Management of soil fertility and sustained crop productivity in rice-based agro-ecosystems in Mizoram, Northeast India

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Rice is the main staple crop grown in a large area under hill and lowland agriculture systems of Mizoram. However, the present rice production is not sufficient to meet the requirement of rice in the state because of the mismanagement of soil fertility and thereby increasing emissions of greenhouse gases. This paper discusses rice cultivation and production scenario in Mizoram and suggested the strategies for sustainable productivity through management of soil fertility, water balance, use of appropriate rice variety and adoption of effective plant protection. Further, improved soil fertility in these ecosystems will improve the carbon sequestration potential with less environmental impacts. Suggestions made were tested with a case study using combinations of various fertilizer (inorganic and biological alone and in combination) treatments viz. NPK, NPK + Biofertilizer, Biofertilizer in relation to Control to assess the effect of various treatments on soil nutrient status and crop yield in sub-tropical lowland agriculture systems of Mizoram. The combination of NPK + Biofertilizer revealed maximum increase in the level of soil nutrients and grain yield in rice cultivars followed by NPK, Biofertilizer and Control plots. Thus, integrated nutrient management (combinations of NPK + Biofertilizer) is suggested for sustained rice production with additional soil carbon storage in lowland and hill agro-ecosystems in Mizoram.

Key words: soil fertility management, sustained crop productivity, rice crop, Mizoram, biofertilizer, NPK

INTRODUCTION

Agricultural systems nowadays have great significance not only for their role in achieving food security but also have the potential to negate the impact of climate change due to enhancement of atmospheric CO$_2$ and other greenhouse gases by increasing the long term carbon (C) storage in the soil organic matter (IPCC 2001). In India, Green Revolution started in the 1960s based on use of commercial fertilizer and pesticides along with novel crop strains developed using genetics and biotechnology (Mooney et al., 2005), has made the country self sufficient for nourishing the growing populations. However, this agricultural intensification has negative impact on the soil fertility and thus there is a plateau formation in Indian agriculture production. Maintenance of soil organic matter is a major problem in sustained high crop production practices and environmental contamination in Indian agriculture (Kushwaha et al., 2000, 2001; Kaufman and Watanasak, 2011).

Presently, India is producing about 240 million tonnes (Mt) of food grains which needs to be doubled by the year 2050 to meet the growing population of the country. This can only be met by adoption of modern technologies in Indian Agriculture to overcome increasing challenges of biotic and abiotic stresses experienced by crops. Farming
in India is mainly practiced by farmers in small areas (1-4 ha) with lower fertilizer application (84.3 kg ha\(^{-1}\) in arable lands) compared to China (266.4 kg ha\(^{-1}\) in arable land) (Mondal et al., 2011). Researchers have shown that systematic soil testing followed by proper application of nutrient (nitrogen, N; phosphorus, P; potassium, K) NPK fertilizer can increase productivity level by 2-3 times in most of the Indian states (Mondal and Basu, 2009; Siddiq, 2000). Rice (Oryza sativa L.) is an important cereal crop and presently more than half of the World’s population subsists on this crop, which has great significance in the South-east Asian countries (Manzoor et al., 2006). As the World population is expanding exponentially and half of this increase is supposed to occur in Asian countries which are primarily based on rice food (Gregory et al., 2000). Thus, the management of rice based agricultural systems through soil organic matter is of prime importance for the country like India.

The nutrient requirement of natural ecosystems are met out by the proper recycling of organic matter and nutrients through the complex processes of mineralization and immobilization by microorganisms in soil (Tripathi and Singh 1992, Tripathi and Singh 1996, Tripathi et al., 2008). However, the bulk demands of these nutrients in agricultural systems are lacking because of less soil organic matter and weak microfloral development due to the continuous harvesting loss of organic matter. Therefore, agro-ecosystems soils are characterized by the lack of tight coupling of nutrients between plant and soil, and thereby the complex soil processes are strongly influenced to support the crop growth due to the lack of proper synchronization nutrient availability with crop demand (Tripathi et al., 2008; Tripathi and Singh, 2008; Tripathi, 2009). This leads to the loss of added soil nutrients from agro-ecosystems to ground water and riverine ecosystems (Tripathi and Singh, 2000; Tripathi, 2009). Hart et al., 1993 have reported that most of the added N (ca. 30% to 45%) is stored within or recycled through heterotrophic soil microflora. Agricultural systems in general and in tropical region in particular often require replenishment of N through exogenous sources as inorganic fertilizers. But the long-term sustainability of such systems is in question because rate of release of nutrient particularly N and P in soils often do not match crop demand with fertilizer applications (Robertson et al., 2000, Singh et al., 2007) due to the lack of micro-floral development. In addition, highly concentrated inorganic nutrient additions have been reported to have detrimental environmental impacts (Matson et al 1997, Venterea and Rolston 2000). Organic materials (crop residue, compost or green manures) have been advocated as an alternate source of nutrients (Tilman, 1998), and are considered to have the potential for conservation of soil moisture, one of the major constraints to crop productivity in dryland, besides providing soil nutrients (Singh et al., 2007). Thus, there is an urgent need to develop economically feasible and ecologically sound nutrient management in agricultural systems that conserve natural resources without any environmental impact. This can be possible by knowing the amount of nutrient flows and is susceptible for loss and by synchronizing soil nutrient release with that of crop nutrient (N and P) demand.

This paper presents the rice cultivation scenarios of Mizoram, a northeast Indian state, which includes problems of rice cultivation and the possible solutions for the sustained rice productivity by improving soil organic matter in the state with less environmental consequences.

Rice cultivation areas in the state of Mizoram

In Mizoram, majority of population (~60%) are dependent on agriculture production for their livelihood, however, only 5% of the total area is under cultivation and about 7% of the total cultivated area is under irrigation (Anon., 2010). Maize and paddy are the major food crops cultivated on the hill slopes and rely on the natural rainfall which is triggered by the south-west monsoon. In addition, pulses, sugarcanes, chillies, ginger, tobacco, vegetables, turmeric, potato, bananas and pineapples are the crops grown in the state. Forest accounts for nearly 89% of the total land area. Rice continues to remain the chief food crop and the staple food of the Mizo, however, Mizoram is still not self sufficient in rice production. State has undulating terrain which is divided into hills and valleys. Hills run north to south direction parallel to each other with valleys in between the two hills. Hills can be broadly categorized as: (i) high hills (> 1300 m amsl), (ii) medium hills (between 500 m and 1300 m amsl) and (iii) low hills (< 500 m amsl). According to land classification of the state based on soil survey, 58,638 ha of land has been demarcated as available potential land for paddy and other seasonal crops cultivation. The moderate slopes falling under Class III (55,196 ha), Class IV (1,50,015 ha) and Class VI (10,12,114 ha) which are suitable for terracing, horticulture and plantation crops respectively (Figure 1).

During the last 20 years (from 1986-2006) the area under rice cultivation was broadly constant with sharp increase in the rice production because of intense use of chemical fertilizers to meet the growing demand of population which was not sufficient at any time point (Anon., 2006). During the recent years the rice production has continuously decreased due to mismanagement practices operated in the past. This has led to tremendous pressure on the farmers and the local Government to increase rice production in the state on sustainable basis to make it self sufficient for rice which is one of the major staple crop of the state (Anon., 2006). Thus, there is an urgent need to increase the productivity of lowland to achieve self sufficiency in rice production. The cultivable land under rice (wet rice cultivation, WRC and
Prospects for rice cultivation and production in Northeast region

Rice is one of the main crops of the North-eastern region of India accounting for about 89% of the cropped area and 92% of the total food grains production (Misra and Misra, 2006). It is also a major crop of the North Eastern hilly ecosystem with an area of around one million hectare giving an average productivity of 1.45 t ha\(^{-1}\) (Anonymous, 1995). Rice cultivation area in North-eastern India accounts for 8.04* of the total geographical area and contributes 6.43 per cent of production of rice in the country, which indicated a significant decline in the average productivity of rice in the northeast region as compared to the national productivity (Anon., 2000). This region has rich diversity of local rice germplasm, and it is believed that the NEH region is the birthplace of rice in the world (Borthakur, 1993; Dhillon et al., 2001). Although there is a good potential for rice production in the state, Mizoram is lagging much behind the other advanced states in rice production. Increasing human population of the state has necessitated to increase the production of rice in Mizoram, which can be achieved through genetic manipulation and development of high yielding varieties suitable to this region (Gupta et al., 1995; Pattanayak et al., 1998; Reddy et al., 1999; Gupta,
2001); and by careful manipulation, efficient and judicious utilization and management of the resources available for rice cultivation in hills (Mishra and Gupta, 1998; Mishra and Satapathy, 2003; Mishra et al., 2004). Several studies were carried out by various workers on the integrated nutrient management in rice cultivation (Gaur et al., 1972; Tan, 1992; Padalia, 1975; Mishra and Sharma, 1997).

The net rice cultivable area in Mizoram is about 54,250 ha which produces 1,03,040 tonnes of rice annually with an average productivity of 1.90 t ha$^{-1}$. The cultivable land under lowland rice accounts for ~25% of the total rice cultivation area and ~40% of the total rice production with an average productivity of 2.82 t ha$^{-1}$. Rice under lowland (2.82 t ha$^{-1}$) has recorded higher per unit area of productivity than Jhum cultivation (1.57 t ha$^{-1}$). This is mainly because of loss of top fertile soils along with organic matter and nutrients from the shifting cultivation sites and their deposition into lowland rice cultivation area because of frequent rains.

Majority of the wet rice cultivation (WRC) areas of Mizoram are practiced on 0-5% slopes. Recently, the state Government has worked out a plan to calculate the potential of WRC area on 5-10% slope that has been estimate to be about 74,644 hectares, which would account for ~3.54% of the state's total geographical area. The net area cultivated is about 11,198 hectares that is, about 15 per cent of the total WRC potential area (Lalzarliana, 2010). Forests cover account for about 9610.95 Km$^2$ or 9,61,095 hectares, that is, 45.58 per cent of the total land area. An area of 3965.91 Km$^2$ is under 'jhum' which is 18.80 per cent of the geographical area. Thus, development of lowlands having potential for rice cultivation and providing minor irrigation may be recommended to encourage settled cultivation in valleys and terraced slopes.

Until now, most yield increases in rice have come from the combination of modern high yielding varieties and increased use of fertilizer. This approach was highly efficient but there are strong indications about the plateau formation in rice yield due to decrease in N use efficiency. Thus, enhancement of nutrient use efficiency must focus primarily on minimizing N losses and maximizing physiological N utilization by the rice plant. Institutional and policy support to farmers is crucial for ensuring agricultural input supplies, farm credit, and minimum support price in a holistic approach for sustainable increase in rice production. Even with the existing technologies it is possible to increase the production by closing the yield gaps in rice. Commercial fertilizer applications to tropical soils under intensive agriculture often reduce overall soil fertility because of the eventual depletion of other plant nutrients as result of deceased soil organic matter content and increased runoff and leaching losses of nutrients from the system, and causing eutrophication of rivers and lakes (Tripathi, 2009).

In the next 5 years much emphasis is being placed to restore soil health that should support sustained crop productivity in the state. In this regards, the recent New Land-use Programme (NLUP) of Mizoram has emphasized state’s Government plan to extend rice cultivation in the low land while keeping a larger area of the hill slopes for afforestation and forestry sector. An attempt is also being made to reclaim land having potential for wet rice cultivation and also to provide irrigation facilities to encourage settled cultivation in valleys and terraced rice cultivation on slopes (Anon., 2010). This would, reduce the pressure on the declining forests in the hill slopes due to practice of shifting cultivation. It has been estimated that the annual rice production could be doubled or increased even more if all the potential lowland areas are developed for rice cultivation with appropriate nutrient management strategies. Thus, extension of rice cultivation in lowland of Mizoram on permanent basis using integrated nutrient management is suggested as one of the most effective and viable alternative to increase the rice production which is an ecologically sound and economically feasible option to replace rice cultivation in hill slopes of Mizoram. Farmers may be encouraged to grow other cash crops depending upon the slopes, edaphic and climatic factors, or they may be advised to take up other trades related to forestry, horticulture and agroforestry sectors. This presents the result of the soil fertility management trials carried in rice based agro-ecosystems in Mizoram to achieve the goals of sustained crop productivity and social livelihood by maintaining the soil fertility.

**MATERIALS AND METHODS**

**Study area and location of the experiment**

The experimental site was located (24°23′ - 24°23′ N lat and 92° 69′ - 92° 71′ E long) about 5 km apart from Kolasib town along the side of Bairabi main road. The elevation of the study site is 218 m amsl. Climate of the Kolasib district is tropical monsoon type having humid and warm summer and dry and cool winter. The climate of the study site is influenced by the periodic cyclonic disturbances, local mountain and valley breezes. The study area falls under sub-tropical with hot and wet summer and moderately cold and dry winter. May and June are the hottest months in a year with maximum air temperature of 36±2°C and the January is the coldest month with minimum air temperature of 7±2°C. The percent mean Relative Humidity (RH) increases from May to August reaches maximum with on-set of North East monsoon and the lowest during dry period (from January-March).

The soils in the valley flat lands of Kolasib District are dominated mainly by loose sedimentary formations, deep and moderately to poorly drained. The soils are brown to
dark brown, poor in bases, moderately acidic to neutral with pH ranging from 6.5 to 7.5, organic carbon content 0.5-1.0%, available phosphate 0.005-0.007%. The texture of the soil is mostly sandy loam to sandy clay loam. The percent clay, silt and sand in the upper 50cm soil ranges from 15-35, 10-34 and 40-75, respectively, in these soils (Anon., 2010).

Experimental design and field

The experiment was conducted during wet seasons (from May–October) in 2005 and 2006 using Randomized Block Design (RBD) with three replications. There were 12 sub plots in each replication (3 Rice cultivars x 4 nutrients) and the total sub–plots were 36 with 3 replications. The size of each sub-plot was 4m x 4m (16 m²) with gap of 0.5m between sub-plots. Three rice cultivars (IR-64, Shahsarang and RCPL – 187-4 Lumpanas) were cultivated in the experimental plots under different nutrients applications.

Nutrient application

A mixture of Urea for N, single super phosphate for P and Muriate of Potash for K was applied in the field at 80, 60 and 40 kg ha⁻¹, respectively in two split doses in the main field before and after transplanting of rice. The full dose of P and K with half dose of N was applied in two split doses at tillering and panicle initiation stages. *Azospirillum* and *Phosphobacter* were used as a biofertilizer in the present study. *Azospirillum* and *Phosphobacter* treatment is given in the seed and seedlings of rice before transplanting. Equal quantity (200 g powder) of *Azospirillum* and *Phosphobacter* was dissolved in 450 ml of water and the seeds are soaked one night before sowing in the nursery bed and dried. The root portions of transplanted rice seedlings are dipped in bacterial suspension for 15-30 minutes and then transplanted.

Soil analysis

Soil nutrient analysis was done at the beginning of the study (June) at each site with three replicates (n=3) from 0-15cm depth. Soil nutrient status of the experimental plots was recorded before (i.e. May) and after (i.e. July) nutrient application, and after harvesting of rice (that is, November). For the analysis soil samples were collected from different plots and mixed thoroughly and brought to the laboratory in sterile bags and analysed. Soil subsamples were air-dried and passed through a 2-mm sieve for analysis. Soil organic carbon, total N, available P and exchangeable K was analysed as per the methods outlined Jackson (1958). Soil was digested with concen trate H₂SO₄ and N was determined by the micro-Kjeldahl distillation method. P was estimated by phosphomolibdic blue color method using colorimeter as per Olsen Method (Olsen *et al*., 1954) and K with a flame photometer (Ghosh *et al*., 1983).

RESULTS AND DISCUSSION

Effect of nutrient application on soil fertility

The variation in soil pH across the experiment and before and after the experiment ranged from 6 to 7. The soil pH tended to increase after application of fertilizers in relation to control, however, it decreases in the second year compared to first year (Figure 3a). N addition has been reported to decrease the soil pH and increase Al toxicity in soils many natural ecosystems across the World (Koehler *et al*., 2009; Liu *et al*., 2011, Ramirez *et al*., 2012). Soil organic C content varied from 0.5-0.9% across the treatment, year and crop stages (Figure 3b). However, the variations were not significant between the year and the stages of rice but marked variations were recorded across the treatment with a maximum in NPK+biofertilizer treatment. In general, NPK content of the soil increased after the addition of nutrients but the significant increase was noted in NPK+biofertilizer treatment after the application (Figure 3c-e). This suggests that combination of inorganic and biofertilizer is most suitable for the soil nutrient management in these systems. Treatment effect before the start of the experiment was not significant. However, most nutrients are significantly decreased in the soil after the harvest of rice suggesting the amount of nutrients loss from the system due their incorporation in rice plant and their possible loss due to harvesting. Further, the nutrient depletion was recorded in the second year compared to first year across the year and the stages. However, the decrease was marked in NPK+biofertilizer and biofertilizer treated plots suggesting that this combination is sufficient to meet the nutrient requirement of the rice crop in this region with decreased leaching losses of nutrient from the system due to increased soil microbial activity. Long term experiments clearly indicated that a balanced use of NPK fertilizer, especially in combination with organic manure not only maintained, but even improved soil productivity (Nambiar and Ghosh, 1984; De Datta *et al*., 1988). Majority of the inorganic N addition seems lost from the system through leaching, runoff, denitrification and volatilization (von Uexkull, 1993). Further, in order to make an in-depth evaluation of the nutritional aspects of soil a separate investigation involving interdisciplinary approach would be needed.

Effect of nutrient application on rice yield

The grain yield of rice was significantly affected by NPK,
Biofertilizer and NPK + Biofertilizer treatments in three rice cultivars \( (p \leq 0.05) \). The maximum grain yield of the three rice cultivars was recorded under NPK+ Biofertilizer treatments followed by that under NPK and Biofertilizer compared to Control (Figure 4). This indicates that the productivity of rice cultivation in the lowland of Mizoram is significantly increased with combinations of organic and inorganic nutrients.

The cost-benefit ratio (CB-ratio) of rice cultivation (taking the average of the three rice cultivars) under NPK, NPK + Biofertilizer, Biofertilizer and Control is worked out to be 1:2.6, 1:3.0, 1:2.6 and 1:1.9 respectively (Figure 5). The Cost-benefit ratio of rice cultivation for NPK + Biofertilizer is almost double to that of Control indicating that this would be the more suitable combination than the others for rice cultivation in lowland of Mizoram. However, the optimum dose of fertilizer, organic and biofertilizer amendment would need further study and analysis for a few more years to recommend more suitable options for the farmers of Mizoram.

**Conclusion**

Expansion of rice cultivation area to potential area of 74,644 hectares with proper soil fertility management...
through exogenous inorganic and organic nutrients, water balance, use of appropriate rice variety and adoption of effective plant protection measures may be the possible solutions to sustain the rice productivity and the livelihood of the people in Mizoram. The extension of rice cultivation in lowland of Mizoram on permanent basis may be one of the most effective and viable alternative to increase the rice production, and would also be an ecologically sound and economically feasible option to replace rice cultivation in hill slopes of Mizoram.

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