Journal of Natural Resource Conservation and Management
Vol. 1, No. 1, pp 7-14, 2020
https://www.anrcm.org/journal/

# Soil acidity and nutrient availability in Inceptisol of Meghalaya as influenced by *Azolla* incorporation

**Shubham Singh and Sanjay-Swami**

*School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University, Umiam-793103, Meghalaya, India*

Received : February 6, 2020
Revised : April 7, 2020
Accepted : April 20, 2020

**ABSTRACT**

A field experiment was conducted at School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences, Umiam, Meghalaya during *kharif* 2017 to investigate the influence of *Azolla* on soil acidity and nutrient availability in acid Inceptisol of Meghalaya. Rice (var. Shasharang) was raised as test crop with six treatments *viz.,* control (T1), fresh *Azolla* incorporation @ 1.6 t $ha^{-1}$ (T2), 30 kg N $ha^{-1}$ through urea (T3), 60 kg N (T4), 30 kg N $ha^{-1}$ + *Azolla* 1.6 t $ha^{-1}$ (T5) and 60 kg N $ha^{-1}$ + *Azolla* 1.6 t $ha^{-1}$ (T6) in randomized block design with four replications. The experimental soil was sandy clay loam in texture having pH 5.1, bulk density 1.36 Mg $m^{-3}$ and organic carbon 17.5 g $kg^{-1}$. The highest soil pH was observed in T2 and increased significantly in treatments receiving both *Azolla* and mineral N-fertilizer (T2, T5 and T6) compared to their sole applications (T1, T3 and T4). The exchangeable calcium and magnesium (c mol ($p^+$) $kg^{-1}$), CEC (c mol ($p^+$) $kg^{-1}$) and base saturation percentage also showed the same trends and the highest values were observed as 1.92, 7.90 and 24.30 in T2. However, in contrast to this, the lowest values of exchangeable aluminum, exchangeable acidity and acidity saturation percentage were observed in T2 indicating that the sole application of *Azolla* improved soil acidity indices. The soil available P and K contents were recorded higher in the treatments with *Azolla* integrated with mineral fertilizer (T2, T5 and T6) as compared to the sole application of urea (T3 and T4) or control (T1) at different crop growth stages and at maturity. Available phosphorus in T6 was statistically significant over T4 whereas T5 was significant over T3 with respect to advancement in crop age. The organic carbon data followed the same trends.

***Keywords:*** *Azolla* incorporation, soil acidity, nutrient availability, acid soil, Meghalaya.

## INTRODUCTION

Soil acidity may be defined as soil system's proton donating capacity ($H^+$ ions) during its transition from a given state to a reference state. Acid soil is base unsaturated soil which has got enough of adsorbed exchangeable $H^+$ ions to give a pH lower than 7.0 (Sanjay-Swami and Maurya, 2018). There are five major reasons for soils to become acidic: leaching due to heavy rainfall, acidic parent material, organic matter decay and release of organic acids, harvest of high-yielding crops and presence of alumina-silicate minerals (Lyngdoh and Sanjay-Swami, 2018; Sanjay-Swami and Lyngdoh, 2019). Soil acidity is one of the major constraints in crop production through-out the world (Singh *et al*., 2014).

In India, about 90 million hectare area is affected by soil acidity problems. However, about 25 m ha are critically degraded having pH less than 5.5 (Mandal, 1997). Acidic soil are deficient in available plant nutrient like $Ca^{+2}$, $Mg^{+2}$, and to some extent $K^+$, P, Mo and B. Strongly acidic soil contain $Fe^{+3}$ and $Al^{+3}$ in toxic concentration. There is also poor microbial activity in these soils. Due to this, it is very essential to manage these soils (Sharma and Singh, 2002).

About 21 million hectare (m ha) of acid soils are found in North Eastern Hill (NEH) region of India with maximum area in Arunachal Pradesh followed by Assam. Meghalaya consist of 2.24 m ha of acidic soil. Here soil are rich in organic carbon, which is a measure of nitrogen supplying potential of the soil, deficient in available phosphorus and medium to low in available potassium. Base saturation of the soil is less than 35 percent (Sadras and Lemaire, 2014). These soils are not suitable for intensive crop production. The toxicity of soil aluminum has been recognized as one of the important factors limiting the productivity of rice on acid soils with pH less than 5.5. Quantifying optimum soil acidity indices is an important strategy for achieving maximum economic rice yield on acid soils (Yadav and Sanjay-Swami, 2019).

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 (N). The essential functions 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 P-fixing capacity, especially in acidic soils of NEH region. Therefore, it is very much important to give emphasis on available P status with time intervals to synchronize the crop P demand.

Rice is the main food crop of Meghalaya accounting for 60 percent of cultivable area with a productivity of less than 2.0 t $ha^{-1}$ compared to national average of 2.85 t $ha^{-1}$ due to soil acidity related constraints. Phosphorus deficiency coupled with low P-fertilizer use efficiency (P-fue), more often only 10-15 per cent has been observed to be a limiting factor for rice production in low land acidic soils.

*Azolla* is a floating fern having endo-symbiotic $N_2$ fixing Cyanobacterium, *Anabaena-Azollae*. It is a multipurpose crop and can be used as bio-fertilizer also. With a doubling of biomass within two days, *Azolla* ranks amongst the fastest-growing plants on our planet and thus can provide large bio-mass. It produces around 300 tonnes of green bio-hectare per year under normal sub tropical climate (http://megapib.nic.in/azolla.htm). Although, some information on P 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 P fixation and its availability in acid soils. The efficient use of *Azolla* is still limited due to lack of insights in the P availability with time and in the corresponding mechanisms. Keeping in mind the above facts, the present study has been carried out with the aim of evaluating the performance of *Azolla* (*Azolla pinnata*) with or without N-fertilizer on soil acidity and nutrient availability in rice (*Oryza sativa* L.) cv. Shasharang.

## 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 field experiment was conducted during *kharif* season of 2017 taking rice as test crop in randomized block design (RBD) with six treatments and four replications *viz.*, control (T1), *Azolla* incorporation 1.6 t $ha^{-1}$ on fresh weight basis (T2), 30 kg N $ha^{1}$ (T3), 60 kg N $ha^{1}$ (T4), 30 kg N $ha^{1}$ + *Azolla* 1.6 t $ha^{-1}$ (T5) and 60 kg N $ha^{1}$ + *Azolla* 1.6 t $ha^{-1}$ (T6). The *Azolla* was incorporated one day prior to transplanting manually. The mineral nitrogen was applied through urea fertilizer. The recommended dose of P @60 kg $P_2O_5$ $ha^{-1}$ and K @40 kg $K_2O$ $ha^{-1}$ were applied at the time of transplanting. All the agronomic practices were followed for raising test crop. The N, P and K content in *Azolla* on dry weight basis are given in Table 1. After harvest of rice crop, soil samples were collected treatment-wise for analysis. The pH was determined by using standard pH meter as procedure described by Piper (1966). The soil physico-chemical properties of the experimental site along with their method of estimation are presented in Table 2. Soil organic carbon was determined by wet digestion method of Walkley and Black (1934).

Soil acidity indices were estimated using standard methods and calculated with the help of the following formulas:

$$CEC\ (cmol_c\ kg^{-1}) = S\ (Ca^{2+}, Mg^{2+}, K^+, H^+, Al^{3+})$$

**Table 1.** NPK content in *Azolla* in dry weight basis

| S.No. | Particulars | Value | Methods | Reference |
|---|---|---|---|---|
| 1. | Total N (%) | 4.2 | Modified Micro Kjeldahl method | Jackson (1973) |
| 2. | Total P (%) | 0.6 | Di-acid digestion and yellow colour development method | Jackson (1973) |
| 3. | Total K (%) | 1.9 | Flame photometric method | Jackson (1973) |

**Table 2.** Initial physico-chemical properties of experimental soil

| S. No. | Particulars | Value | Method adopted | Inferences |
|---|---|---|---|---|
| **A.** | **Physical Analysis** | | | |
| 1. | Particle size analysis | | | |
| | Coarse sand | 2.10 | International pipette method | Olmstead *et al*. (1930) |
| | Fine sand | 60.12 | | |
| | Silt | 16.66 | | |
| | Clay | 21.12 | | |
| 2. | Bulk density (Mg $m^{-3}$ ) | 1.26 | Core method | Black (1965) |
| **B.** | **Chemical Analysis** | | | |
| 1. | pH | 5.1 | pH meter with glass electrode | Piper (1966) |
| 2. | Organic carbon (g $kg^{-1}$) | 17.5 | Walkley and Black Method of rapid titration | Walkley and Black (1934) |
| 3. | Available nitrogen(kg $ha^{-1}$) | 288.62 | Alkaline potassium permanganate method | Subbiah and Asijah (1956) |
| 4. | Available $P_2O_5$(kg $ha^{-1}$) | 17.23 | Bray and Kurtz No. 1 method | Bray and Kurtz (1945) |
| 5. | Available potassium(kg $ha^{-1}$) | 201.46 | Neutral normal ammonium acetate method | Knudsen *et al*. (1982) |
| 6. | Exchangeable Aluminium (c mol ($p^+$) $kg^{-1}$) | 2.25 | Titrimetric Determination | Jackson (1973) |
| 7. | Exchangeable Acidity (c mol ($p^+$) $kg^{-1}$) | 3.02 | Titrimetric Determination | Jackson (1973) |
| 8. | Exchangeable Calcium + Magnesium(c mol ($p^+$) $kg^{-1}$) | 1.3 | Complexometric Titration Method | Jackson (1973) |
| 9. | CEC(c mol ($p^+$) $kg^{-1}$) | 7.33 | Ammonium acetate saturation method | Jackson (1973) |

Where Ca, Mg, K, H and Al are in centimoles of positive charge per kilogram.

$$\text{Base saturation (\%)} = \frac{\sum(\text{Ca, Mg, K, Na})}{\text{CEC}} \times 100$$

$$\text{Aluminium saturation (\%)} = \frac{(\text{Al})}{\sum(\text{Ca, Mg, K, Al})} \times 100$$

$$\text{Acidity saturation (\%)} = \frac{(\text{H} + \text{Al})}{\text{CEC}} \times 100$$

$$\text{Saturation of Ca, Mg and K (\%)} = \frac{(\text{Ca})}{\text{CEC}} \times 100,$$

$$\frac{(\text{Mg})}{\text{CEC}} \times 100 \text{ or } \frac{(\text{K})}{\text{CEC}} \times 100$$

$$\text{Ratio of Ca : Mg, Ca : K and Mg : K} = \frac{\text{Ca}}{\text{Mg}}, \frac{\text{Ca}}{\text{K}} \text{ or } \frac{\text{Mg}}{\text{K}}$$

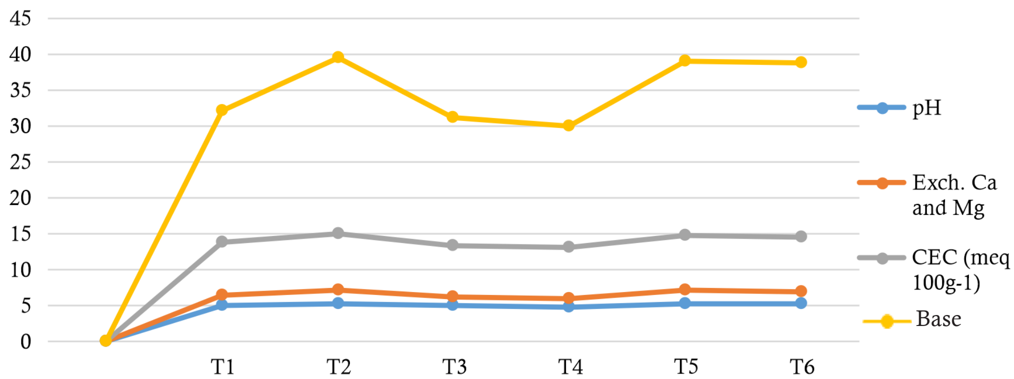
The data recorded for various parameters were analyzed statistically by following procedure of Gomez and Gomez (1984).

## RESULTS AND DISCUSSION

### Soil acidity indices

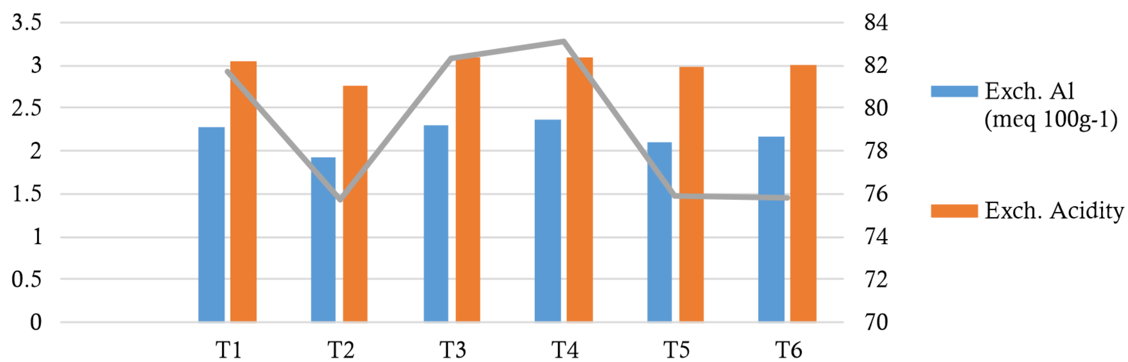
The soil pH ranged from 4.96 to 5.35 with the highest value recorded in *Azolla* 1.6 t $ha^{-1}$ indicating reduction in soil acidity with application of *Azolla* (Fig. 1). The effect of *Azolla* and urea application on soil pH was very little (statistically non-significant) among the treatments. This increase might be due to decrease of $Al^{3+}$ and release of basic cations during decomposition of manures, whereas application of nitrogenous fertilizers decreases the pH due to residual acidity of fertilizers. The similar results have been reported in the findings of Zhang *et al.* (2008) and Yaduvanshi and Sharma (2016).

The exchangeable aluminium ranged from 1.92 in *Azolla* incorporation @ 1.6 t $ha^{-1}$ to 2.37 c mol ($p^+$) $kg^{-1}$ in 60 kg N $ha^{-1}$ and exchangeable acidity ranged from 2.77 to 3.10 c mol ($p^+$) $kg^{-1}$ (Fig. 2). The slow reduction of acidity might be explained by the steady formation of organic material with functional groups such as carboxyl and phenolic groups during




T1- Control, T2- *Azolla* incorporation @ 1.6 t 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 t ha$^{-1}$,
T6- 60 kg N ha$^{-1}$ through urea with *Azolla* incorporation @ 1.6 t ha$^{-1}$

**Figure 1.** Effect of N application through urea and *Azolla* on pH, CEC, Base saturation and Exch. Ca and Mg after harvesting of paddy




T1-Control, T2- *Azolla* incorporation @ 1.6 t 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 t ha$^{-1}$,
T6- 60 kg N ha$^{-1}$ through urea with *Azolla* incorporation @ 1.6 t ha$^{-1}$

**Figure 2.** Effect of N application through urea and *Azolla* on Exch. Al, Exch. acidity and Acidity saturation percentage after harvesting of paddy

decomposition and by the 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 calcium and magnesium content of soil was highest in T2 (*Azolla* incorporation @ 1.6 t ha$^{-1}$) with 1.92 (c mol ($p^+$) kg$^{-1}$) soil which was followed by T5 (30 kg N ha$^{-1}$ through urea + *Azolla* incorporation @ 1.6 t ha$^{-1}$) with 1.87 (c mol ($p^+$) kg$^{-1}$) soil (Fig. 1). Base saturation is the percentage of the CEC occupied by the acidic cations $Ca^{+2}$, $Mg^{+2}$ and $K^+$ follows the same trends as exch. $Ca^{+2}$ and $Mg^{+2}$. The higher concentration of exchangeable calcium and magnesium in *Azolla* treatments over the 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 and Sharma (2002) and Sohlihya (2015).

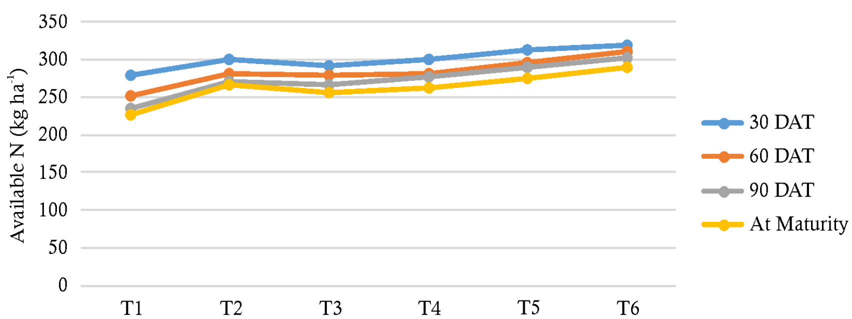
The CEC was significantly and positively correlated with different treatment combinations with highest value in T2 (*Azolla* incorporation @ 1.6

t ha$^{-1}$) due to higher organic carbon content and its incorporation in the soil. Similar observations have been reported by (Cyamweshi *et al.,* 2013).

**Soil available nutrients**

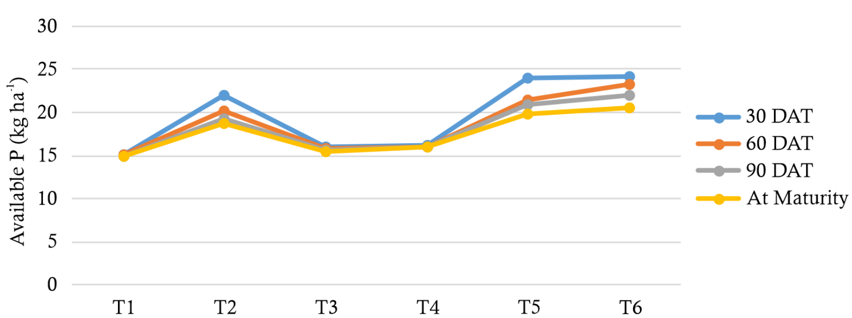
Available N shows a decreasing trend with advancement of crop age. It ranges from 227.45 kg ha$^{-1}$ in post-harvest soil to 319.37 kg ha$^{-1}$ in 30 days after transplanting. At harvest, available N was highest in the treatment receiving nutrition from combined application of 60 kg N ha$^{-1}$ through urea along with *Azolla* incorporation @ 1.6 t ha$^{-1}$ (Fig. 3). It was due to the fact that there was more microbial activities and higher rate of mineralization of soil or organic nitrogen with advancement of crop age resulted in more availability of nitrogen with combined source of application of nutrients. While the higher soil available nitrogen in T4 as compared to T2 and T1 might be due to faster mineralization as compared to T2 and T1. These results are in line with the findings of Sharma *et al.* (2013) who observed that available nitrogen content in soil increased with the use of recommended dose of fertilizer in combination with *Azolla*.

Available $P_2O_5$ at harvest was highest in the treatments receiving nutrition from combined application of 60 kg N ha$^{-1}$ through urea along with *Azolla* incorporation @ 1.6 t ha$^{-1}$. The available $P_2O_5$ ranged between 14.91 kg ha$^{-1}$ in post-harvest soil to 24.13 kg ha$^{-1}$ in 30 days after transplanting (Fig. 4). The higher soil available phosphorus in combined treatments might be due to high content of organic carbon available and thus help converting the immobilized phosphorus into labile or inorganic phosphorus. The increase of available phosphorus could also be explained by better soil condition and subsequently lesser phosphorus fixation. Organic manure enhanced the labile P in the soil through complexation of cations like $Ca^{+2}$ and $Mg^{+2}$ when it is applied in combination with urea which is in accordance with the findings of Mondal *et al*. (2008), Mahdi *et al*. (2010) and Tamang and Sanjay-Swami (2019).



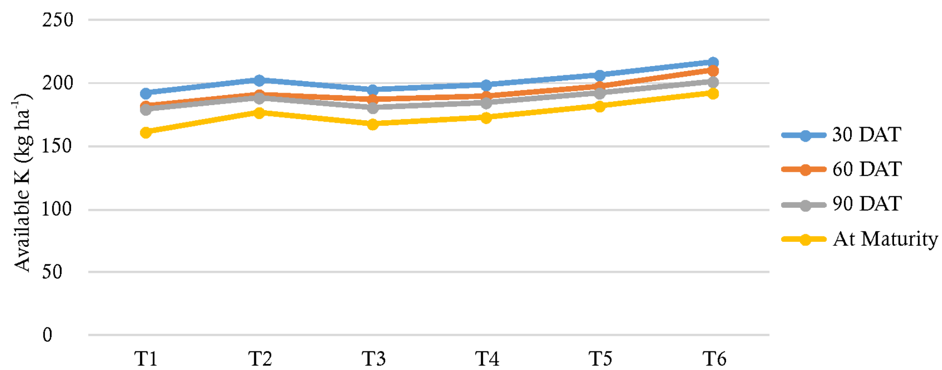

T1- Control, T2- *Azolla* incorporation @ 1.6 t ha$^{-1}$,
T3- 30 kg N ha$^{-1}$ through urea, T4- 60 kg N ha$^{-1}$ through urea,
T5- 30 kg N ha$^{-1}$ through urea with *Azolla* incorporation @ 1.6 t ha$^{-1}$,
T6- 60 kg N ha$^{-1}$ through urea with *Azolla* incorporation @ 1.6 t ha$^{-1}$

**Figure 3.** Effect of N application through urea and *Azolla* on temporal soil N (kg ha$^{-1}$) availability



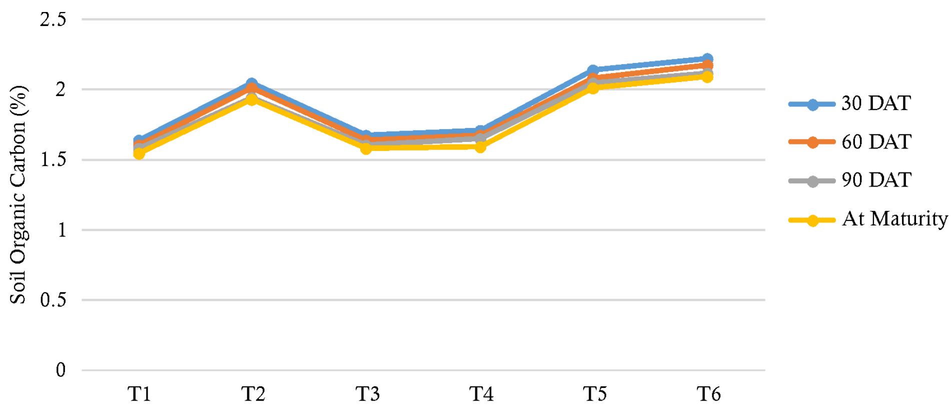

T1- Control, T2- *Azolla* incorporation @ 1.6 t ha$^{-1}$,
T3- 30 kg N ha$^{-1}$ through urea, T4- 60 kg N ha$^{-1}$ through urea,
T5- 30 kg N ha$^{-1}$ through urea with *Azolla* incorporation @ 1.6 t ha$^{-1}$,
T6- 60 kg N ha$^{-1}$ through urea with *Azolla* incorporation @ 1.6 t ha$^{-1}$

**Figure 4.** Effect of N application through urea and *Azolla* on temporal soil P (kg ha$^{-1}$) availability




T1- Control, T2- *Azolla* incorporation @ 1.6 t 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 t ha$^{-1}$,
T6- 60 kg N ha$^{-1}$ through urea with *Azolla* incorporation @ 1.6 t ha$^{-1}$

**Figure 5.** Effect of N application through urea and *Azolla* on temporal soil K (kg ha$^{-1}$) availability




T1- Control, T2- *Azolla* incorporation @ 1.6 t 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 t ha$^{-1}$,
T6- 60 kg N ha$^{-1}$ through urea with *Azolla* incorporation @ 1.6 t ha$^{-1}$

**Figure 6.** Effect of N application through urea and *Azolla* on temporal soil organic carbon (%) availability

Available K shows a decreasing trend with advancement of crop age. It ranges from 160.95 kg ha$^{-1}$ in post-harvest soil to 217.32 kg ha$^{-1}$ in 30 days after transplanting (Fig. 5). At harvest, available K was highest in the combined treatments. Combined source of nutrients activates the soil biologically, thereby increase the mineralization of organic K from manures which might be possible for enhanced K availability (Singh *et al.*, 2005). The beneficial effect of organic manure on available potassium may be ascribed to the reduction of potassium fixation and release of potassium due to the integration of organic matter with clay, besides the direct potassium addition to the potassium pool (Urkurkar *et al.,* 2010).

At harvest, soil organic carbon was highest in the treatments receiving nutrition from combined application of 60 kg N ha$^{-1}$ through urea along with *Azolla* incorporation @ 1.6 t ha$^{-1}$ (2.10 per cent). The soil organic carbon ranged between 1.55 per cent in post-harvest soil to 2.22 percent in 30 days after transplanting (Fig. 6). The application of *Azolla* along with urea significantly increased the soil organic carbon as compared to the application of urea alone. This may be attributed to the inclusion of *Azolla* which added humus to the soil and thus mass per unit volume decreased resulting in increased in organic carbon content (Naik and Yakadri, 2004). In combination treatments due to urea it enhances root growth leading to accumulation of more organic residues in the soil. These results are in agreement with the findings of Majumdar *et al*. (2008).

The correlation between various soil properties is given in Table 3.

**Table 3.** The correlation between various soil properties

| | Av.N | Av. P | Av.K | SOC | pH | Exch.Al | Exch.Acidity | Exch.Ca+Mg | CEC |
|---|---|---|---|---|---|---|---|---|---|
| Av. N | 1.000 | | | | | | | | |
| Av. P | 0.859 | 1.000 | | | | | | | |
| Av. K | 0.958 | 0.940 | 1.000 | | | | | | |
| SOC | 0.824 | 0.997 | 0.917 | 1.000 | | | | | |
| pH | 0.418 | 0.802 | 0.573 | 0.840 | 1.000 | | | | |
| Exch. Al | -0.366 | -0.673 | -0.445 | -0.708 | -0.922 | 1.000 | | | |
| Exch. Acidity | -0.267 | -0.536 | -0.331 | -0.570 | -0.827 | 0.972 | 1.000 | | |
| Exch. Ca+Mg | 0.599 | 0.900 | 0.709 | 0.925 | 0.972 | -0.907 | -0.796 | 1.000 | |
| CEC | 0.333 | 0.707 | 0.437 | 0.746 | 0.960 | -0.959 | -0.877 | 0.942 | 1.000 |

## CONCLUSION

The present investigation demonstrated that *Azolla* incorporation @ 1.6 t $ha^{-1}$ ($T_2$) was found most effective in improving soil acidity indices in acidic low land paddy soil of Meghalaya while application of 60 kg N $ha^{-1}$ through urea with *Azolla* incorporation @ 1.6 t $ha^{-1}$ ($T_6$) was found most effective in maintaining a steady pool of soil available N, P, K and organic C and also improving the temporal soil nutrient availability as compared to sole application of organic manure or chemical fertilizers.

## ACKNOWLEDGEMENTS

Authors acknowledge the financial support and other facilities provided by the School of Natural Resource Management, College of Post Graduate Studies in Agricultural Sciences, Central Agricultural University, Umiam for soil and plant analysis.

### Conflict of Interest

The authors declare that they have no competing interests.

## REFERENCES

Black, C.A. (1965). *Methods of soil analysis, Part-1, Chemical and Microbiological Properties*. Agronomy Monograph. No.9, American Society Agronomy Inc. Madison. Wisconsin. USA, pp: 18-25.

Bray, R.H., and Kurtz, L.T. (1945). Determination of total, organic and available forms of phosphorus in soils. *Soil Sci.,* 59(1), 39-46.

Chyamweshi, R.A., Mukashema, A., Ruganzu, V., Gatarayiha, M.C., Nabahungu, N.L. and Mbonigaba, J.J. (2013). Improving nutrient availability and coffee yield on acid soils of the Central Plateau of Southern Rwanda. *Afric. Crop Sci. Conf. Proc.,* 11, 803-810.

Gamuyao, R., Chin, J.H., Tanaka, J.P., Pesaresi, P., Catausan, S., Dalid, C., Loedin, I.S., Mendoza, E.M.T, Wissuwa, M. and Heuer, S. (2012). The protein kinase Pstoll from traditional rice confers tolerance of phosphorus deficiency. *Nature*, 488, 535-539.

Gomez, K.A. and Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research*, John Wiley and Sons.

Hati, K.M., Swarup, A., Mishra, B., Manna, M.C., Wanjari, R.H., Mandal, K.G. and Misra, A.K. (2008). Impact of long-term application of fertilizer, manure and lime under intensive cropping on physical properties and organic carbon content of an Alfisol. *Geoderma,* 148, 173-179.

http://megapib.nic.in/azolla.htm

Jackson, M.L. (1973). *Soil Chemical Analysis*. Prentice Hall of India. Pvt. Ltd., New Delhi, pp: 186-192.

Knudsen, D., Paterson, G. A. and Pratt, P. F. (1982). Lithium, sodium and potassium. In: Page, A.L. *et al.* (ed.) *Methods of Soil Analysis.* Part 2, 2nd edn. Madison, Wisconsin, pp. 225-246.

Lyngdoh, E.A.S. and Sanjay-Swami (2018). Phytoremediation effect on heavy metal polluted soils of Jaintia Hills in North Eastern Hill Region. *Int. J. Curr. Microbiol. App. Sci.,* 7(11), 1734-1743. doi.org/10.20546/ijcmas.2018.711.199

Mahdi, S.S., Hassan, G.I., Samoon, S.A., Rather, H A., Showkat, A.D. and Zehra, B. (2010). Bio-fertilizers in organic agriculture*. J. Phytol.,* 2(10), 42–54.

Majumdar, B., Mandal, B., Bandyopadhyay, P.K., Gangopadhyay, A. and Mani, P.K. (2008). Organic amendments influence soil organic carbon pools and rice-wheat productivity. *Soil Sci. Soc. Am. J.,* 72, 775-785.

Mandal, S.C. (1997). Introduction and historical overview. In: *Acidic Soils of India* (eds.) Mahapatra, I.C., Mandal, S.C., Misra, C., Mitra, G.N. and Panda, N., ICAR, New Delhi, 3-24.

Mondal, S.S., Jana, P., Prasenjit, A., Chandra, B. and Pradyut, M. (2008). Integrated nutrient management for sustaining productivity and soil fertility build-up in rice-lathyrus-sesame cropping system. *Indian J. Agric. Sci.,* 78, 534–536.

Naik, B.B. and Yakadri, M. (2004). Effect of integrated nutrient management on yield of hybrid rice (*Oryza sativa* L.). *J. Res. ANGRAU*, 30(1),76.78.

Ohno, T., Fernandez, I.J., Hiradate, S. and Sherman, J.F. (2007). Effects of soil acidification and forest type on water soluble soil organic matter properties. *Geoderma,* 140, 176-187.

Ohno, T. and Amirbahma, A. (2010). Phosphorus availability in boreal forest soils: A geochemical and nutrient uptake modeling approach. *Geoderma,* 155, 46-54.

Olmstead, L.B., Alexander, L.T. and Middleton, H.E. (1930). A Pipette method of mechanical analysis of soils based on Improved Dispersion Procedure. United States Department of Agriculture, Washington, D.C., pp.3-18.

Piper, C.S. (1966). *Soil and plant analysis*. Hans's publishers, Bombay.

Sadras, V.O. and Lemaire, G. (2014). Quantifying crop nitrogen status for comparisons of agronomic practices and genotypes. *Field Crops Res*., 164, 54-64.

Sanjay-Swami and Lyngdoh, E.A.S. (2019). Restoration of degraded land in coal mine areas of Jaintia Hills, Meghalaya through phytoremediation. *Soil and Water Conser. Bull.,* No. 4, Indian Association of Soil and Water Conservationists, Dehradun, UK, pp. 17-24.

Sanjay-Swami and Maurya, A. (2018). Critical limits of soil available phosphorous for rapeseed (*Brassica Compestris var. Toria*) growing acidic soils of Meghalaya. *J. Expt. Biol. Agric. Sci.*, 6(4), 732-738.

Sharma, G.D., Thakur, R., Som, R., Kauraw, D.L. and Kulhare, P.S. (2013). Nutrient uptake, protein content of wheat and soil fertility in a Typic Haplustert. *The BioScane*., 8, 1159-1164.

Sharma, S.B., Sayyed, R.Z., Trivedi, M.H. and Gobi, T.A. (2013). Phosphate solubilizing microbes: sustainable approach for managing phosphorus deficiency in agricultural soils. *Springer Plus*, 2, 587.

Sharma, S.K. and Sharma S.N. (2002). Integrated nutrient management for sustainability of rice-wheat cropping system. *Indian J. Agric. Sci*., 72, 573-576.

Sharma, U.C. and Singh, R.P. (2002). Acid soils of India: Their distribution, management and future strategies for higher productivity. *Ferti. News,* 47(3), 45-52.

Singh, A.K., Bordoloi, L.J., Kumar, M., Hazarika, S. and Parmar, B. (2014). Land use impact on soil quality in eastern Himalayan region of India. *Environment Monitoring and Assessment*, 186, 2013–2024.

Singh, L.N., Singh, R.K.K., Singh, A.H. and Chhangte, Z. (2005). Efficacy of urea in integration with *Azolla* and vermicompost in rainfed rice production and their residual effect on soil properties. *Indian J. Agric. Sci.,* 75, 44-45.

Sohlihya, B. (2015). *Influence of organic amendments on phosphorus nutrition and aluminium toxicity in groundnut*. M.Sc. Thesis, submitted to School of Natural Resource Management, College of Post Graduate Studies, CAU, Umiam Meghalaya, p. 78.

Subbiah, B.V. and Asija, G.L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.,* 25(8), 259-260.

Tamang, B. and Sanjay-Swami (2019). Temporal availability of phosphorus and sulphur in acid Inceptisol as influenced by graded application of P and S under black gram (*Vigna mungo* L. Hepper) production. *Leg. Res.: An Inter. J.,* DOI: 10.18805/LR-4127.

Urkurkar, J.S., Tiwari, A., Shrikanth-Chitale and Bajpai, R.K. (2010). Influence of long term use of inorganic and organic manures on soil fertility and sustainable productivity of rice (*Oryza sativa*) and wheat (*Triticum aestivum*) in Inceptisols. *Indian J. of Agril. Sci*., 80(3), 208-212.

Walkley, A., and Black, I.A. (1934). An examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci*., 37(1), 29-38.

Yadav, O.S. and Sanjay-Swami (2019). Performance of tomato (*Solanum lycopersicum* L.) in acid soil under integrated nutrient management with biochar as a component. *Int. J. Curr. Microbiol. App. Sci.,* 8(05), 793-803.

Yaduvanshi, N.P.S. and Sharma, D.R. (2016). Utilization of organics, amendment and fertilizers with sodic water irrigation: long-term effect on soil properties and rice-wheat productivity. *J. Indian Soc. Soil Sci.,* 64(3), 255-260.

Yamaji, N., Takemoto, Y., Miyaji, T., Ueno, N.M., Yoshida, K.T. and Feng-Ma, J. (2017). Reducing phosphorus accumulation in rice grains with an impaired transporter in the node. *Nature,* 541, 92-95.

Zhang, H., Wang, B. and Xu, M. (2008). Effects of inorganic fertilizer inputs on grain yields and soil properties in a long-term wheat-corn cropping system in south China. *Commun. Soil Sci. Plant Anal.,* 39, 1583-1599.