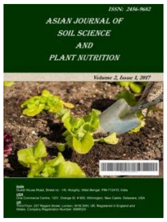

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Amendment of Acidic Soil with Lime and Manure for Enhancing Fertility, Nutrient Uptake and Yield of Wheat-Mungbean-Monsoon Rice in the Old Himalayan Piedmont Plain

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Authors' contributions

This work was carried out in collaboration between all authors. Authors BSS, MHM, MJ and MMR designed the study, performed the statistical analysis and wrote the protocol. Authors BSS and MNEAS wrote the first draft of the manuscript. Authors MNEAS and JS managed the analyses of the study. Author MNAS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Soil acidic conditions and the decline in soil fertility are among the critical factors that constraint higher crop productivity in the Old Himalayan Piedmont Plain (OHPP), Bangladesh. The study was conducted to evaluate the effect of lime and manure on soil fertility, nutrients and yields of wheat, mungbean and rice. Experiments were done at Agricultural Research Station (ARS), Bangladesh Agricultural Research Institute (BARI) farm and farmer field over two consecutive years with the cropping pattern, namely wheat-mungbean-transplanted (T.) aman rice/monsoon rice. The

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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 farmyard manure 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 pH 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 phosphorus availability increased, zinc and boron availability decreased, but the potassium and sulphur 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 plant nutrient uptake by wheat, mungbean and rice followed the trend of these crops yield increase, i.e., crops that were able to uptake more nutrients shown higher yields. The treatment combinations with 1 t ha^{-1} lime and 3 t ha^{-1} poultry manure 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 Himalayan piedmont soil of Bangladesh.

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 (Agro ecological zone, AEZ #1), among others, has moderately to strongly acid soils ranging from 4.6 to 6.5 [1]. Acid soils possess toxic concentration of Al^{3+}, Fe^{3+} and Mn^{2+}, deficient in P concentration and lower availability of bases which in turn cause decrease in crop yield. Common crops such as potato, rice, wheat, mungbean, in piedmont areas adversely being affected by soil acidity [2]. Legumes are highly affected due to soil acidity [3,4]. Soil acidity can cause by inefficient use of chemical fertilizers in intensive agricultural systems where leaching, light textured soil, higher rainfall and hot-humid climate exist. Among these causes, especially NH^{4+}-N and urea-N 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+} are important [5]. Occasionally liming is done to modify soil pH and optimize 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 soil in piedmont area 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 the piedmont area [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 pH 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 an optimum pH (preferably pH not below 4.5) for the growth of different highland and medium highland land 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]. However, intensive farming system that affecting soils have not studied based on cropping pattern explicitly. 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, in turn residue 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. 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 study involving cropping pattern over several growing seasons including residual effects of fertilizers is not studied with necessary crop and soil variables in the Piedmont area. 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 OHPP (AEZ #1) to improve soil acidic condition, fertility, plant nutrients uptake for crop productivity and yields.

2. MATERIAL AND METHODS

2.1 Study Locations, Climate and Cropping Season

The experiments were carried out at two sites in Thakurgaon Sadar Upazila, Thakurgoan 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 Cropping Pattern

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 Binadhan 7 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.

- L_0M_0 Control (no lime, no manure)
- L_0M_{PM} (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)
- L_2M_{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 [1]. 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.

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	20 cm x continuous	30 cm x continuous	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}. 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, $ZnSO_4.7H_2O$ 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 12m^2 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 (A, B, C). However, for soil samples, texture was determined by hydrometer method [37], pH was measure with 1: 2.5 soil-water ratio [38], organic matter was determined by wet digestion method [39], total N was measured by Micro-Kjeldahl method, cation exchange capacity was determined by sodium acetate saturation method [40] and available P of acidic soil was determined using method [41]. Exchangeable K, Ca and Mg was determined by method [42], available S, Zn and B was determined by using methods [43-45] respectively. For plant samples, N was measured by Micro-Kjeldahl method, P and K determined by [46], S and Zn determined by [47] and B was measured by method [45].

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) [48]. Data analysis was done by computer using MSTAT-C software [49].

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_0M_0	3.76	3.83	3.10	3.27	4.16	4.27	3.90	4.02
L_0M_{PM}	4.06	4.12	3.47	3.58	4.43	4.45	4.17	4.22
L_0M_{FYM}	4.16	4.25	3.65	3.77	4.55	4.60	4.43	4.50
L_1M_0	4.28	4.38	4.05	4.12	4.70	4.80	4.55	4.62
L_1M_{PM}	5.03	5.21	4.92	4.97	5.53	5.73	5.40	5.43
L_1M_{FYM}	4.63	4.77	4.60	4.48	5.00	5.15	4.98	5.03
L_2M_0	4.43	4.31	4.40	4.40	4.83	4.68	4.83	4.87
L_2M_{PM}	4.30	4.25	4.28	4.28	4.70	4.67	4.72	4.77
L_2M_{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 ≤ 0.01; SE (±) = Standard error of means*

3. RESULTS AND DISCUSSION

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 (Appendix Tables 7-9).

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 L_1M_{PM}. The next highest yielding treatments were L_1M_{FYM} and L_2M_0 followed by the treatments L_2M_{PM} and L_2M_{FYM}. The result indicated that the 1 t ha^{-1} lime with poultry manure (L_1M_{PM}) treatment gave better yield compared to 2 t ha^{-1}lime with poultry manure (L_2M_{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 L_1M_{PM}. The next highest yielding treatments were L_1M_{FYM}, L_2M_0, L_2M_{PM} and L_2M_{FYM}. Results indicated that the 1 t ha^{-1}lime with poultry manure at 3 t ha^{-1}(L_1M_{PM}) treatment gave better yield compared to 2 t ha^{-1}lime with poultry manure (L_2M_{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 L_1M_{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 L_1M_{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 L_1M_{FYM} treatment (5.00 and 5.15 t ha^{-1}; and 4.98 and 5.03 t ha^{-1}).

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 L_1M_{PM} treatment (100.36 and 104.13 cm and 94.26 and 98.36). The next highest plant height was observed in L_1M_{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 L_1M_{PM} which was statistically identical with L_1M_{FYM} (7.06 and 4.63) treatment. In farmer field, the maximum number of tillers plant^{-1} was observed in treatment L_1M_{PM} (4.86 and 4.96) which was statistically similar with L_1M_{FYM} and L_2M_0 treatments.

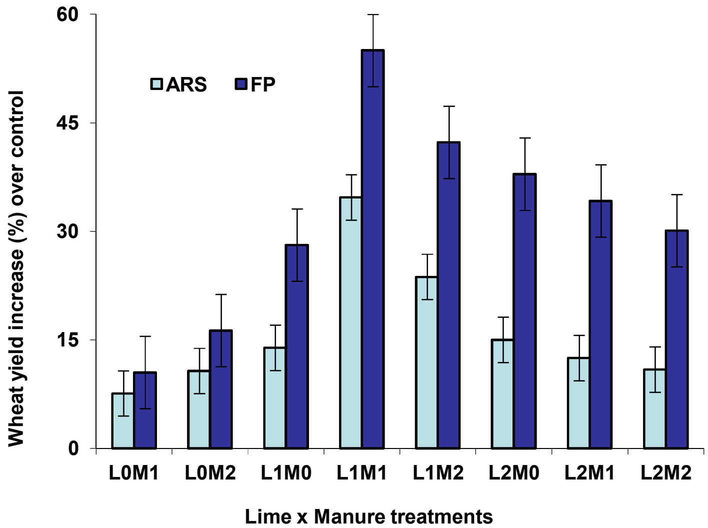

Fig. 1. Effects of lime and manure treatments on % grain yield (wheat) increase over control at ARS and farmer plot; results are the average of 2 years

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

3.1.3 Effects on wheat grains spike^{-1} and 1000- grain weight

The lime and manure interaction were 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 L_1M_{PM} which was statistically similar with L_1M_{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 L_1M_{PM} treatment in both study sites.

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 ad B uptake by wheat. Influence 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}). 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}(L_1M_{PM}) produced higher P uptake (31.15 and 31.78 kg ha^{-1}), next to it was L_1M_{FYM} (27.61 and 28.41 kg ha^{-1}); and then L_2M_{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 L_1M_{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 (L_1M_{PM}) was higher than that of lime at 1 t ha^{-1}with farmyard manure (L_1M_{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 (L_1M_{PM}) which was higher than that of lime at 1 t ha^{-1} with farmyard manure (L_1M_{FYM}) and L_2M_{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}(L_1M_{PM}) had better effect on B uptake compared to lime 1 t ha^{-1} with farmyard manure at 5 t ha^{-1}(L_1M_{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 L_1M_{PM} treatment (1.64 t ha^{-1}) which was superior over all other treatments in Year 1. In case of Year 2, the L_1M_{PM} treatment showed the highest seed yield (1.63 t ha^{-1}). In farmer field, the L_1M_{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 L_1M_{PM} treatment. The L_1M_{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 L_1M_{PM} treatment, which was superior over all other treatments in Year 1. In case of Year 2, the L_1M_{PM} treatment showed the highest stover yield 2.73 t ha^{-1}. In farmer's field, the L_1M_{PM} showed also the highest stover yield (2.65 and 2.60 t ha^{-1}).

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.

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 34.06-46.00 g in Year 1 and 34.10-46.03 g in Year 2. At farmer field, the 1000-seed weight (g) varied from 34.17-45.90 g in Year 1 and from 34.00-45.40 g in Year 2.

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_0M_0	86.40	84.70	78.43	83.06	5.56	3.66	3.43	3.46
L_0M_{PM}	91.10	89.56	81.40	86.70	5.86	3.96	3.93	3.76
L_0M_{FYM}	93.66	93.26	85.10	90.70	6.33	4.23	4.13	4.03
L_1M_0	94.83	95.93	86.23	94.40	6.40	4.40	4.30	4.33
L_1M_{PM}	100.36	104.13	94.26	98.36	7.80	5.16	4.86	4.96
L_1M_{FYM}	96.83	97.13	91.20	95.03	7.06	5.63	4.70	4.80
L_2M_0	93.40	94.60	89.53	94.06	6.80	4.50	4.60	4.66
L_2M_{PM}	95.76	94.10	87.56	92.60	6.30	4.40	4.53	4.56
L_2M_{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*

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_0M_0	38.4	31.6	28.4	29.3	43.4	38.7	35.7	38.0
L_0M_{PM}	41.5	35.1	32.5	35.1	45.8	43.0	39.1	41.6
L_0M_{FYM}	42.9	37.5	36.5	36.0	48.3	45.5	42.3	45.5
L_1M_0	48.0	38.7	40.1	39.0	49.3	48.1	47.2	47.7
L_1M_{PM}	51.5	46.6	44.3	45.2	53.0	56.1	53.2	54.6
L_1M_{FYM}	49.3	44.5	43.0	41.8	50.8	50.8	50.6	51.8
L_2M_0	47.6	42.5	41.7	40.0	49.7	50.3	51.3	51.0
L_2M_{PM}	47.4	39.1	40.9	38.7	48.5	48.8	50.9	48.9
L_2M_{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*

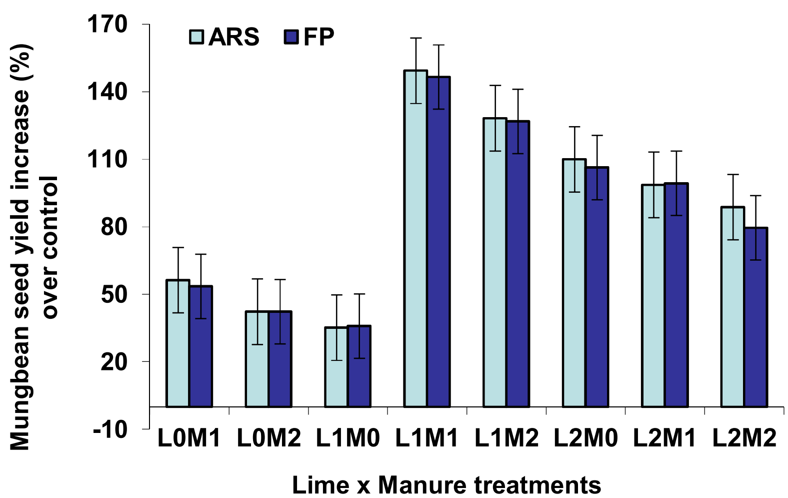

Fig. 2. Residual effects of lime and manure treatments on % seed yield (mungbean) increase over control at ARS and farmer plot; results are the average of 2 years

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

3.4 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.

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} (L_1M_{PM}) produced higher plant height compared to L_1M_{FYM} and L_2M_{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} (L_1M_{PM}) produced higher tillers.

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} (L_1M_{PM}) produced higher panicle length than L_1M_{FYM} and L_2M_{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} (L_1M_{PM}) produced higher number of grains panicle^{-1}.

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 (L_1M_{PM}) had the highest N uptake (155.37 and 153.37 kg ha^{-1}), next to it L_1M_{FYM} produced N uptake of 143.93 and 141.45 kg ha^{-1}in two subsequent years. Then L_1M_{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}(L_1M_{PM}) showed the highest (30.18 and 30.25 kg ha^{-1}) P uptake, next to it L_1M_{FYM} produced the 28.13 and 27.75 kg ha^{-1}P uptake. Then L_1M_{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}(L_1M_{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}(L_1M_{PM}) was higher than that to lime at 1 t ha^{-1}with FYM at 5 t ha^{-1}(L_1M_{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}(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 also L_2M_{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} (L_1M_{PM}) demonstrated that the highest B uptake (0.241 and 0.237 kg ha^{-1}), next to it L_1M_{FYM} produced B uptake of 0.214 and 0.210 kg ha^{-1}and then L_2M_{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 pH tended to increase as the time advanced particularly in limed plots, as expected and obviously pH increase was more in 2 t ha^{-1} liming than in 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 pH increased by 0.75 units under wheat based cropping pattern when 1 t ha^{-1}lime was applied to the first crop. Such pH 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 [11,14,50-53]. However, addition of manure had also positive influence on pH rise; however, the soil pH change between the two manure over the periods of observation was not consistent. Change in OM content showed a similar trend of pH 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

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_0M_0	0.70	0.72	0.72	0.70	1.45	1.47	1.42	1.38
L_0M_{PM}	1.10	1.12	1.10	1.08	1.90	1.92	1.87	1.83
L_0M_{FYM}	1.00	1.02	1.02	1.00	1.80	1.82	1.77	1.73
L_1M_0	0.95	0.97	0.95	0.98	1.70	1.72	1.67	1.62
L_1M_{PM}	1.76	1.78	1.77	1.73	2.72	2.73	2.65	2.60
L_1M_{FYM}	1.63	1.61	1.62	1.60	2.50	2.52	2.47	2.43
L_2M_0	1.48	1.50	1.48	1.45	2.47	2.48	2.38	2.35
L_2M_{PM}	1.40	1.42	1.43	1.40	2.23	2.25	2.20	2.15
L_2M_{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; ** $P \leq 0.01$; SE (±) = Standard error of means.*

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_0M_0	8.30	8.43	8.73	8.60	8.03	8.10	7.97	7.83
L_0M_{PM}	10.93	11.07	10.83	10.50	9.70	9.77	9.57	9.43
L_0M_{FYM}	10.80	10.93	10.80	10.63	9.10	9.17	9.13	9.00
L_1M_0	9.26	9.40	9.33	9.13	9.00	9.06	8.93	8.73
L_1M_{PM}	18.13	18.27	17.67	17.33	12.33	12.40	12.13	11.93
L_1M_{FYM}	15.06	15.20	14.90	14.63	11.30	11.37	11.27	11.07
L_2M_0	11.20	11.33	11.13	10.93	9.70	9.77	9.33	9.13
L_2M_{PM}	12.96	13.10	12.67	12.47	10.66	10.77	10.23	10.07
L_2M_{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 (±)	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 ≤ 0.01; SE (±) = Standard error of means.*

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

Lime × 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 (±)	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 ≤ 0.01; SE (±) = Standard error of means.*

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.*

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_0M_0	84.3	83.5	79.6	77.9	8.33	8.06	7.60	8.13
L_0M_{PM}	90.7	91.4	83.9	83.5	8.80	8.73	8.37	8.93
L_0M_{FYM}	93.1	92.4	88.1	87.9	9.80	9.67	9.33	9.46
L_1M_0	95.9	95.4	92.3	92.2	10.40	10.33	9.60	10.03
L_1M_{PM}	102.0	101.5	100.7	100.3	12.06	11.93	11.80	11.93
L_1M_{FYM}	98.4	97.6	97.3	94.8	11.50	11.37	10.33	10.83
L_2M_0	96.1	95.9	94.8	92.7	10.93	10.87	9.60	10.40
L_2M_{PM}	95.6	95.2	93.7	92.1	10.83	10.70	8.93	10.13
L_2M_{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.*

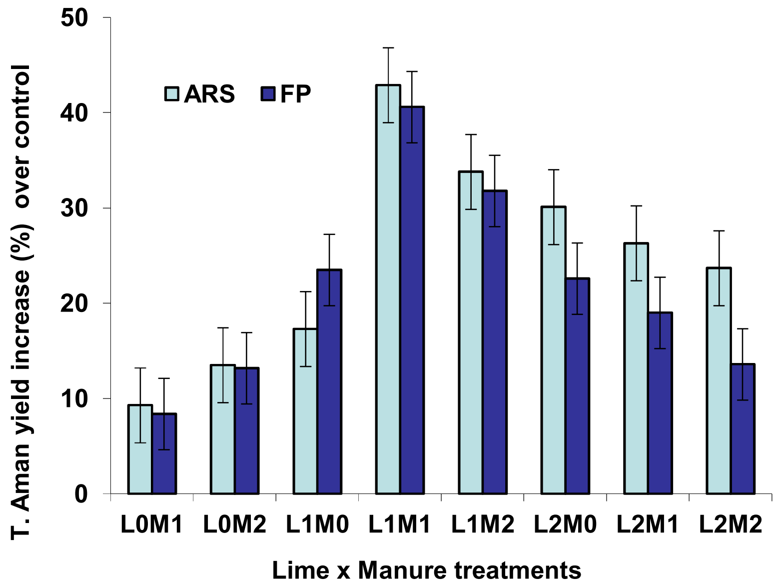

Fig. 3. Residual effects of lime and manure treatments on % grain yield (T. aman) increase over control at ARS and farmer's plot in Thakurgaon; results are the average of 2 years

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

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 pH. 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 pH rise induced by liming. Decreasing Zn availability with increasing soil pH has been observed by many workers in the past [54-56]. However, plant nutrients uptake and changes in availability due to liming and manure has been studied by several authors [13,14,26,53,54]. The findings of this study are in agreement with the fact that soil amendment (namely lime and manure) can optimize pH for plant growth, productivity and higher return through yield increase as well as soil fertility ensured under wheat and rice based cropping system in the Piedmont soils of Bangladesh.

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_0M_0	19.9	19.7	19.0	20.1	76.8	76.3	79.2	80.1
L_0M_{PM}	22.1	21.9	21.1	21.7	83.3	82.9	87.0	88.7
L_0M_{FYM}	22.9	22.8	20.9	22.4	88.9	88.5	90.7	95.3
L_1M_0	23.1	22.9	21.7	24.4	94.4	94.1	95.8	98.9
L_1M_{PM}	25.1	24.9	24.3	27.3	109.7	109.2	106.5	110.1
L_1M_{FYM}	23.9	23.7	22.9	25.9	100.1	99.7	98.4	99.3
L_2M_0	23.5	23.2	22.1	25.7	97.4	97.1	95.4	96.4
L_2M_{PM}	23.0	22.9	21.7	24.7	95.6	95.5	92.8	95.4
L_2M_{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*

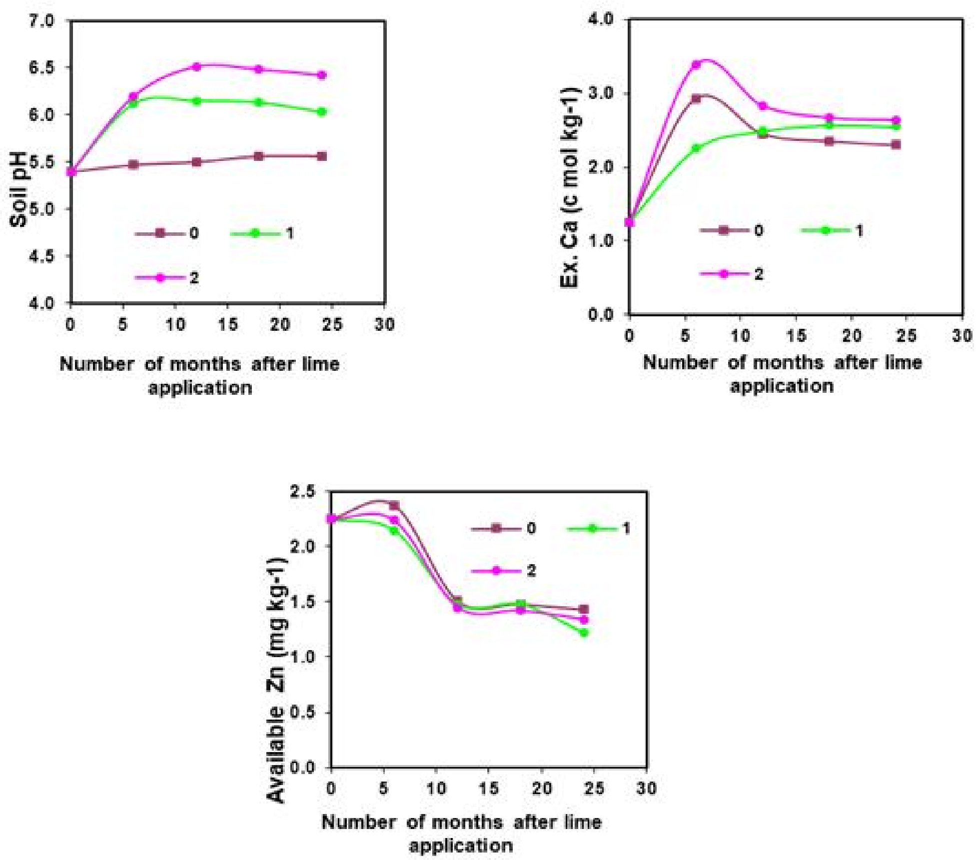

Fig. 4. Effects of lime (dolomite) rates (t ha^{-1}) on soil pH, exchangeable Ca and available Zn in the wheat-mungbean-T.aman cropping pattern

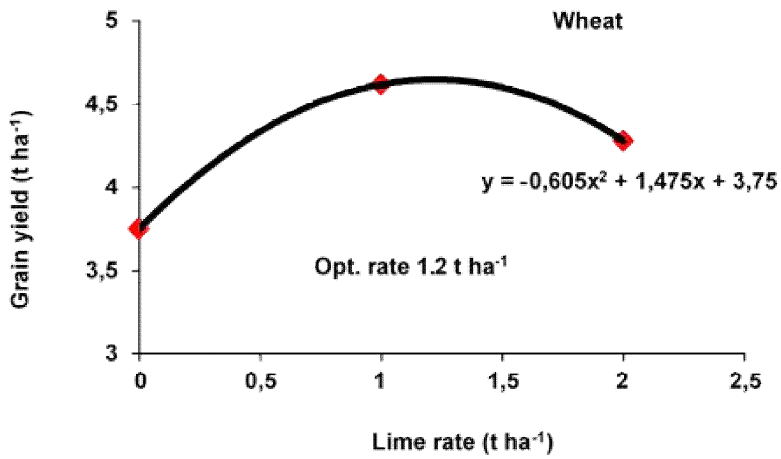

Fig. 5. Crop response curve for lime in wheat; results are the average of two study sites and consecutively of two years

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 [48]. Rate of lime (Ly) that maximizes yield: Ly = -b/2c, where b and c are the estimates of the regression coefficients. The equation thus obtained for wheat was $Y = 3.75 + 1.475x – 0.609 x^2$ (Fig. 5). From the equation, the Ly value is estimated as 1.2 t $ha^{-1}$for wheat. Thus, the estimated value of optimum dololime 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.

4. CONCLUSION

Lime and manure affected significantly for soil acidity and nutrients amelioration, and higher grain yield of wheat, mungbean and T. aman rice. Amendment of soils with 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 achieving sustainable soil fertility and crop yield in the 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 a 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 was found higher. 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 and fertility management, choice of rotational crop and productivity of rice and wheat based cropping systems in the Old Himalayan Piedmont Plain of Bangladesh.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Appendix tables

Table 1A. Methods of soil analysis for different soil parameters

Soil properties	Methods
Soil texture	Hydrometer method. The textural class was determined using Marshall's Triangular Coordinates by USDA system.
pH	Glass-electrode pH meter with 1: 2.5 soil-water ratio.
Organic matter	Wet digestion method. The organic matter was oxidized by 1N potassium dichromate and the amount of organic carbon in the aliquot was determined by titration against 0.5 N ferrous sulphate heptahydrate solution in presence of 0.025M O-phenanthroline ferrous complex.
Total N	Micro-Kjeldahl method. Soil sample was digested with conc. H_2SO_4 in presence of catalyst mixture (K_2SO_4:$CuSO_4$: Se = 10: 1: 0.1). Nitrogen in the digest was measured by distillation with 10N NaOH followed by titration of the distillate trapped in H_3BO_3 indicator solution with 0.01 N H_2SO_4.
CEC	Sodium acetate saturation method. Soil sample was shaken with an excess of 1M sodium acetate solution (1:10 soil-extractant ratio) to remove the exchangeable cations and saturate the exchange sites with sodium. The replaced Na was determined by flame photometer.
Available P	P was extracted by 0.03N NH_4F and 0.025N HCl and determined colorimetrically using molybdate blue ascorbic acid method.
Exchangeable K, Ca and Mg	Elements were extracted by repeated shaking and centrifugation of the soil with neutral 1M NH_4OAc solution followed by decantation. The K concentration in the extract was determined by flame photometer and Ca & Mg concentrations by atomic absorption spectrophotometer (AAS), as outlined by [7].
Available S	S was extracted by 500 ppm P solution from Ca $(H_2PO_4)_2.H_2O$ and determined by turbidity method using $BaCl_2$.
Available Zn	Elements were extracted by 0.005 M DTPA solution and the determination directly by Atomic Absorption Spectrophotometer.
Available B	B was extracted by mono-calcium bi-phosphate method and the determination by spectrophotometer following azomethine-H method.

Table 1B. Methods of plant analysis for N, P, K, S, Zn and B

Elements	Methods
N	Micro-Kjeldahl method. The plant sample was digested with conc. H_2SO_4 in presence of catalyst mixture (K_2SO_4: $CuSO_4$: Se = 10: 1: 0.1). Nitrogen in the digest was estimated by distillation with 10N NaOH followed by titration of the distillate trapped in H_3BO_3 indicator solution with 0.01 N H_2SO_4.
P	The plant sample was digested with di-acid mixture (HNO_3-$HClO_4$) and this digest was used to determine P, K, S and Zn contents. The P was determined colorimetrically using molybdovanadate solution yellow colour method.
K	The concentration of K in the acid digest was determined directly by flame photometer.
S	The S concentration in the acid digest was determined by turbidity method using $BaCl_2$.
Zn	The concentration of Zn in the acid digest was determined directly by atomic adsorption spectrophotometer.
B	The B concentration in the acid digest was determined by spectrophotometer following azomethine-H method.

Table 2A. Textural class, CEC and pH of the initial soils

Site No.	Experimental site	Mechanical composition			Textural class	CEC[a] (meq/100gm soil)	pH
		% sand	% silt	% clay			
Wheat –Mungbean- T. Aman rice pattern							
1	ARS farm, BARI	67	18	15	Sandy loam	29.6, H	5.4
2	Farmer's field Thakurgaon	48	33	19	Silt loam	28.8, H	4.8

[a] H= High status, VH=Very high status

Table 2B. OM, Total N, available P and S and exchangeable K, Ca and Mg status of the initial soils

Site #	OM %	Total N (%)	Available status (mg kg^{-1})		Exchangeable status (c mol kg^{-1})		
			P	S	K	Ca	Mg
Wheat – Mungbean - T. Aman rice pattern							
1	1.03	0.05	76.07	14.11	0.12	1.26	0.80
ARS Farm	L	VL	VH	L	L	VL	M
2	2.41	0.12	96.25	14.0	0.07	1.92	0.80
FF	M	L	VH	L	VL	L	M

ARS = Agricultural Research Station, FF = Farmer's Field; VL= Very Low, L= Low, M= Medium, H= High, VH= Very High

Table 2C. Available B, Zn, Cu, Fe and Mn status of the initial soils under different cropping patterns

Site #	Available status (mg kg^{-1})	
	B	Zn
Wheat – Mungbean - T. Aman rice pattern		
1	0.30	2.25
ARS Farm	L	VH
2	0.40	1.45
FF	M	Opt.

Table 3. Influence of lime × manure interaction on nutrient uptake (kg ha^{-1}) by wheat (grain and straw) in the wheat –mungbean-T. aman rice cropping pattern at ARS (BARI) farm, Thakurgaon

Lime × Manure interaction	Year 1						Year 2					
	N	P	K	S	Zn	B	N	P	K	S	Zn	B
L_0M_0	59.42	17.47	73.43	14.73	0.267	0.139	59.66	17.49	75.77	14.60	0.275	0.151
L_0M_{PM}	75.42	20.99	83.38	17.24	0.321	0.171	75.40	21.12	84.99	16.79	0.323	0.191
L_0M_{FYM}	73.94	21.63	87.67	17.21	0.326	0.174	74.53	21.71	87.34	16.98	0.332	0.197
L_1M_0	79.84	24.76	99.20	18.74	0.302	0.163	80.87	24.94	100.45	18.57	0.310	0.180
L_1M_{PM}	106.99	31.15	123.23	24.37	0.386	0.216	109.53	31.78	126.49	24.75	0.398	0.251
L_1M_{FYM}	92.41	27.61	111.29	21.76	0.346	0.194	94.54	28.41	112.12	22.08	0.356	0.219
L_2M_0	87.36	26.90	104.89	19.86	0.317	0.170	83.71	26.02	100.35	18.93	0.309	0.178
L_2M_{PM}	90.99	27.02	105.08	20.84	0.329	0.185	88.63	26.24	101.80	20.40	0.324	0.208
L_2M_{FYM}	86.42	25.91	101.73	19.95	0.316	0.180	86.23	25.77	101.37	19.75	0.320	0.200
CV (%)	2.52	2.55	2.20	2.86	1.98	2.42	1.99	2.59	2.19	2.89	1.80	2.74
Sig. level	**	**	**	**	**	**	**	**	**	**	**	**
S.E. (±)	1.2166	0.3660	1.2577	0.3206	0.0369	0.0247	0.9617	0.3715	1.2498	0.3204	0.0340	0.0312

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

Table 4. Residual effects of lime × manure interaction on nutrient uptake (kg ha^{-1}) by mungbean (seed and stover) in the wheat-mungbean-T. aman rice cropping pattern at ARS (BARI) farm, Thakurgaon

Lime × manure interaction	Year 1						Year 2					
	N	P	K	S	Zn	B	N	P	K	S	Zn	B
L_0M_0	34.56	6.09	13.48	4.61	0.059	0.068	35.01	6.10	10.53	4.66	0.079	0.067
L_0M_{PM}	57.94	10.31	22.13	7.93	0.107	0.110	58.32	10.24	26.45	7.90	0.102	0.106
L_0M_{FYM}	52.32	9.25	20.03	6.81	0.098	0.101	52.48	9.18	29.27	6.87	0.099	0.099
L_1M_0	52.26	10.04	20.09	7.54	0.099	0.100	52.81	10.11	27.88	7.50	0.131	0.097
L_1M_{PM}	100.71	19.26	39.14	13.92	0.193	0.191	100.83	19.19	39.53	13.92	0.178	0.145
L_1M_{FYM}	90.84	17.21	35.04	12.50	0.171	0.172	91.04	17.08	46.39	12.48	0.159	0.168
L_2M_0	79.80	15.40	31.38	11.66	0.149	0.145	79.55	15.38	43.69	11.62	0.147	0.142
L_2M_{PM}	80.35	15.56	31.20	11.19	0.155	0.154	80.85	15.57	39.76	11.14	0.148	0.149
L_2M_{FYM}	76.25	14.65	29.00	10.63	0.145	0.147	76.51	14.63	38.05	10.64	0.086	0.144
CV (%)	5.87	5.90	6.00	5.79	5.87	5.43	5.66	5.99	8.31	5.93	7.79	8.57
Sig. level	**	**	**	**	**	**	**	**	**	**	**	**
S.E. (±)	2.3545	0.4457	0.9300	0.3226	0.0443	0.0414	2.2772	0.4511	4.3780	0.3298	0.0490	0.0620

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

Table 5. Residual effects of lime × manure interaction on nutrient uptake (kg ha^{-1}) by T. aman rice (grain and straw) in the wheat-mungbean-T. aman rice pattern at ARS (BARI) farm, Thakurgaon

Lime × manure interaction	Year 1						Year 2					
	N	P	K	S	Zn	B	N	P	K	S	Zn	B
L_0M_0	76.58	16.18	96.21	11.32	0.385	0.125	75.97	16.81	78.46	11.23	0.383	0.120
L_0M_{PM}	102.47	20.18	154.48	14.67	0.462	0.167	101.91	20.39	116.28	14.62	0.461	0.164
L_0M_{FYM}	103.48	20.07	155.81	14.65	0.458	0.164	101.92	20.62	154.46	14.75	0.458	0.163
L_1M_0	114.89	22.27	172.17	16.39	0.499	0.174	113.45	22.58	162.86	16.40	0.450	0.173
L_1M_{PM}	155.37	30.18	227.51	21.82	0.673	0.241	153.37	30.25	192.33	21.70	0.667	0.237
L_1M_{FYM}	143.93	28.13	214.61	20.15	0.622	0.214	141.45	27.75	219.12	19.87	0.611	0.210
L_2M_0	128.47	26.48	199.00	18.63	0.570	0.198	127.01	25.61	205.23	18.30	0.563	0.195
L_2M_{PM}	136.47	26.58	199.91	19.15	0.590	0.210	133.09	26.45	196.79	19.07	0.586	0.207
L_2M_{FYM}	130.41	26.41	192.70	18.37	0.557	0.191	127.20	25.25	199.78	18.15	0.550	0.188
CV (%)	3.52	3.19	3.66	3.79	3.73	3.93	5.20	4.59	4.37	4.83	4.64	4.55
Sig. level	**	**	**	**	**	**	**	**	**	**	**	**
S.E. (±)	2.4654	0.4430	3.7819	0.3770	0.1154	0.0425	3.5892	0.6347	3.6873	0.4775	0.1423	0.0484

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

Table 6. Changes in soil properties as influenced by lime and manure in the wheat-mungbean-T. aman rice cropping pattern at ARS, BARI farm, Thakurgaon

Treatments	pH	Organic matter (%)	Available P (mg kg^{-1})	Exchangeable K (c mol kg^{-1})	Exchangeable Ca (c mol kg^{-1})	Available Mg (mg kg^{-1})	Available S (mg kg^{-1})	Available Zn (mg kg^{-1})	Available B (mg kg^{-1})
Initial soil	5.40	1.03	38.03	0.12	1.26	0.80	14.11	2.25	0.30

Treatments	pH				Organic matter (%)				Available P (mg kg^{-1})			
	After 6 months	After 12 months	After 18 months	After 24 months	After 6 months	After 12 months	After 18 months	After 24 months	After 6 months	After 12 months	After 18 months	After 24 months
T_1: L_0M_0	5.47	5.50	5.56	5.56	1.22	1.43	1.45	1.46	38.35	39.20	38.17	32.65
T_2: L_0M_{PM}	5.47	5.70	5.76	5.66	1.56	1.43	1.65	1.61	45.10	47.55	42.70	32.75
T_3: L_0M_{FYM}	5.91	5.70	5.77	5.67	1.65	1.32	1.68	1.60	40.00	47.70	43.30	33.30
T_4: L_1M_0	6.12	6.15	6.13	6.03	1.29	1.27	1.50	1.48	50.50	48.50	44.05	34.10
T_5: L_1M_{PM}	6.48	6.28	6.25	6.23	1.51	1.75	1.70	1.67	50.40	47.85	22.70	37.70
T_6: L_1M_{FYM}	6.30	6.19	6.19	6.09	1.77	1.57	1.65	1.63	50.49	47.40	44.25	38.75
T_7: L_2M_0	6.20	6.51	6.48	6.42	1.28	1.53	1.62	1.60	49.60	48.22	42.60	38.10
T_8: L_2 M_{PM}	6.02	6.54	6.37	6.27	1.53	1.47	1.71	1.69	49.29	46.35	39.60	39.10
T_9: L_2M_{FYM}	6.41	6.59	6.26	6.16	1.47	1.50	1.70	1.68	50.60	48.80	39.50	39.60

Treatments	Exchangeable K (c mol kg^{-1})				Exchangeable Ca (c mol kg^{-1})				Available Mg (mg kg^{-1})			
	After 6 Months	**After 12 Months**	**After 18 Months**	**After 24 Months**	**After 6 Months**	**After 12 Months**	**After 18 Months**	**After 24 Months**	**After 6 Months**	**After 12 Months**	**After 18 Months**	**After 24 Months**
T_1: L_0M_0	0.14	0.12	0.11	0.11	2.93	2.45	2.35	2.30	0.67	0.39	0.35	0.32
T_2: L_0M_{PM}	0.14	0.14	0.13	0.10	3.08	2.56	2.56	2.60	0.89	0.58	0.53	0.42
T_3: L_0M_{FYM}	0.17	0.13	0.12	0.11	3.23	2.37	2.45	2.44	0.94	0.47	0.44	0.33
T_4: L_1M_0	0.16	0.14	0.12	0.11	2.25	2.49	2.57	2.55	0.41	0.78	0.75	0.50
T_5: L_1M_{PM}	0.16	0.14	0.11	0.11	3.07	2.74	2.61	2.60	0.93	0.81	0.78	0.51
T_6: L_1M_{FYM}	0.22	0.15	0.13	0.12	3.01	2.71	2.54	2.52	0.61	0.91	0.88	0.45
T_7: L_2M_0	0.22	0.14	0.12	0.11	3.39	2.83	2.67	2.64	1.15	1.13	1.10	0.75
T_8: L_2 M_{PM}	0.15	0.14	0.12	0.12	2.95	2.76	2.67	2.65	0.68	1.04	1.00	0.56
T_9: L_2M_{FYM}	0.15	0.14	0.12	0.12	3.01	2.61	2.72	2.72	0.91	1.03	0.90	0.73

Treatments	Available S (mg kg^{-1})				Available Zn (mg kg^{-1})				Available B (mg kg^{-1})			
	After 6 Months	**After 12 Months**	**After 18 Months**	**After 24 Months**	**After 6 Months**	**After 12 Months**	**After 18 Months**	**After 24 Months**	**After 6 Months**	**After 12 Months**	**After 18 Months**	**After 24 Months**
T_1: L_0M_0	14.27	14.00	13.27	10.18	2.37	1.51	1.48	1.43	0.52	0.31	0.30	0.31
T_2: L_0M_{PM}	14.53	14.63	13.53	11.16	2.29	1.57	1.47	1.39	0.60	0.29	0.31	0.30
T_3: L_0M_{FYM}	13.43	14.09	13.53	13.51	2.42	1.50	1.50	1.41	0.61	0.32	0.31	0.29
T_4: L_1M_0	15.54	14.78	15.00	13.34	2.15	1.48	1.48	1.22	0.61	0.30	0.30	0.29
T_5: L_1M_{PM}	14.50	15.23	14.30	13.94	2.17	1.27	1.25	1.24	0.73	0.34	0.33	0.31
T_6: L_1M_{FYM}	13.50	15.01	13.01	12.02	2.25	1.44	1.40	1.25	0.49	0.31	0.32	0.30
T_7: L_2M_0	15.36	14.99	15.06	13.54	2.24	1.45	1.42	1.34	0.55	0.29	0.28	0.30
T_8: L_2 M_{PM}	14.00	14.82	14.50	13.56	2.56	1.49	1.47	1.45	0.46	0.31	0.32	0.30
T_9: L_2M_{FYM}	14.92	14.59	14.62	13.57	2.84	1.27	1.25	1.22	0.47	0.30	0.31	0.30

L means lime, PM means poultry manure, FYM means farmyard manure.

Table 7. Nutrient concentration of wheat as affected by lime × manure interaction in the wheat–mungbean–T. aman rice pattern at ARS (BARI) farm, Thakurgaon

Treatments	Nitrogen				Phosphorus				Potassium			
	Grain N (%)		**Straw N (%)**		**Grain P (%)**		**Straw P (%)**		**Grain K (%)**		**Straw K (%)**	
	2009-10	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**	**2009-10**	**2010-11**
L_0M_0	1.303	1.290	0.257	0.240	0.367	0.363	0.907	0.837	0.467	0.457	1.377	1.365
L_0M_{PM}	1.530	1.513	0.300	0.293	0.417	0.413	0.920	0.920	0.493	0.493	1.430	1.453
L_0M_{FYM}	1.457	1.443	0.293	0.287	0.420	0.413	0.913	0.900	0.503	0.500	1.467	1.437
L_1M_0	1.517	1.510	0.313	0.307	0.477	0.467	0.927	0.937	0.510	0.500	1.647	1.637
L_1M_{PM}	1.753	1.747	0.340	0.323	0.513	0.503	0.963	0.970	0.517	0.507	1.758	1.747

Treatments	Nitrogen				Phosphorus				Potassium			
	Grain N (%)		Straw N (%)		Grain P (%)		Straw P (%)		Grain K (%)		Straw K (%)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
L_1M_{FYM}	1.647	1.640	0.323	0.317	0.493	0.493	0.953	0.947	0.510	0.500	1.753	1.713
L_2M_0	1.627	1.617	0.317	0.300	0.507	0.503	0.923	0.923	0.503	0.497	1.710	1.687
L_2 M_{PM}	1.733	1.730	0.350	0.323	0.523	0.513	0.960	0.947	0.523	0.513	1.757	1.713
L_2M_{FYM}	1.70	1.700	0.327	0.310	0.513	0.507	0.947	0.940	0.517	0.507	1.740	1.730
CV (%)	1.61	1.53	2.49	3.09	1.44	1.21	0.95	1.34	1.33	1.51	0.98	1.79
Sig. Level	**	**	*	**	**	**	NS	**	**	**	**	NS
S.E. (±)	0.0560	0.0481	0.0451	0.0536	0.0391	0.0324	0.0512	0.0714	0.0389	0.0251	0.0922	0.0166

Treatments	Sulphur				Zinc				Boron			
	Grain S (%)		Straw S (%)		Grain Zn (µg g^{-1})		Straw Zn (µg g^{-1})		Grain B (µg g^{-1})		Straw B (µg g^{-1})	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
L_0M_0	0.217	0.207	0.162	0.156	51.07	50.90	18.57	18.67	17.90	17.90	17.77	19.33
L_0M_{PM}	0.230	0.217	0.178	0.177	56.77	56.50	20.53	20.40	20.83	20.33	19.43	24.17
L_0M_{FYM}	0.223	0.210	0.174	0.175	56.27	56.13	20.13	20.30	20.57	20.40	19.33	24.00
L_1M_0	0.237	0.227	0.172	0.180	49.33	49.13	19.47	19.77	18.10	18.13	18.13	20.93
L_1M_{PM}	0.267	0.260	0.198	0.195	51.53	51.37	22.90	22.77	22.00	21.67	19.10	24.10
L_1M_{FYM}	0.260	0.253	0.194	0.194	51.03	51.00	22.00	21.83	21.50	21.33	18.93	22.77
L_2M_0	0.247	0.240	0.185	0.183	50.00	50.00	19.87	20.03	18.50	18.33	18.17	21.10
L_2 M_{PM}	0.270	0.267	0.197	0.194	51.53	51.37	22.87	22.67	22.10	21.93	19.10	24.67
L_2M_{FYM}	0.263	0.257	0.193	0.192	51.23	51.17	22.00	21.50	21.77	21.63	19.17	23.43
CV (%)	2.82	3.24	4.64	1.63	1.72	1.68	1.93	1.69	2.47	1.88	2.91	2.91
Sig. Level	NS	NS	NS	NS	**	**	NS	*	NS	NS	NS	*
S.E. (±)	0.0401	0.0444	0.0492	0.0172	0.2161	0.2044	0.2331	0.2040	0.2907	0.2194	0.3156	0.3812

Table 8. Nutrient concentration of mungbean as affected by lime and manure interaction in the wheat–mungbean–T. aman rice pattern at ARS (BARI) farm, Thakurgaon

Treatments	Nitrogen				Phosphorus				Potassium			
	Seed N (%)		Stover N (%)		Seed P (%)		Stover P (%)		Seed K (%)		Stover K (%)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
L_0M_0	2.619	2.597	1.119	1.118	0.422	0.412	0.216	0.215	1.477	1.467	2.179	2.177
L_0M_{PM}	2.910	2.886	1.365	1.362	0.462	0.448	0.275	0.273	1.536	1.533	2.270	2.267
L_0M_{FYM}	2.833	2.787	1.332	1.330	0.452	0.438	0.263	0.260	1.530	1.526	2.259	2.257
L_1M_0	2.920	2.907	1.443	1.440	0.528	0.525	0.296	0.293	1.586	1.583	2.362	2.361
L_1M_{PM}	3.327	3.293	1.543	1.540	0.582	0.572	0.331	0.329	1.707	1.695	2.466	2.465

Treatments	Nitrogen				Phosphorus				Potassium			
	Seed N (%)		Stover N (%)		Seed P (%)		Stover P (%)		Seed K (%)		Stover K (%)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
L_1M_{FYM}	3.225	3.192	1.528	1.525	0.572	0.563	0.315	0.310	1.663	1.653	2.432	2.435
L_2M_0	2.990	2.937	1.436	1.431	0.541	0.538	0.299	0.294	1.618	1.616	2.327	2.330
L_2 M_{PM}	3.280	3.263	1.541	1.538	0.583	0.576	0.331	0.329	1.700	1.695	2.423	2.420
L_2M_{FYM}	2.979	3.158	1.530	1.528	0.575	0.565	0.318	0.315	1.650	1.640	2.411	2.409
CV (%)	3.81	1.07	1.46	1.35	2.30	1.77	1.04	1.87	1.70	1.60	1.48	1.12
Sig. Level	**	NS	**	**	NS	NS	**	**	**	**	**	**
S.E. (±)	0.6618	0.0185	0.0377	0.0287	0.0697	0.0527	0.1767	0.1459	0.0650	0.0553	0.0137	0.0167

Treatments	Sulphur				Zinc				Boron			
	Seed S (%)		Stover S (%)		Seed Zn ($\mu g\ g^{-1}$)		Stover Zn ($\mu g\ g^{-1}$)		Seed B ($\mu g\ g^{-1}$)		Stover B ($\mu g\ g^{-1}$)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
L_0M_0	0.191	0.190	0.226	0.225	32.93	32.80	24.97	24.80	28.07	27.93	33.73	33.60
L_0M_{PM}	0.225	0.220	0.287	0.284	37.17	36.93	34.97	34.83	32.05	31.93	39.33	39.20
L_0M_{FYM}	0.210	0.210	0.262	0.260	36.50	36.40	34.33	34.20	31.73	31.67	38.60	38.50
L_1M_0	0.245	0.240	0.306	0.302	37.20	37.13	37.97	37.80	32.17	31.93	40.97	40.50
L_1M_{PM}	0.280	0.278	0.330	0.328	46.07	45.93	41.20	40.97	36.57	36.37	46.53	46.30
L_1M_{FYM}	0.270	0.267	0.323	0.321	45.77	45.70	38.33	38.20	36.00	35.90	45.27	45.07
L_2M_0	0.260	0.253	0.316	0.315	37.97	37.83	37.37	37.23	32.37	32.10	39.23	39.13
L_2 M_{PM}	0.276	0.267	0.328	0.327	45.90	45.67	40.77	40.60	36.80	36.60	45.67	45.47
L_2M_{FYM}	0.271	0.269	0.319	0.316	45.17	45.07	38.70	38.50	36.03	35.92	45.13	45.07
CV (%)	1.40	2.00	1.29	1.15	1.62	1.42	1.89	1.66	1.07	1.77	1.81	1.69
Sig. Level	**	**	**	**	**	**	**	**	NS	NS	*	**
S.E. (±)	0.2008	0.2808	0.2228	0.1970	0.1440	0.0937	0.1886	0.1375	0.2070	0.1493	0.1938	0.1655

Table 9. Nutrient concentration of T Aman rice as affected by lime × manure interaction in the wheat–mungbean–T. aman rice pattern at ARS (BARI) farm, Thakurgaon

Treatments	Nitrogen				Phosphorus				Potassium			
	Grain N (%)		Straw N (%)		Grain P (%)		Straw P (%)		Grain K (%)		Straw K (%)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
L_0M_0	1.250	1.248	0.457	0.460	0.276	0.273	0.103	0.104	0.228	0.226	1.454	1.456
L_0M_{PM}	1.375	1.370	0.663	0.665	0.288	0.285	0.127	0.126	0.276	0.274	2.182	2.175
L_0M_{FYM}	1.355	1.350	0.640	0.625	0.285	0.281	0.122	0.121	0.260	0.258	2.152	2.147
L_1M_0	1.425	1.417	0.724	0.715	0.300	0.297	0.133	0.132	0.336	0.330	2.320	2.317
L_1M_{PM}	1.523	1.520	0.817	0.777	0.330	0.327	0.143	0.142	0.369	0.370	2.427	2.425

Treatments	Nitrogen				Phosphorus				Potassium			
	Grain N (%)		Straw N (%)		Grain P (%)		Straw P (%)		Grain K (%)		Straw K (%)	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
L_1M_{FYM}	1.503	1.497	0.793	0.789	0.323	0.318	0.140	0.139	0.358	0.355	2.397	2.385
L_2M_0	1.424	1.421	0.713	0.715	0.310	0.310	0.131	0.130	0.344	0.340	2.335	2.325
L_2 M_{PM}	1.520	1.518	0.809	0.774	0.328	0.323	0.141	0.140	0.365	0.362	2.413	2.415
L_2M_{FYM}	1.502	1.497	0.775	0.762	0.320	0.317	0.139	0.138	0.356	0.350	2.390	2.385
CV (%)	1.60	1.41	1.45	4.15	1.83	1.12	1.88	1.82	1.17	1.05	1.36	1.30
Sig. Level	*	**	**	**	**	**	**	**	**	**	**	**
S.E. (±)	0.0495	0.0340	0.5964	0.1671	0.1478	0.1954	0.0663	0.0619	0.2171	0.1921	0.0459	0.0383

Treatments	Sulphur				Zinc				Boron			
	Grain S (%)		Straw S (%)		Grain Zn (µg g^{-1})		Straw Zn (µg g^{-1})		Grain B (µg g^{-1})		Straw B (µg g^{-1})	
	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11	2009-10	2010-11
L_0M_0	0.120	0.119	0.110	0.111	22.40	22.30	49.63	49.83	11.30	11.20	13.40	12.87
L_0M_{PM}	0.138	0.136	0.134	0.135	24.50	24.50	54.70	54.60	14.33	14.20	16.17	15.93
L_0M_{FYM}	0.133	0.132	0.130	0.132	23.30	23.17	52.93	52.80	13.20	13.10	15.70	15.60
L_1M_0	0.144	0.143	0.144	0.145	25.50	25.40	56.37	56.27	13.83	13.70	16.30	16.20
L_1M_{PM}	0.156	0.155	0.153	0.154	28.60	28.50	60.07	59.93	15.70	15.60	17.93	17.80
L_1M_{FYM}	0.153	0.152	0.148	0.149	27.13	27.07	58.70	58.50	15.30	15.20	16.40	16.30
L_2M_0	0.148	0.147	0.142	0.141	25.77	25.70	56.40	56.30	14.07	14.07	16.20	16.10
L_2 M_{PM}	0.155	0.154	0.152	0.153	28.20	28.07	59.80	59.70	15.50	15.40	17.60	17.50
L_2M_{FYM}	0.152	0.151	0.149	0.150	27.40	27.30	57.70	57.60	15.13	15.07	15.93	15.93
CV (%)	1.83	0.99	1.99	1.66	1.54	1.42	1.48	1.39	1.07	1.89	1.01	1.93
Sig. Level	**	**	**	**	**	**	**	**	**	**	**	**
S.E. (±)	0.0694	0.0818	0.0801	0.0539	0.0808	0.0631	0.1559	0.1267	0.0884	0.0732	0.0940	0.0857

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