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Effect of nitrogen application through urea and *Azolla* on yield, nutrient uptake of rice and soil acidity indices in acidic soil of Meghalaya

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Abstract

Aim : To investigate the effect of nitrogen application through urea and *Azolla* on yield, nutrient uptake of rice (*Oryza sativa* L.) cv. Shasharang and to assess the improvement in soil acidity indices in acidic soil of Meghalaya.

Methodology : A field experiment was conducted with six treatments *viz.,* control (T_1), *Azolla* incorporation @ 1.6 tonnes ha^{-1} (T_2), 30 kg N ha^{-1} through urea (T_3), 60 kg N ha^{-1} through urea (T_4), 30 kg N ha^{-1} through urea + *Azolla* incorporation @ 1.6 tonnes ha^{-1} (T_5) and 60 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1} (T_6). The experiment was laid out in RBD and replicated four times. The physico-chemical properties of the experimental soil were pH 5.1, SOC 1.75 percent, available N, P and K as 288.62, 17.23 and 201.46 kg ha^{-1}, respectively.

Results : The application of 60 kg N ha^{-1} through urea along with *Azolla* incorporation @ 1.6 tonnes ha^{-1} (T_6) recorded highest dry matter i.e. 58. 15 g hill^{-1} at maturity of rice. Similarly, 60 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1} produced highest grain and straw yield i.e. 4.2 t ha^{-1} and 7.68 t ha^{-1} followed by T_5 and T_4. The magnitude of increase in N, P and K concentration and uptake in grain was 28.57, 97.02; 26.09, 84.21 and 15.69, 76.47 percent in T_6 over T_1. The analysis of soil acidity indices indicated that highest improvement in pH was observed in T_2 over all other treatments. Further, pH increased significantly in the treatments receiving *Azolla* incorporation (T_2, T_5 and T_6) compared with the sole application of urea/control (T_1, T_3 and T_4). The exchangeable calcium and magnesium (meq 100 g^{-1}), CEC (meq 100 g^{-1}) and base saturation percentage also showed the same trends and the highest values were observed as 1.92, 7.90 and 24.30 in T_2. However, in contrast to this, the lowest values of exchangeable aluminium, exchangeable acidity and acidity saturation percentage were observed in T_2 indicating that the sole application of *Azolla* improved soil acidity indices.

Interpretation : It may be concluded from the present study that *Azolla*-urea nitrogen system may be suitable for getting optimum production of rice under tropical conditions and improving soil acidity indices because of its ability to fix atmospheric nitrogen.

Key words: *Azolla* incorporation, Integrated nutrient management, Rice yield, Soil acidity indices.

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Introduction

Rice is the most widely consumed staple food for a large part of the world's population, especially in Asia. It is the agricultural commodity with third highest worldwide production of 741.5 million tonnes (FAOSTAT, 2014). In India, it has a total production of 106.5 Mt whereas in Meghalaya it is limited to 2.8 lakh tones (DES, 2015). The food demand is on the increase whereas the factor productivity and rate of response of crops to applied fertilizers under intensive farming conditions are continuously declining with every passing year. The energy crisis and high fertilizer costs have created considerable concern and the use of organic materials as a source of plant nutrients for lowland rice. The success of rice production depends mostly on an efficient and economical supply of nitrogen apart from irrigation. The use efficiency of nitrogen from fertilizer sources in lowland rice is quite low, around 30 to 50 percent, because of its loss from soils through various chemical and biochemical processes. It has, therefore, become necessary to look for alternative renewable resources to meet at least a part of the nitrogen demand of rice crops. Nitrogen-fixing blue-green algae (BGA) or cyanobacteria and *Azolla* have been shown to be the most important in maintaining and improving the productivity of rice fields among organic sources (Raja *et al.,* 2012). *Azolla* is a free-floating water fern that floats in the water and fixes atmospheric nitrogen because of its association with the nitrogen fixing cyanobacterium, Anabaena (Bocchi and Malgioglio, 2010; Singh *et al.,* 2018). An *Azolla-Anabena* system is ideal for the cultivation of rice under tropical conditions because of its ability to fix atmospheric nitrogen and capacity to multiply at faster rates (Bocchi and Malgioglio, 2010; Bhuvaneshwari and Singh, 2015; Asghar *et al.,* 2018).

Phosphorus is also an indispensable input in agricultural production systems as one of the most essential macro-element required for growth and development of plants after nitrogen. The essential functions of phosphorus are energy storage and transfer, signal transduction, macromolecular biosynthesis, photosynthesis and respiration chain reactions (Sharma *et al.,* 2013). Natural phosphorus reserves are limited and it is, therefore, important to develop phosphorus-efficient crops (Gamuyao *et al.,* 2012). More than 60 percent of the total phosphorus in cereal crops is finally allocated into the grains and is, therefore, removed at harvest. This removal accounts for 85 percent of the phosphorus fertilizers applied to the field each year (Yamaji *et al.,* 2017). Phosphorus deficiency occurs widely in lowland soils that possess high native phosphorus-fixing capacity, especially in acidic soil of Meghalaya (Lyngdoh and Sanjay-Swami, 2018). Soil acidity is one of the major yield constraints to rice production in various parts of the world as well as in the North-Eastern region of India. The toxicity of soil aluminium has been recognized as one of the important factors limiting the productivity of rice on acid soils with pH less than 5.5. As a result, the productivity of acid soils of the NE region is very low (<1 t ha^{-1}) (Sanjay-Swami and Maurya, 2018; Sanjay-Swami *et al.,* 2019). Although, some information on phosphorus sorption and fixation using organic matter incorporation in acid soils exist (Ohno *et al.,* 2007; Ohno and Amirbahma, 2010), there is dearth of information on the use of *Azolla* to minimize phosphorus fixation in acid soils. Quantifying optimum soil acidity indices is an important strategy for achieving maximum economic rice yield on acid soils. Keeping this in view, the present investigation was carried out to study the effect of nitrogen application through urea and *Azolla* on yield, nutrient uptake of rice (*Oryza sativa* L.) cv. Shasharang and to assess the improvement in soil acidity indices in acidic soil of Meghalaya.

Materials and Methods

The experiment was conducted at Research Farm of the College of Post-Graduate Studies in Agricultural Sciences (CPGS-AS), Central Agricultural University, Umiam, Ri-Bhoi district of Meghalaya. The experimental soil was acidic in nature exhibiting pH 5 (1:2.5) with SOC 1.75 percent, available nitrogen, phosphorus and potassium as 288.62, 17.23 and 201.46 kg ha^{-1}, respectively. The field experiment was conducted during kharif season of 2017 taking rice as test crop in a Randomized Block Design (RBD) having six treatments and four replications *viz.,* control (T_1), *Azolla* incorporation @ 1.6 tonnes ha^{-1} (T_2), 30 kg N ha^{-1} through urea (T_3), 60 kg N ha^{-1} through urea (T_4), 30 kg N ha^{-1} through urea + *Azolla* incorporation @ 1.6 tonnes ha^{-1} (T_5) and 60 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1} (T_6). The field was ploughed with power tiller and divided into individual experimental plots of 3 x 1.5 m^2 with proper arrangement of bunds and irrigation channel.

The required quantity of *Azolla* was incorporated as green manure on fresh weight basis one day prior to transplanting of seedlings whereas the treatment wise split (50 percent) doses of nitrogen *viz.* 30 and 60 kg ha^{-1} along with full recommended doses of phosphorus and potassium were applied at the time of transplanting. The remaining 50 percent of nitrogen were applied in two split doses, *i.e.,* 25 percent at active tillering stage and rest 25 percent at panicle initiation stage as top dressing. Twenty-five-day old seedlings were removed carefully from nursery bed and two seedlings in each hill were transplanted within 30 min in the main field to avoid any shock. All the agronomic practices were followed for raising the rice crop. The nitrogen, phosphorus and potassium content in *Azolla* on dry weight basis was 4.2, 0.6 and 1.9 percent, respectively.

For measuring dry matter production, five plant hills were selected randomly from each plot and then cut from the base. The samples were first washed properly, air dried and then oven dried at 70°C till a constant weight was obtained. The weight was recorded using an electric balance and the dry matter production was expressed in grams per hill. Grain, straw and biological yield of rice were recorded after the harvest of the crop when optimum moisture content was achieved and expressed in t ha^{-1}. Grain and straw samples from each plot were dried in an oven and then grinded for estimation of nitrogen, phosphorus and potassium concentration by modified Kjeldahl method (Bremner and Mulvaney, 1982), vanadomolybdate phosphoric yellow colour method (Koenig and Johnson,1942) and flame photometer after making proper dilutions, respectively. The uptake of nitrogen, phosphorus and potassium (kg ha^{-1}) by rice was calculated. The soil samples from each plot were collected by core sampling after harvesting of rice crop. Soils were mixed, dried, ground and passed through a 0.2 mm stainless sieve and analyzed for soil acidity indices following the standard methods (Jackson, 1973). The data recorded for various parameters were analyzed statistically by following the procedure of Gomez and Gomez (1984).

Results and Discussion

The combined application of *Azolla* and urea exhibited significant impact on plant dry matter production in rice at 90 DAT and at maturity (Fig. 1). Application of 60 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1} (T_6) recorded highest plant dry matter, *i.e.,* 58.15 g hill^{-1} at maturity of rice which is significantly superior over control plot, *i.e.,* 47.27 g hill^{-1}. Higher content of total dry matter accumulation was likely due to increased supply of nitrogen and phosphorus with *Azolla*-urea nutrient supply system and higher difference between the total amounts of current photosynthesis and plant respiration, as a result of this surplus difference, total dry matter production further increased (Yang *et al.,* 2007).

Grain yield of rice increased significantly with different levels of *Azolla* and urea (Fig. 2). It was found that T_6 treatment gave highest yield with 4.2 t ha^{-1} which was trailed by T_5 treatment with 3.77 t ha^{-1}. Among the sole treatment of *Azolla* and urea, urea treatment showed better performance. Similarly, there was significant effect of different treatments on straw yield of rice crop which followed the pattern of grain yield. Different treatments brought significant difference on biological yield of rice. The highest biological yield was recorded in T_6 treatment which was significantly superior over T_1, T_2 and T_3 treatments whereas statistically at par with T_4 and T_5. Recently, Buragohain *et al.* (2018) reported that the incorporation of fresh or dry *Azolla* biomass into the soil always increased grain and straw yield of rice. They also reported that *Azolla* hybrid along with fertilizer nitrogen increases the grain yield and yield component of rice. The results obtained by Mensah *et al.* (2015) also corroborate with this fact. Similarly, Chandel *et al.* (2010) obtained significant increased in grain yield of rice when *Azolla* was used along with 100 kg N ha^{-1} as USG (Urea Super Granule).

The reason for increased yield components and grain yield of rice in *Azolla* incorporated treatments might be due to higher availability of *Azolla* nitrogen to rice plants. When *Azolla* is incorporated into the flooded soil, it undergoes active decomposition and the nitrogen released in ammonical form is readily absorbed by the rice plants. The low yield reported in *Azolla* unincorporated treatments could be due to lower rate of decomposition and possibly less availability of *Azolla*-N to rice plants. Moreover, Ghosh *et al.* (2004) also reported that rice plants absorbed more than 50 percent of 15N labelled *Azolla*-N incorporated at the time of transplanting and when *Azolla* was kept on the surface of water, less than 10 percent of its nitrogen was available to rice plants. Therefore, the efficiency of *Azolla* bio-fertilizer can be increased by incorporating it into the rice soil, which avoids loss of nitrogen and higher yield response could be obtained from rice plants. Increased dry matter and grain yields observed in the present study with *Azolla* application also had been reported by Ladha *et al.* (2000). The higher levels of nitrogen concentration (1.44 percent) in grain were recorded in 60 kg N ha^{-1} through urea T_6 treatment compared to urea application alone (Table 1). Similar trend was observed for nitrogen content in straw of rice under different treatments. Significantly, the highest nitrogen uptake (60.27 kg ha^{-1}) by grain was recorded in the treatment T_6 which was significant over all other treatments followed by the treatment T_5 with nitrogen uptake of 48.32 kg ha^{-1}. Similar trend was observed for nitrogen uptake in straw. The following sequence were observed for nitrogen uptake in straw $T_6>T_5>T_4>T_3>T_2>T_1$, respectively. The total nitrogen uptake was significantly affected by different treatments (Table 1).

These results revealed that application of nitrogen to the soil through *Azolla* incorporation and urea application showed positive influence in improving nutritional level both in the grain and straw by increased availability of nitrogen through *Azolla*-urea nitrogen supply system. The increased availability of nitrogen in plant system coupled with increased metabolic activity at cellular level might increase nitrogen uptake and their accumulation in partitioning towards grain and straw. Increased accumulation of nitrogen in grain and straw along with improved metabolism led to greater translocation of this nutrient. Increased uptake of nitrogen seems to be due to the fact that uptake of nutrient is a product of biomass accumulated by particular part and its nutrient content and the increased uptake of nitrogen leads to increased plant nutrient concentration. Thus, positive impact of urea application and *Azolla* incorporation on both these aspects ultimately led to higher accumulation of nitrogen concentration. These results are in line with the findings of Banik and Sharma (2015). The beneficial effect of *Azolla* can be related to better availability of nitrogen due to their narrow C: *N ratio* thereby resulting in more mineralization of nitrogen. Ansari *et al.* (2008) also observed that decomposition of *Azolla produces* organic acids which are capable of releasing the nutrients associated with clay minerals resulting in better availability of nutrients. The highest nitrogen concentration and uptake in the grain and straw of rice plant were recorded in the combined treatment T_6 and T_5 over sole treatment of urea (T_3 and T_4) and *Azolla* (T_2). Favourable effects of manuring on uptake of nitrogen have also been reported by Gupta *et al.* (2006), Singh *et al.* (2011), and Konyak and Sanjay-Swami (2018).

Significantly higher levels of phosphorus concentration (0.29 percent) in grain was recorded T_6 treatment which is the combined application of urea and *Azolla*, compared to the urea application alone (Table 2). The phosphorus concentration in straw ranged from 0.07-0.15 percent. The effect of urea and *Azolla* largely influences the uptake of phosphorus in rice. The phosphorus uptake

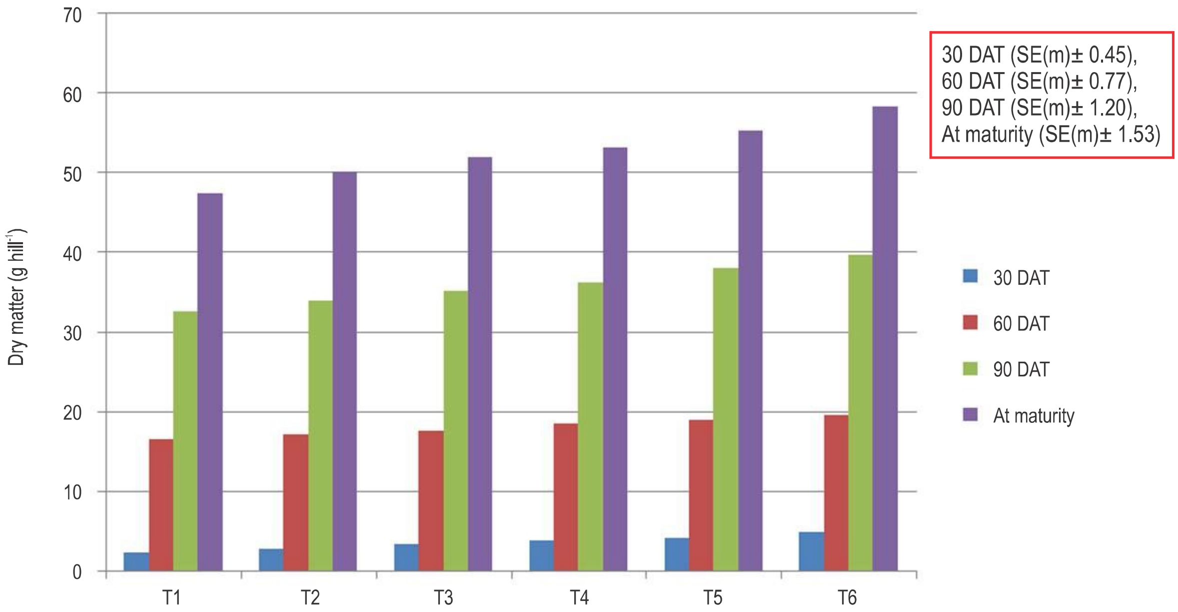

Fig. 1(a): Effect of nitrogen application through urea and *Azolla* on plant dry matter production (g hill^{-1}) of rice.

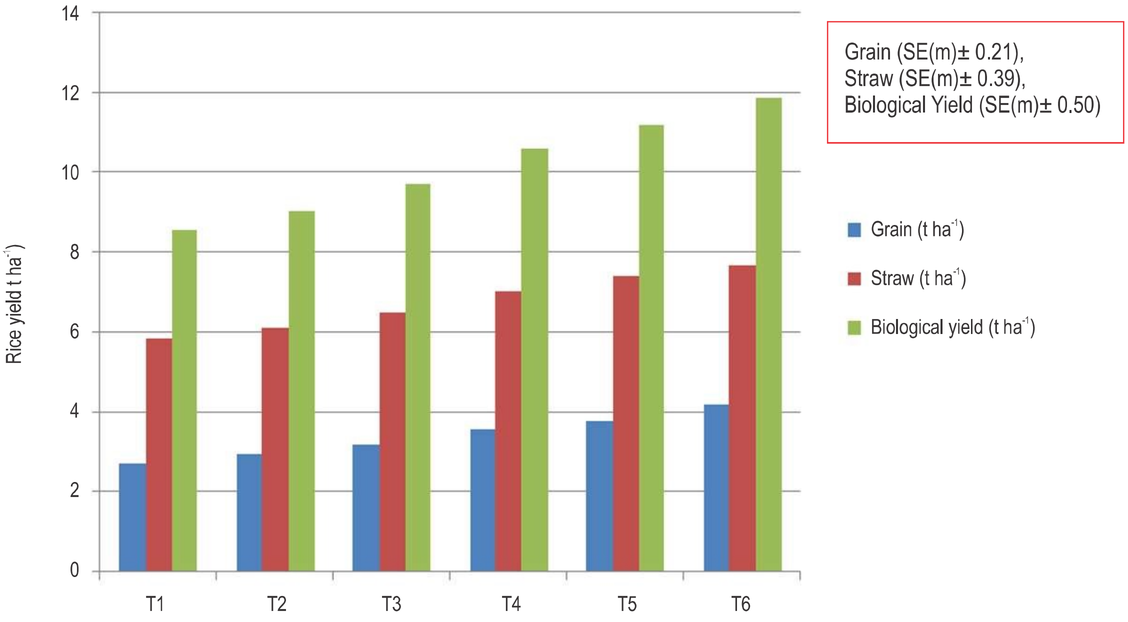

Fig. 1(b):Effect of nitrogen application through urea and *Azolla* on grain, straw and biological yield (t ha^{-1}) of rice.T1 -Control; T2 -*Azolla* incorporation @ 1.6 tonnes ha-1; T3-30 kg N ha-1 through urea; T4 -60 kg N ha-1 through urea; T5 -30 kg N ha-1 through urea with *Azolla* incorporation @ 1.6 tonnes ha-1 and T6 -60 kg N ha-1 through urea with *Azolla* incorporation @ 1.6 tonnes ha-1.

Table 1: Effect of nitrogen application through urea and *Azolla* on nitrogen concentration and uptake by rice

Treatment	Grain Conc. (%)	Straw Conc. (%)	Grain uptake (kg ha^{-1})	Straw uptake (kg ha^{-1})	Total uptake (kg ha^{-1})
T$_1$	1.12	0.51	30.59	29.97	60.56
T$_2$	1.16	0.52	34.13	32.00	66.13
T$_3$	1.20	0.53	41.85	37.52	80.48
T$_4$	1.28	0.55	42.96	38.59	88.86
T$_5$	1.31	0.56	48.32	40.54	80.45
T$_6$	1.44	0.57	60.27	43.43	103.70
SE(m)±	0.10	0.05	2.57	2.36	4.00
CD (P=0.05)	0.31	NS	7.75	7.11	12.04

T$_1$-Control; T$_2$- *Azolla* incorporation @ 1.6 tonnes ha^{-1}, T$_3$- 30 kg N ha^{-1} through urea; T$_4$- 60 kg N ha^{-1} through urea; T$_5$- 30 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1}; T$_6$- 60 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1}

Table 2: Effect of nitrogen application through urea and *Azolla* on phosphorus concentration and uptake by rice

Treatment	Grain Conc. (%)	Straw Conc. (%)	Grain uptake (kg ha^{-1})	Straw uptake (kg ha^{-1})	Total uptake (kg ha^{-1})
T$_1$	0.23	0.07	6.27	4.28	10.55
T$_2$	0.24	0.09	7.09	4.68	11.76
T$_3$	0.24	0.08	8.39	5.34	14.07
T$_4$	0.25	0.09	8.73	6.95	15.71
T$_5$	0.26	0.12	9.28	6.42	15.34
T$_6$	0.29	0.15	11.55	9.00	20.56
SE(m)±	0.02	0.01	0.41	0.55	0.71
CD (P=0.05)	0.06	0.02	1.24	1.67	2.13

T$_1$-Control, T$_2$- *Azolla* incorporation @ 1.6 tonnes ha^{-1}, T$_3$- 30 kg N ha^{-1} through urea, T$_4$- 60 kg N ha^{-1} through urea, T$_5$- 30 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1}, T$_6$- 60 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1}

in grain varied from 6.27 kg ha^{-1} to 11.55 kg ha^{-1}. Significantly higher uptake (6.27 kg ha^{-1}) by grain was recorded in the treatment T$_6$ which was significant over all other treatments followed by the treatment T$_5$ with phosphorus uptake of 9.28 kg ha-$^{-1}$. A similar trend was observed in phosphorus uptake in straw. The total phosphorus uptake varied from 20.56 kg ha^{-1} to 10.55 kg ha^{-1}. There was around 25.39 percent increase in treatment T$_6$ when compared with treatment T$_4$ whereas it increased by 11.66 percent treatment T$_5$ in comparison to T$_4$ treatment. The higher phosphorus uptake values in integrated treatments might be due to the fact that *Azolla* (organic materials) form chelates with Al^{3+} and Fe^{3+} result in low phosphorus fixing capacity thereby releasing the phosphorus and, thus, increasing its availability to plants and also showing synergistic effect between nitrogen and phosphorus. Similar results were reported by Patro *et al.* (2009) and Singh *et al.* (2011). Prakash and Bhadoria (2003) reported that the increased P uptake under integrated treatments might be due to the production of organic acids during decomposition of organic matter, which are capable of releasing the phosphorus associated with clay minerals and better availability from both organic and chemical sources.

There was no significant difference on potassium concentration in grain due to different treatments however potassium uptake by grain in rice was significantly affected by different treatments under study (Table 3). Among the treatments, highest total potassium uptake (114.56 kg ha^{-1}) was observed in T$_6$ treatment which was significant over T$_4$ treatment. This might be due to good proliferation of root system, resulting in better absorption of potassium in the plots receiving combined application (T$_6$ and T$_5$) over the sole treatment of urea (T$_3$ and T$_4$) and *Azolla* (T$_2$). Moreover, the increased K uptake under conjunctive use of urea and *Azolla* also might be due to priming effect, such that *Azolla* on decomposition releases organic acids which solubilize native *i.e.*, fixed and non-exchangeable forms of K and charge the soil solution with K$^+$ ions at later stages of crop growth (Singh *et al.,* 2005). Similar results were also reported by Sharma and Sharma (2002), Gupta *et al.* (2006), Dong *et al.* (2012), and Konyak and Sanjay-Swami (2018). Low potassium uptake values under control plots could be due to lower yield as continuous cropping without any external input decreases native potassium supply.

Table 3: Effect of nitrogen application through urea and *Azolla* on potassium concentration and uptake of rice

Treatment	Grain Conc. (%)	Straw Conc. (%)	Grain uptake (kg ha^{-1})	Straw uptake (kg ha^{-1})	Total uptake (kg ha^{-1})
T_1	0.51	1.11	13.94	64.71	78.65
T_2	0.53	1.14	15.51	69.42	84.93
T_3	0.52	1.12	17.80	79.03	97.45
T_4	0.54	1.13	18.42	80.14	103.73
T_5	0.56	1.15	20.19	83.54	97.93
T_6	0.59	1.18	24.60	89.96	114.56
SE(m)±	0.05	0.08	1.48	3.69	5.14
CD (P=0.05)	NS	NS	4.44	11.12	15.48

Table 4: Effect of nitrogen application through urea and *Azolla* on soil acidity indices after harvesting of rice

Treatment	pH	Exch. Al (cmol (p+) kg^{-1})	Exch. Acidity (cmol (p+) kg^{-1})	Exch. Ca^{+2} and Mg^{+2} (cmol (p+) kg^{-1})	CEC (cmol (p+) kg^{-1})	Base saturation (%)	Acidity (Al+H) saturation (%)
T_1	5.13	2.28	3.06	1.34	7.33	18.28	81.72
T_2	5.35	1.92	2.77	1.92	7.90	24.30	75.70
T_3	5.01	2.31	3.09	1.27	7.18	17.69	82.31
T_4	4.96	2.37	3.10	1.18	6.99	16.88	83.12
T_5	5.28	2.11	2.98	1.87	7.77	24.07	75.93
T_6	5.27	2.17	3.01	1.81	7.49	24.17	75.83
SE(m)±	0.22	0.09	0.08	0.02	0.12	01.08	01.41
CD (P=0.05)	NS	0.26	NS	NS	0.36	03.39	04.50

T_1-Control, T_2- *Azolla* incorporation @ 1.6 tonnes ha^{-1}, T_3- 30 kg N ha^{-1} through urea, T_4- 60 kg N ha^{-1} through urea, T_5- 30 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1}, T_6- 60 kg N ha^{-1} through urea with *Azolla* incorporation @ 1.6 tonnes ha^{-1}

There was no significant change in soil pH observed under different treatments (Table 4). A slight increase in soil pH was observed in the treatments where *Azolla* was used whereas soil pH slightly decreased where urea was used in comparison to the initial soil pH (5.1). The increase in soil pH might be attributed to decrease of Al^{3+} ions and release of basic cations during decomposition of organic manure (*Azolla*) whereas application of nitrogenous fertilizers decreases the pH due to residual acidity of fertilizers. These results are in consonance with the findings of Zhang *et al.* (2008) and Yaduvanshi and Sharma (2016). The exchangeable Al in soil ranged from 1.92 to 2.37 cmol(p$^+$) kg^{-1}. The highest value (2.37 cmol (p$^+$) kg^{-1}) was recorded in T_4 whereas the lowest value (1.92 cmol (p$^+$) kg^{-1}) was recorded in T_2 treatment. A slight increase in exchangeable Al was observed in the treatments where urea was used whereas a slight decrease was observed where *Azolla* was used in comparison to the initial exchangeable Al (2.25 cmol(p+) kg^{-1}). There was an increase of 18.99 percent in T_6 treatment.

The exchangeable acidity content in all treatments was non-significant as presented in Table 4. The exchangeable acidity in soil ranged from 2.77 to 3.10 cmol (p+) kg^{-1}. The highest value (3.10 cmol (p+) kg^{-1}) was recorded in T_4 whereas the lowest value (2.77 cmol (p+) kg^{-1}) was recorded in T_2 treatment. This might be attributed to the fact that the proton consuming ability of humic materials might have reduced acidity in this case. Slow reduction of acidity might be explained by the steady formation of organic material with functional groups such as carboxyl and phenolic groups during decomposition and by low solubility of $CaCO_3$. Moreover, the pH increase with manure treatment could be attributed to the reduction of exchangeable aluminium and acidity in these acidic soils (pH 4.5–5.5). This reduction is considered to occur through aluminium and hydrogen precipitation or chelation on organic colloids or by complexation of soluble aluminium and hydrogen by organic molecules, especially organic acids (Hati *et al.*, 2008). The exchangeable Ca and Mg of the soil ranged from 1.18 to 1.92 cmol (p+) kg^{-1}. The highest value (1.92 cmol (p+) kg^{-1}) was recorded in T_2 whereas the lowest value (1.18 cmol (p+) kg^{-1}) was recorded in T_4 treatment. *Azolla* treatments, both sole and combined, were found to be superior in maintaining higher concentration of exchangeable calcium and magnesium over sole application of urea, which might be due to higher concentration of organic matter produced by decomposition of *Azolla* in the soil. The higher concentration of exchangeable calcium and magnesium in *Azolla* treatments over urea treatments and control was due to the fact that *Azolla* additions increased the exchangeable calcium status of the soils due to increase in biomass production and its incorporation in the soil. Better soil physical conditions increased soil microbiological activity and more mineralization by the microbes from soil pool which might have increased the exchangeable calcium in the soil. Similar observations have been reported by Sharma *et al.* (2013).

The exchangeable CEC of soil was significantly and positively correlated with different treatment combinations (Table 4). The highest value (7.90 cmol (p+) kg^{-1}) was recorded in T$_2$ treatment due to higher organic carbon content whereas the lowest value (6.99 cmol (p+) kg^{-1}) was recorded in T$_4$ treatment. The treatments receiving *Azolla* were superior in maintaining exchangeable CEC due to high biomass incorporation in the soil. Similar observations were reported by Chyamweshi *et al.* (2013). Base Saturation Percentage (BSP) in T$_6$ treatment was significant over T$_1$ treatment as presented in Table 4. Base saturation is the percentage of CEC occupied by basic cations like Ca^{+2}, Mg^{+2} and K^{+}. It follows the same trend as exchangeable Ca^{+2} and Mg^{+2} (Sharma *et al.,* 2013). Acidity saturation is the percentage of the CEC occupied by the acidic cations like H^{+} and Al^{+3}. Acidity Saturation Percentage (ASP) in soil was significant between the treatments. The highest value for ASP (83.12 percent) was recorded in T$_4$ whereas the lowest (75.7 percent) was recorded in T$_2$ treatment. It followed the same trend as exchangeable Al and exchangeable acidity (Hati *et al.,* 2008). Based on the findings of the present study, it may be concluded that application of 60 kg N ha^{-1} through urea in combination with incorporation of *Azolla* @ 1.6 tonnes ha^{-1} is the best suitable option for getting optimum production of rice and sustainability of soil health in low land acid soil of Meghalaya. The findings of this study may be of significant use for the farmers of Meghalaya as they can include fresh *Azolla* biomass as a component of integrated nutrient management along with urea in low land rice cultivation and can boost-up production in acidic soil while managing soil acidity in a better way, thereby ensuring long-term sustainability of soil health.

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