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Productivity and soil fertility of the rice–wheat system in the High Ganges River Floodplain of Bangladesh is influenced by the inclusion of legumes and manure

M. Shakhawat Hossain[a], Akbar Hossain[b,*], M.A.R. Sarkar[c], M. Jahiruddin[d], Jaime A. Teixeira da Silva[e,**], M. Israil Hossain[f]

[a] On-Farm Research Division, Bangladesh Agricultural Research Institute, Rajshahi, Bangladesh
[b] Wheat Research Centre, Bangladesh Agricultural Research Institute, Dinajpur 5200, Bangladesh
[c] Department of Agronomy, Bangladesh Agricultural University, Mymensingh, Bangladesh
[d] Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh
[e] P.O Box 7, Miki-cho post office, Ikenobe 3011-2, Kagawa-ken 761-0799, Japan
[f] Bangladesh Agricultural Research Institute, Joydebpur, Gazipur, Bangladesh

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ABSTRACT

Productivity of the rice–wheat system is critical to the food security of Bangladesh. However, many concerns about the sustainability of this system exist because of low soil organic matter (SOM). In this context, an experiment was performed in the agro-ecological zone of the High Ganges River Floodplain (HGRF) at the Regional Wheat Research Centre (RWRC), Rajshahi of the Bangladesh Agricultural Research Institute (BARI) over two consecutive years, 2009–2010 and 2010–2011. The experiment evaluated the productivity and changes in soil fertility of the wheat–rice cropping sequence as influenced by an integrated plant nutrition system (IPNS) and through the inclusion of legume crops. Two factors were considered: cropping sequence and IPNS treatment. A legume crop was fitted to the existing wheat–rice sequence, resulting in four cropping sequences: wheat–mungbean–rice, wheat–blackgram–rice, wheat–dhaincha–rice and wheat–fallow–rice. There were six fertilizer/manure treatments: 100% recommended artificial fertilizer, farmers' practice (FP) and four IPNS treatments. The IPNS treatments comprised two rates of poultry manure (PM; 3 and 6 t ha^{-1}) and cowdung (CD; 5 and 10 t ha^{-1}). For the IPNS treatments, 100% nutrient rates were adjusted with manure (PM and CD) and artificial fertilizers. The inclusion of legumes in the wheat–rice cropping sequence, particularly the use of mungbean, resulted in the highest productivity. This system rendered 57% higher wheat equivalent yield (WEY) than the wheat–fallow–rice cropping sequence. The incorporation of legume residues into the soil increased SOM, total N, available P and available Zn, but exchangeable K and available S were depleted under all crop rotations. The simultaneous use of chemical fertilizer and organic manure (OM; PM and CD) with the IPNS approach resulted in higher crop productivity and system WEY as well as higher rates of OM, especially IPNS with 6 t ha^{-1} PM. This indicates that chemical fertilizers alone could not provide adequate and balanced nutrition for potential yield of the tested crops. SOM, total N, available P and available Zn improved in treatments that included OM (both PM and CD) but the increment was greater in the combination of IPNS with higher rates of both OMs in the wheat–dhaincha–rice cropping sequence. K and S decreased in all nutrient treatments compared to initial soil. The wheat–mungbean–rice cropping sequence under IPNS with OM (especially 3–6 t ha^{-1} PM) resulted in best crop productivity (wheat, 4.55; rice, 5.48; WEY of mungbean, 4.54 and system WEY, 13.19 t ha^{-1}) in both years.

Abbreviations: AEZ, agro-ecological zone; BARC, Bangladesh Agricultural Research Council; BARI, Bangladesh Agricultural Research Institute; BBS, Bangladesh Bureau of Statistics; FP, farmers'practice; FYM, farmyard manure; GM, green manure; GY, grain yield; HGRF, High Ganges River Floodplain; IPNS, integrated plant nutrition system; OC, organic carbon; OM, organic manure; PM, poultry manure; RWRC, Regional Wheat Research Centre; SOM, soil organic matter; STB, soil test and high yield goal basis; STVI, soil test value interpretation; WEY, wheat equivalent yield.

* Corresponding author.
** Corresponding author.
E-mail addresses: tanjimar2003@yahoo.com (A. Hossain), jaimetex@yahoo.com (J.A. Teixeira da Silva).

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1. Introduction

The rice–wheat (R–W) system is one of the world's largest agricultural production systems, covering an area of 26 million ha, spread over the Indo-Gangetic Plains (IGP) in South Asia (about 12.37 million ha) and China (Balasubramanian et al., 2012; Chauhan et al., 2012). In South Asia, it occupies 9.2 million ha in India, 2.2 million ha in Pakistan, 0.4 million ha in Bangladesh, and 0.55 million ha in Nepal, extending across the IGP into the Himalayan foothills (Timsina et al., 2010). The R–W system contributes 97% of total food grain production (BBS, 2012; Hossain and Teixeira da Silva, 2013a,b) and 94% of the national calorie intake in Bangladesh (Timsina and Connor, 2001; Hossain and Teixeira da Silva, 2013b). It is estimated that demand for food and non-food commodities is likely to increase by 75–100% globally between 2010 and 2050 (Keating et al., 2010; Tilman et al., 2011). The increase in demand in South Asia is expected to be at least as much. As there is little scope for expanding the area under cultivation in South Asia, there is thus an urgent need to further intensify land use and increase productivity of cereal systems to meet growing demand. Projections indicate that the production of rice, wheat, and maize must increase by about 1.1%, 1.7%, and 2.9% per annum, respectively, over the next four decades to ensure food security in South Asia (Ladha et al., 2003a; Gathala et al., 2013). To meet this increasing demand for cereals, there is a need for crop intensification while increasing resource-use efficiency and reducing the environmental footprint or 'ecological intensification' (Ladha et al., 2009; Doré et al., 2011; Hochman et al., 2013). Soils in the IGP contain low soil organic matter (SOM) content and are being consistently depleted of their finite reserve of nutrients by crops (Singh et al., 2004). This is because farmers in the IGP traditionally remove wheat and rice straw from fields for use as cattle feed and several other purposes such as livestock bedding, thatching material for houses and bio-fuel (Samra et al., 2003; Chauhan et al., 2012). Earlier findings noted that the R–W system has been depleting the major nutrients-N (nitrogen), P (phosphorous), K (potassium), and S (sulphur)—from the soil and thus creating a nutrient imbalance, leading to deterioration in soil quality through declining SOM (Bhandari et al., 2002; Alam et al., 2013). As a result, the productivity of the R–W system is decreasing with deficiencies in N, P, and K being the most extensive. One ton of wheat grains is estimated to remove 24.5, 3.8, and 27.3 kg of N, P, and K, respectively, whereas similar production of rice grains removes 20.1, 4.9, and 25.0 kg of N, P, and K (Chauhan et al., 2012). Therefore, an increasing scarcity of resources (soil fertility, labour, water, and energy) and rising production costs, together with variable climate, are major challenges for sustainability of the R–W system (Chauhan et al., 2012; Gathala et al., 2013).

SOM is an important factor for sustainable soil fertility and productivity and the continuous use of organic materials such as crop residues, green manure (GM) and animal manure strongly influence soil productivity and N dynamics in the soil–plant system (Timsina and Connor, 2001; Schmidt and Merbach, 2004; Leite and Madari, 2011; Chauhan et al., 2012; Singh et al., 2014). The R–W production system generates a large amount of crop residues annually. The inclusion of legume crops as GM or grain legumes in the R–W cropping system is more beneficial than a simple R–W sequence (Singh et al., 2011; Gathala et al., 2013; Cupina, 2014) and holds promise in organic agriculture (Sarkar et al., 2004). Legumes in rotation are not only responsible for biological nitrogen fixation, but can also improve nutrient availability, soil structure, reduce the incidence of disease and promote mycorrhizal colonization (Wani et al., 1995; Cupina, 2014). Using *Sesbania* sp. as GM in a rice–rice system increased the organic carbon (OC) content of soil from 0.29% to 0.45% over six years at Ludhiana, India (Ali, 2003). *Vigna radiata* L. and *Phaseolus mungo* L., two grain legumes, mature in 60–80 days and can thus be easily grown as short duration summer pulse crops in the fallow period between wheat and rice. The inclusion of legumes in the R–W system would thus supply biomass and N to soil. Moreover, farmers can reap seeds, providing a valuable supplemental source of vegetable protein and possibly an additional economic source of revenue (Singh et al., 2005; Timsina et al., 2006; Gathala et al., 2013).

Livestock manure provides N, P, K, S and many trace minerals and also serves as a soil conditioner by increasing SOM and improving soil porosity and water holding capacity (Rahman et al., 2014). In Bangladesh, the poultry industry has grown considerably, increasing the stock of poultry manure (PM). As PM contains a high concentration of nutrients (Agbede et al., 2008; Chan et al., 2008), the addition of even a small quantity, in an integrated manner or alone, could meet the shortage of cowdung (CD) or farmyard manure (FYM) to some extent. Chan et al. (2008),Agbede et al. (2008) and Chauhan et al. (2012) reported that PM significantly reduced soil bulk density and temperature, increased SOM, soil and leaf N, P, K, calcium (Ca) and magnesium (Mg) concentrations, and increased the porosity and moisture content of soil in the R–W cropping system. On the other hand, an integrated plant nutrition system (IPNS) can be a good approach to combat nutrient depletion and to promote sustainable crop production. IPNS as a concept and farm management strategy embraces and transcends from single season crop fertilization efforts to planning and management of plant nutrients in crop rotations and farming systems on a long-term basis for enhanced productivity, profitability and sustainability (FRG, 2012).

There is a large volume of information available on nutrient management in R–W systems with chemical fertilizer alone or with the use of organic sources but those studies have focused primarily on agronomic aspects (Bhandari et al., 2002; Ladha et al., 2003b; Chauhan et al., 2012). However, very little or no information is available on an IPNS approach to sustain such systems. Therefore, the present study was undertaken to evaluate the diversification of the R–W cropping system in relation to IPNS-based nutrient management for sustaining productivity and soil fertility.

2. Materials and methods

2.1. Experimental Site

An experiment based on a two-year R–W cropping sequence was established at the Regional Wheat Research Centre (RWRC), Rajshahi of the Bangladesh Agricultural Research Institute (BARI) (24°22′N; 88°39′E; 20 masl) during November 2009–October 2011. The experimental site belongs to the agro-ecological zone of the High Ganges River Floodplain (AEZ-11) (FRG, 2012). Texturally, the soil is a silty clay loam of pH 8.4 and with 0.81% organic matter. The site is on flood-free, high land with medium-permeability soil (FRG, 2012; Table 1).

Seasonal weather data including rainfall, relative humidity, mean daily minimum and maximum temperature, and solar radiation (sunshine hours) for the study period are presented in Fig. 1 and Fig. 2.

2.2. Experimental design and treatments

A two-factorial experiment was conducted for two consecutive years (2009–2010 and 2010–2011) to achieve the objectives of this study. Six nutrient management treatments were compared for four R–W cropping sequences. There were 24 treatment combinations in the experiment. A split-plot design with three replications was used, with cropping sequences as main plots and nutrient treatment as sub-plots. Thus, the field experiment