 and 35.03-100.83 kg ha^{-1} in Year 2. Influence of lime at 1 t ha^{-1} with poultry manure at 3 t ha^{-1} (L_1M_{PM}) was higher than that of lime at 1 t ha^{-1} with farmyard manure at 5 t ha^{-1} (L_1M_{FYM}) and L_2M_{PM} . The P uptake (seed + stover) ranged from 6.09-19.26 kg ha^{-1} in Year 1 and 6.10-19.19 kg ha^{-1} in Year 2. The L_1M_{PM} produced the highest p uptake (19.26 and 19.19 kg ha^{-1}) and next to it L_1M_{FYM} produced P uptake (17.21 and 17.08 kg ha^{-1}). The K uptake (seed + stover) ranged from 13.48-39.14 kg ha^{-1} in Year1 and 10.53-46.39 kg ha^{-1} in Year 2. S uptake ranged from 4.61-13.92 kg ha^{-1} in Year 1 and 4.66-13.92 kg ha^{-1} in Year 2. 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 L_2M_{PM} . As observed in Year 1, the Zn uptake ranged from 0.059-0.193 kg ha^{-1} and in Year 2, it varied from 0.079-0.178 kg ha^{-1} . In both years, the highest Zn uptake (0.193 and 0.178 kg ha^{-1}) was obtained from lime at 1 t ha^{-1} with poultry manure at 3 t ha^{-1} (L_1M_{PM}), next to it was 0.171 and 0.159 kg ha^{-1} Zn uptake recorded with L_1M_{FYM} followed by Zn uptake of 0.155 and 0.148 kg ha^{-1} due to L_1M_{FYM} . The B uptake (seed + stover) ranged from 0.068-0.190 kg ha^{-1} in Year 1 and 0.067-0.167 kg ha^{-1} in Year 2 over the nine lime- manure treatment combinations. The highest B uptake (0.191 kg ha^{-1}) was obtained

from L_1M_{PM} , the next result was obtained from L_1M_{FYM} (0.172 kg ha⁻¹) and then the B uptake of 0.154 kg ha⁻¹ was obtained from L_1M_{FYM} . In Year 2, the highest B uptake (0.168 kg ha⁻¹) was recorded with L_1M_{FYM} , the next highest (0.149 kg ha⁻¹) with L_2M_{PM} and then 0.145 kg ha⁻¹ B uptake obtained from L_1M_{PM} .

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

T. aman rice, the third crop in the pattern, was significantly influenced by the different lime and manure treatments used for the first crop (wheat). Data were recorded on grain and straw yields, growth and yield components and nutrient concentration.

3.5.1 Effects on grain and straw yield of T.aman rice

There was a significant lime and manure interaction on the grain and straw yield of T. aman rice (Table 7). At ARS, BARI farm, the grain yield ranged from 3.93-5.63 t ha⁻¹ in Year 1 and 3.90-5.57 t ha⁻¹ in Year 2. At farmer field, the grain yield varied from 3.80-5.40 t ha⁻¹ in Year 1 and from 3.93-5.48 t ha⁻¹ in Year 2. Considering average yield over 2 years, it appeared that the seed yield at ARS farm varied from 3.92-5.60 t ha⁻¹ and at farmer plot it ranged from 3.87-5.44 t ha⁻¹, the L_1M_{PM} treatment recorded the highest yield and the L_0M_0 (control) did the lowest. Calculating yield increase over control, the L_1M_{PM} treatment resulted in 42.9% yield benefit at research farm and 40.6% yield benefit at farmer's plot (Fig. 3). While at research farm, the straw yield ranged from 6.00-8.52 t ha⁻¹ in Year 1 and 5.93-8.48 t ha⁻¹ in Year 2. At farmer field, the straw yield varied from 5.83-8.17 t ha⁻¹ in Year 1 and 5.98-8.33 t ha⁻¹ in Year 2. Lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L_1M_{PM}) was the superior treatment which performed higher straw yield.

Table 7. Interaction effects of lime and manure on the grain and straw yields of T. aman rice in the wheat-mungbean-T. aman rice cropping pattern

Lime × Manure interaction	Grain yield (t ha ⁻¹)				Straw yield (t ha ⁻¹)			
	Research farm		Farmer's field		Research farm		Farmer's field	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
L_0M_0	3.93	3.90	3.80	3.93	6.00	5.93	5.83	5.98
L_0M_{PM}	4.30	4.27	4.13	4.26	6.53	6.53	6.23	6.48
L_0M_{FYM}	4.47	4.43	4.31	4.45	6.70	6.73	6.53	6.73
L_1M_0	4.63	4.57	4.70	4.86	6.75	6.82	7.10	7.37
L_1M_{PM}	5.63	5.57	5.40	5.48	8.52	8.48	8.17	8.33
L_1M_{FYM}	5.27	5.22	5.07	5.13	8.17	8.03	7.67	7.85
L_2M_0	5.13	5.07	4.66	4.83	7.77	7.70	7.03	7.40
L_2M_{PM}	4.97	4.93	4.51	4.70	7.53	7.50	6.80	7.20
L_2M_{FYM}	4.90	4.80	4.36	4.43	7.31	7.27	6.47	6.73
CV (%)	3.86	5.01	4.11	2.89	3.73	4.76	3.91	2.78
Sig. level	**	**	**	**	**	**	**	**
SE (±)	0.1072	0.1374	0.1080	0.0781	0.1553	0.1983	0.1550	0.1143

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

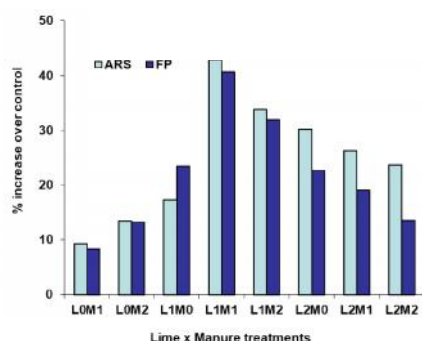


Fig. 3. Residual effects of lime and manure treatments on % grain yield (T. aman) increase over control at ARS and farmer's plot in Thakurgaon; results are the average of 2 years.

L0, L1 and L2 represent lime dose at 0, 1 and 2 t ha⁻¹, respectively; M1 and M2 represent poultry manure and FYM, respectively.

3.5.2 Effects on plant height and tillers hill⁻¹ of T. aman rice

There was a significant lime and manure interaction on the plant height and tillers hill⁻¹ of T. aman rice (Table 8). At ARS, BARI farm, the plant height varied from 84.3-102.0 cm in Year 1 and 83.5-101.5 cm in Year 2. At farmer field, the plant height varied from 79.6-100.7 cm in Year 1 and from 77.9-100.3 cm in Year 2. Lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) produced higher plant height compared to L₁M_{FYM} and L₂M_{PM} over the sites and years. While at ARS, BARI farm, the tillers hill⁻¹ ranged from 8.33-12.06 in Year 1 and 8.06-11.93 in Year 2. At farmer field, the tillers hill⁻¹ varied from 7.60-11.80 in Year 1 and from 8.13-11.93 in Year 2. Lime at 1 t ha⁻¹ with poultry manure at 1 t ha⁻¹ (L₁M_{PM}) produced higher tillers.

Table 8. Interaction effects of lime and manure on the plant height and tillers hill⁻¹ of T. aman rice in the wheat-mungbean-T. aman rice pattern

Lime × Manure interaction	Plant height (cm)				Tillers hill ⁻¹ (no.)			
	Research farm		Farmer's field		Research farm		Farmer's field	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
L ₀ M ₀	84.3	83.5	79.6	77.9	8.33	8.06	7.60	8.13
L ₀ M _{PM}	90.7	91.4	83.9	83.5	8.80	8.73	8.37	8.93
L ₀ M _{FYM}	93.1	92.4	88.1	87.9	9.80	9.67	9.33	9.46
L ₁ M ₀	95.9	95.4	92.3	92.2	10.40	10.33	9.60	10.03
L ₁ M _{PM}	102.0	101.5	100.7	100.3	12.06	11.93	11.80	11.93
L ₁ M _{FYM}	98.4	97.6	97.3	94.8	11.50	11.37	10.33	10.83
L ₂ M ₀	96.1	95.9	94.8	92.7	10.93	10.87	9.60	10.40
L ₂ M _{PM}	95.6	95.2	93.7	92.1	10.83	10.70	8.93	10.13
L ₂ M _{FYM}	94.2	93.6	91.4	91.2	10.53	10.40	8.80	9.93
CV (%)	2.41	2.33	2.82	2.68	3.66	4.92	5.20	3.95
Sig. level	**	**	**	**	**	**	**	**
SE (±)	1.3129	1.2640	1.4866	1.3946	0.2188	0.2903	0.2816	0.2278

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

3.5.3 Effects on panicle length and grains panicle⁻¹

There was a significant lime × manure interaction on the panicle length and grain panicle⁻¹ of T. aman rice (Table 9). At ARS, BARI farm, the panicle length ranged from 19.9 - 25.1 cm in Year 1 and 19.7-24.9 cm in Year 2. At farmer field, the panicle length varied from 19.0 to 24.3 cm in Year 1 and from 20.1-27.3 cm in Year 2. Lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) produced higher panicle length than L₁M_{FYM} and L₂M_{PM} over the sites and years. While at ARS (BARI) farm, the number of grains panicle⁻¹ ranged from 76.8-109.7 in Year 1 and 76.4-109.2 in Year 2. At farmer field, the grains panicle⁻¹ of T. aman rice varied from 79.2-106.5 in Year 1 and from 80.1-110.1 in Year 2. Lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) produced higher number of grains panicle⁻¹.

Table 9. Interaction effects of lime and manure on the panicle length and grains panicle⁻¹ of T. aman rice in the wheat-mungbean-T. aman rice pattern

Lime × Manure interaction	Panicle length (cm)				Grains panicle ⁻¹ (no.)			
	Research farm		Farmer's field		Research farm		Farmer's field	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
L ₀ M ₀	19.9	19.7	19.0	20.1	76.8	76.3	79.2	80.1
L ₀ M _{PM}	22.1	21.9	21.1	21.7	83.3	82.9	87.0	88.7
L ₀ M _{FYM}	22.9	22.8	20.9	22.4	88.9	88.5	90.7	95.3
L ₁ M ₀	23.1	22.9	21.7	24.4	94.4	94.1	95.8	98.9
L ₁ M _{PM}	25.1	24.9	24.3	27.3	109.7	109.2	106.5	110.1
L ₁ M _{FYM}	23.9	23.7	22.9	25.9	100.1	99.7	98.4	99.3
L ₂ M ₀	23.5	23.2	22.1	25.7	97.4	97.1	95.4	96.4
L ₂ M _{PM}	23.0	22.9	21.7	24.7	95.6	95.5	92.8	95.4
L ₂ M _{FYM}	22.4	22.3	21.7	24.7	93.7	93.3	90.9	94.4
CV (%)	3.14	4.00	3.23	2.47	2.32	2.46	2.42	1.96
Sig. level	**	*	*	**	**	**	*	*
SE (±)	0.4140	0.5235	0.4054	0.3440	1.2508	1.3229	1.2974	1.0822

*Subscripts of L represent lime rate (t ha⁻¹); M represent kind of manure; PM means poultry manure (3 t ha⁻¹) and FYM means farmyard manure (5 t ha⁻¹); CV = Coefficient of variation; ** P ≤ 0.01, * P ≤ 0.05; SE (±) = Standard error of means.

3.6 Effects on nutrient uptake by T. aman rice

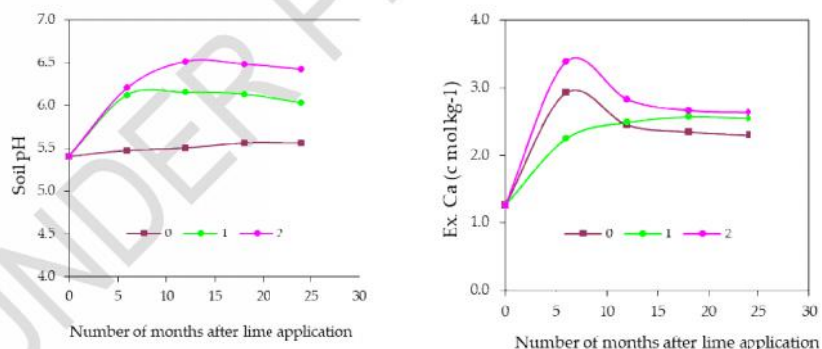
The nutrient uptake by T. aman rice is calculated using the data of crop yield and nutrient concentration (grain and straw) from ARS, BARI farm, Thakurgaon. The nutrients under study included N, P, K, S, Zn and B.

Interaction effect of lime and manure on the N, P, K, S, Zn and B uptake of T. aman rice was significant for the variables studied (Appendix Table 5). At ARS, BARI farm, the N uptake ranged from 76.58-155.37 kg ha⁻¹ in Year 1 and 75.97-153.37 kg ha⁻¹ in Year 2. Lime at 1 t ha⁻¹ with poultry manure (L₁M_{PM}) had the highest N uptake (155.37 and 153.37 kg ha⁻¹), next to it L₁M_{FYM} produced N uptake of 143.93 and 141.45 kg ha⁻¹ in two subsequent years. Then L₁M_{PM} produced 136.47 and 133.09 kg ha⁻¹ N uptake. The P uptake (grain + straw) ranged from 16.18-30.18 kg ha⁻¹ in Year 1 and 16.81-30.25 kg ha⁻¹ in Year 2. Lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) showed the highest (30.18 and 30.25 kg ha⁻¹) P uptake, next to it L₁M_{FYM} produced the 28.13 and 27.75 kg ha⁻¹ P uptake. Then L₁M_{PM} showed (26.58 and 26.45 kg ha⁻¹) P uptake in two years respectively. The K uptake ranged from 96.21-227.51 kg ha⁻¹ in Year 1 and 38.46-119.12 kg ha⁻¹ in Year 2 where lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) produced the highest K uptake. The S uptake ranged from 11.32-21.82 kg ha⁻¹ in Year 1 and 11.23-21.70 kg ha⁻¹ in Year 2. Crop response to lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) was higher than that to lime at 1 t ha⁻¹ with FYM at 5 t ha⁻¹ (L₁M_{FYM}) in terms of S uptake (grain + straw) by the crop. The Zn uptake ranged from

0.386-0.672 kg ha⁻¹ in Year 1 and 0.383-0.667 kg ha⁻¹ in Year 2. This shows a lime and manure interaction on the Zn uptake by *T. aman* rice. Results indicate that crop response to lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) was higher than that of lime at 1 t ha⁻¹ with farmyard manure at 5 t ha⁻¹ (L₁M_{FYM}) and also L₂M_{PM} treatment. The B uptake ranged from 0.125-0.241 kg ha⁻¹ in Year 1 and 0.120-0.237 kg ha⁻¹ in Year 2. Lime at 1 t ha⁻¹ with poultry manure at 3 t ha⁻¹ (L₁M_{PM}) demonstrated that the highest B uptake (0.241 and 0.237 kg ha⁻¹), next to it L₁M_{FYM} produced B uptake of 0.214 and 0.210 kg ha⁻¹ and then L₂M_{PM} produced 0.210 and 0.207 kg ha⁻¹ B uptake in two years, respectively.

3.7. Changes in soil properties due to lime and manure application

Soil p^H tended to increase as the time advanced particularly in limed plots, as expected and obviously p^H increase was more in 2 t ha⁻¹ liming than in 1 t ha⁻¹ liming. Soil pH increased up to 12-18 months and then decreased in further time with crops in the tested cropping pattern (Appendix Table 6). At research farm, over 24 months period, soil p^H increased by 0.75 units under wheat based cropping pattern when 1 t ha⁻¹ lime was applied to the first crop. Such p^H change was 1.11 units for 2 t ha⁻¹ lime added under the cropping pattern (Fig. 4). The results support the previous findings showing that lime is effective in alleviating soil acidity [11,14,39-42]. However, addition of manure had also positive influence on p^H rise; however the soil p^H change between the two manure over the periods of observation was not consistent. Change in OM content showed a similar trend of p^H change indicating that OM content reached into plateau after 18 months of liming and/or manuring, and then decreased a to some extent after further 6 months. Such change was visible in manure treated plots. The exchangeable Ca and Mg contents increased after 6 months of liming and then decreased to stable value over the extended period. The P availability in soil increased after liming, as expected, which was related to change in soil p^H. The K and S availability remains almost unchanged over lime/manure treatments. Both Zn and B availability decreased, particularly after 12 months. However, still the micronutrient level was adequate for sustenance of normal plant growth. Manure had no remarkable influence on micronutrient availability. While SOM content increased with manure and lime addition. SOM increased little more in FYM treated plots than in PM treated plots. The exchangeable Ca content considerably increased after 6 month of liming and then decreased to an almost stable value up to 24 months of liming (Fig. 4). The P availability increased, and the Zn and B availability decreased after liming which was related to soil p^H rise induced by liming. Decreasing Zn availability with increasing soil p^H has been observed by many workers in the past [43-45].



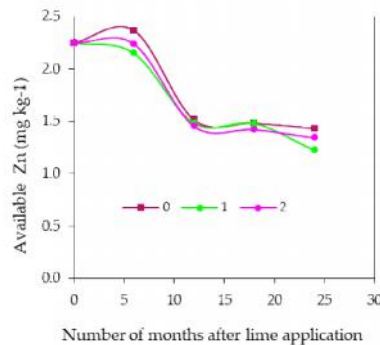


Fig. 4. Effects of lime (dolomite) rates (t ha^{-1}) on soil pH, exchangeable Ca and available Zn in the wheat-mungbean-T.aman cropping pattern

An attempt has been made to fit the grain yield versus lime rates to the quadratic equation ($y = a + bx + cx^2$) to find out the optimum lime rate for the crops (wheat) following the procedure as outlined by [37]. Rate of lime (L_y) that maximizes yield: $L_y = -b/2c$, where b and c are the estimates of the regression coefficients. The equation thus obtained for wheat was $Y = 3.75 + 1.475x - 0.609x^2$ (Fig. 5). From the equation, the L_y value is estimated as 1.2 t ha^{-1} for wheat. Thus, the estimated value of optimum dolomite application appears to be close to the value (1 t lime ha^{-1}) that obtained from statistical analysis, although there is a limitation that the equations have been made using only three rates of lime, including control.

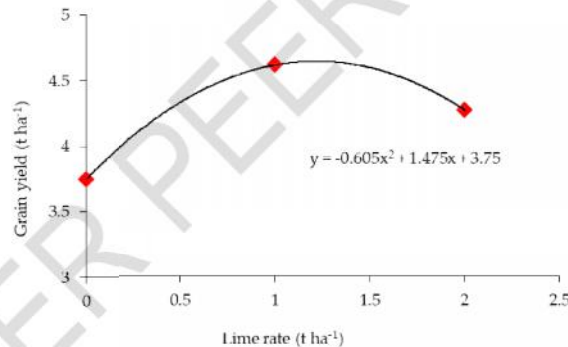


Fig. 5. Crop response curve for lime in wheat; results are the average of two study sites and consecutively of two years.

4. CONCLUSION

Lime and manure affected significantly for soil acidity and soil property amelioration and higher grain yield of wheat, mungbean and T. aman rice. Amendment of soils with dolomite @ 1 t ha^{-1} coupled with poultry manure @ 3 t ha^{-1} or FYM @ 5 t ha^{-1} would be an efficient practice for achieving sustainable soil fertility and crop yield in Old Himalayan Piedmont Plain. Application of lime once in 2-3 years and manure once a year is adequate to arrest soil fertility depletion and to enhance crop yield in piedmont soil for wheat based cropping pattern and mungbean as rotation crop. In particular, this study identified that lime and manure applications improve soil acidity and plant nutrient availability, thereby impacted on yield contributing characters of wheat, mungbean and T. aman. Consequently, crop productivity in the examined cropping pattern increased. The studies were done in the research and farmer fields; and conducted for two consecutive years to observe the integrity of results derived from set of experiments. The findings of this study would immensely contribute in soil acidity management, choice of rotational

crop and productivity of rice and wheat based cropping systems of the Old Himalayan Piedmont Plain of Bangladesh.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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