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# Can sustainability of maize-mustard cropping system be achieved through balanced nutrient management?

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ABSTRACT

Information on optimization of nutrient management (NM) protocols for maize-mustard cropping system to achieve sustainability with regards to crop yield, nutrient use efficiency, soil quality, energy balance and profitability is limited. We evaluated NM practices for maize-mustard cropping system in a comprehensive manner using five criteria such as i) crop yield response, ii) recovery efficiency of plant nutrients, iii) soil quality index, iv) energy efficiency, and v) profitability of cultivation for acidic soils under subtropical conditions of northeast India. Eight NM treatments comprising of organic [farmyard manure (FYM)], inorganic fertilizers including micronutrients (Zn, B) and some of their combinations were tested using randomized complete block design with three replications for five consecutive maize-mustard cropping sequences during 2010–2015. Yield and yield related characters of the crops were recorded and nutrient concentration in representative plant parts was analysed for determination of their uptake, harvest index and use efficiency at each harvest. The initial and post-harvest (after fifth cropping sequence) soil samples were collected at 0-0.20 m depth from each of the experimental plots and analysed for physical, chemical and biological soil quality attributes. Energy and economic efficiency of the cropping systems was computed using fertilizers, seeds, plant protection chemicals, farm machineries for tillage and irrigation and human labor inputs and crop yield outputs. Yield and yield related characters, plant nutrient uptake and use efficiency, energy and economic variables of cultivation and soil properties were subjected to analysis of variance. Balanced supply of nutrients including micronutrients (Zn, B) through integration of organic and inorganic sources was proved to be sustainable in respect of crop productivity, economic viability and maintenance of environmental health. This helped improve recovery efficiency of applied nutrients as well as soil quality by increasing soil organic C, microbial biomass C and plant available nutrient content. Integrated use of 120-35-50-5-1 kg N-P-K-Zn-B with 10 Mg FYM ha$^{-1}$ was proved to be the best due to significantly higher crop yield (5.80 Mg kernel and 1.22 Mg grain ha$^{-1}$ for maize and mustard, respectively), recovery efficiency of applied nutrients (average recovery efficiency 64.5%), soil quality index (2.0), energy efficiency (energy gain 234,530 MJ ha$^{-1}$) and economic return (marginal rate of return 3.5) as compared to the other NM treatments. Application of 120-35-50-5-1 kg N-P-K-Zn-B ha$^{-1}$ or its combination with reduced rate of organic manure (5 Mg FYM ha$^{-1}$) can also achieve sustainability with minimum conciliation with yield, nutrient recovery, environmental quality and economic benefit. Supply of nutrients only through organic sources (e.g., FYM) will not be sustainable for maize-mustard cropping system.

## 1. Introduction

Maize (*Zea mays* L.)-mustard (*Brassica campestris* L.) cropping sequence is the most predominant in subtropical hill agro-ecosystems of northeast India. Both maize and mustard deplete high amount of nutrients from the soil (Das et al., 2010). This necessitates for replenishment of nutrients in the soil to maintain crop nutrition and productivity of the cropping system. Light textured acidic soils of northeast India,

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which receive high precipitation and contain abundant amount of Fe and Al oxides and hydroxides, are inherently deficient in micronutrients, particularly in Zn and B (Dwivedi et al., 1993; Kumar et al., 2016; Sarkar et al., 2008). Routine application of micronutrient free high analysis N-P-K fertilizers for crop production may further accentuate deficiencies of micronutrients in soils (Batabyal et al., 2015; Seth et al., 2017). Zinc deficiency often results to poor seed germination and seedling development (Alloway, 2008), while B deficiency has been associated with poor root growth (Brown and Hu, 1997). Zinc and B are specifically required for development of reproductive organs, pollen fertility and seed formation of maize and mustard (Malhi et al., 2003; Sharma et al., 1990, 1987). Impairment of these functions due to inadequate supply of Zn and B negatively influence productivity of these crops. Therefore, application of only macronutrients (N-P-K) without synchronized use of micronutrients may not be adequate to harvest optimum yield of maize-mustard cropping in the region.

In addition, fertilizer use is inadequate, imbalanced and poorly managed in northeast India (Sarkar et al., 2016). As a result, productivity of the maize-mustard cropping system in the region i.e., 1.5 Mg maize kernel $ha^{-1}$ + 0.6 Mg mustard grain $ha^{-1}$ is lower than the national average i.e., 1.7 Mg maize kernel $ha^{-1}$ + 1.2 Mg mustard grain $ha^{-1}$ (Das et al., 2010; Joshi et al., 2005). Besides, a suitable integration of inorganic and organic sources of nutrients can constitute effective strategy for closing crop yield gaps in a sustainable manner (Batabyal et al., 2016; Mandal et al., 2008). Fertilizer application to crop is costly in terms of financial cost of production and also in terms of environmental pollution (e.g., eutrophication, N footprint; Mueller et al., 2012). These necessitates for increasing nutrient use efficiency for economic viability as well as environmental sustainability of agro-ecosystems (Sarkar and Baishya, 2017). Soil quality is a critical indicator of sustainable land use. The capacity of soil to provide ecosystem services for a agro-ecosystem are determined by a set of chemical, physical and biological attributes of soil quality (Andrews et al., 2004). Assessment of soil quality, therefore, requires selection of indicators, which are sensitive to changes with anthropogenic management practices (Basak et al., 2016). Besides, crop production now-a-days requires substantial amounts of energy inputs in the form of fertilizers, pesticides, fossil fuels and electricity and its environmental consequences include emission of greenhouse gases to the atmosphere and deterioration of soil, water and air quality (Gelfand et al., 2010; Robertson et al., 2000). Judicious use of energy resources helps achieve optimum crop productivity, which contributes to sustainability to rural livelihoods (Singh et al., 2016).

Previous work demonstrated effects of NM practices exclusively on growth and yield (Gupta et al., 2014; Mahala et al., 2006), yield and nutrient removal (Chandel et al., 2014; Das et al., 2010), nutrient use efficiency (Fageria, 2009; Setiyono et al.; 2010), yield, nutrient efficiency and profitability (Adamtey et al., 2016; He et al., 2009; Pathak and Singh, 2002), yield and soil properties (Prasad et al., 2010; Saha et al., 2010; Sharma and Subehia, 2003; Odunze et al., 2017), soil quality (Dutta et al., 2015; Sofi et al., 2016) and energy use efficiency (Gelfand et al., 2010; Šarauskis et al., 2014; Singh et al., 2016) for maize-based cropping systems. Recently, NM technologies were assessed for cauliflower (*Brassica oleracea* var. *botrytis* L.), broccoli (*Brassica oleracea* var. *italica* L.) and eggplant (*Solanum melongena* L.) taking crop yield and quality, soil quality, carbon and energy balance and economic benefit together as the goal variables (Batabyal et al., 2017, 2016; Tamang et al., 2017). Because of these, we hypothesized that the NM protocols used for maize-mustard cropping system is likely to influence not only crop yield but also nutrition of crop, soil quality, energy balance and profitability of cultivation. Comprehensive assessment of a NM technology considering its influence on all the above parameters is important. This is necessary to screen out the best NM options, which will focus on the current concept of 'farming for health', food and livelihood security of farming community. This experiment was undertaken with the objective to evaluate NM practices for maize-mustard cropping system considering their influence on all the above parameters in a comprehensive manner.

## 2. Materials and methods

### 2.1. Experimental site

The experimental site (24°50.343′ N, 93°55.359′ E, 791 m above msl) is located at the foothill of the Langol Research Farm, Indian Council of Agricultural Research (ICAR) Research Complex for North Eastern Hill Region, Imphal, India. The farm is covering an area of 15 ha and the moderately sloping foothill of the farm is converted into bunded terraces. Rice (*Oryza sativa* L.), maize (*Zea mays* L.), groundnut (*Arachis hypogaea* L.), cowpea [*Vigna unguiculata* (L.) Walp.], common bean (*Phaseolus vulgaris* L.), broad bean (*Vicia faba* L.), mustard (*Brassica campestris* L.) and pea (*Pisum sativum* L.) are grown in the farm and plantation of mango (*Mangifera indica* L.), *Citrus* species, guava (*Psidium guajava* L.), papaya (*Carica papaya* L.) and pineapple [*Ananas comosus* (L.) Merr.] is also there. The climate is subtropical and the soil (*Typic Dystrudepts*) is a sandy clay loam in texture, which is developed on alluvium and colluvium drawn from higher slopes (Sahoo et al., 2010). Daily weather parameters during the experimentation were collected from the meteorological observatory of the farm.

### 2.2. Treatments and crop management

Eight NM treatments (Table 1) were tested for five consecutive maize-mustard cropping sequences during 2010–2015 in a randomized complete block design (10 m × 5 m plots) with three replications. The application rate of inorganic fertilizers and FYM were selected based on the recommendation for the State (Raychaudhuri et al., 2000) and taking into consideration of the economics, which involved huge transportation and labor costs. Urea, single super phosphate, potassium chloride, zinc sulphate ($ZnSO_4.7H_2O$) and borax ($Na_2B_4O_7.10H_2O$) containing 46, 16, 60, 21 and 11% of N, P, K, Zn and B were used as inorganic sources of fertilizers, respectively. Composite maize (cv. Pusa Composite 3) was grown in the rainy (*Kharif*) seasons under rainfed situation. Every year, one month before sowing of maize, well decomposed FYM was mixed within 0.20 m soil depth during land preparation. Nutrient content of FYM was 4.7 g N, 1.1 g P, 1.8 g K, 98 mg Zn and

**Table 1**
Nutrient management treatments for maize-mustard cropping system.

| Treatment | Maize | Mustard |
|---|---|---|
| Control | No fertilizer and farmyard manure | No fertilizer and farmyard manure |
| FYM10 | Farmyard manure at 10 Mg $ha^{-1}$ | No fertilizer and farmyard manure |
| NPK | 120-35-50 kg N-P-K $ha^{-1}$ | 40-12-16 kg N-P-K $ha^{-1}$ |
| NPKZnB | 120-35-50-5-1 kg N-P-K-Zn-B $ha^{-1}$ | 40-12-16 kg N-P-K $ha^{-1}$ |
| NPKZnB + FYM10 | 120-35-50-5-1 kg N-P-K-Zn-B $ha^{-1}$ + FYM at 10 Mg $ha^{-1}$ | 40-12-16 kg N-P-K $ha^{-1}$ |
| NPKZnB + FYM5 | 120-35-50-5-1 kg N-P-K-Zn-B $ha^{-1}$ + FYM at 5 Mg $ha^{-1}$ | 40-12-16 kg N-P-K $ha^{-1}$ |
| ½NPKZnB + FYM10 | 60-17.5-25-2.5-0.5 kg N-P-K-Zn-B $ha^{-1}$ + FYM at 10 Mg $ha^{-1}$ | 20-6-8 kg N-P-K $ha^{-1}$ |
| ½NPKZnB + FYM5 | 60-17.5-25-2.5-0.5 kg N-P-K-Zn-B $ha^{-1}$ + FYM at 5 Mg $ha^{-1}$ | 20-6-8 kg N-P-K $ha^{-1}$ |