Agriculture, Ecosystems and Environment 231 (2016) 79–97

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Productivity impacts and nutrient balances of an intensive potato-mungbean-rice crop rotation in multiple environments of Bangladesh

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ARTICLE INFO

Article history:
Received 29 January 2016
Received in revised form 19 June 2016
Accepted 20 June 2016
Available online xxx

Keywords:
Balance
Crop rotation
Economics
Mungbean
Nutrient
Potato
Productivity
Rice
Uptake

ABSTRACT

Bangladesh needs to produce more food on less land to assure future food security for an increasing population. The two techniques that need to be adopted more frequently are an increase in cropping intensity by producing two or more crops on the same piece of land, and an increase in the productivity of individual crops, particularly their ability to utilize basic or limiting resources such as water and nutrients. In this context, the present study was carried out to assess the most suitable crop rotation based on the dose of organic and inorganic fertilizers as a source of plant nutrients. The potato–mungbean–T. (transplanted) *Aman* rice (P-M-R) crop rotation was applied to three agro-ecological zones (AEZs) of Bangladesh (Bogra, AEZ-25; Joydebpur, AEZ-28; Jessore, AEZ-11). The results from a two-year experiment indicate that the yield of P-M-R was influenced by the nutrient management applied. Except for potato, higher yield was obtained in the second year. The yield of potato and T. *Aman* rice was highest when crop residues were incorporated. In all locations, N (nitrogen) and K (potassium) were depleted in both years, but P (phosphorus), S (sulphur), Zn (zinc) and B (boron) showed a positive balance. Even after completing two cropping cycles and incorporating crop residues with different levels of nutrients, there was little change in soil pH, organic matter (%), total N (%), P, K, S, Zn and B. However, in all three locations, organic matter (%), total N (%), P, K, S, Zn and B increased in plots into which crop residues had been incorporated. The soil test-based nutrient management choice that incorporated crop residues gave a higher net return (3506 US\$ ha^{-1}) than other nutrient management combinations (3351–3483 US\$ ha^{-1}). These results indicate that soil test-based nutrient management and an integrated plant nutrient system that incorporates crop residues are suitable for the potato–mungbean–T. *Aman* rice crop rotation in multiple environments of Bangladesh.

1. Introduction

The population of Bangladesh is increasing rapidly. The current population is 159 million but FAOSTAT projects that the number will increase to 185 million by 2030 and to 202 million by 2050 (FAOSTAT, 2016). Bangladesh has undergone tremendous changes in recent decades in terms of land use. This has affected the intensity of crop rotations. Urbanization and industrialization led to a decrease in the available land area for agriculture by approx. 0.25% annually during 1976–2010, and this rate is expected to continue in the future (BBS, 2011). Bangladesh also suffers regularly from several natural calamities (Haq et al., 2012), which

Abbreviations: AEZ, agro-ecological zone; ARS, Agricultural Research Station; BCR, benefit cost ratio; CD-N-P-K-S-Zn-B, cowdung nitrogen phosphorus potassium sulphur zinc boron; CON, control; CRI, crop residue incorporation; FP, farmers' practice; FRG, fertilizer recommendation guide; HYG, high yield goal; IPNS, integrated plant nutrient system; MBCR, marginal benefit cost ratio; MYG, moderate yield goal; OC, organic carbon; OM, organic matter; P-M-R, potato–mungbean–T. *Aman* rice; SSNM, site-specific nutrient management; SA, strongly acidic; STBN, soil test-based nutrient; T, transplanted.

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http://dx.doi.org/10.1016/j.agee.2016.06.032
0167-8809/

may worsen in the future due to climate change (Hossain and Teixeira da Silva, 2013). Thus, Bangladesh needs to produce more food on less land to assure future food security. To achieve this, the two techniques that need to be adopted more frequently are an increase in the cropping intensity by producing two or more crops on the same land all-year round, and an increase in the productivity of individual crops, particularly their ability to utilize basic or limiting resources such as water and nutrients (FAOSTAT, 2013; Dobermann et al., 2013; Ladha et al., 2016). The demand for food and non-food commodities is estimated to increase by 75–100% globally between 2010 and 2050 with many developing countries, including those in South Asia (India, Bangladesh and Nepal), needing to double their food production (Tilmana et al., 2011; Alexandratos and Bruinsma, 2012). Since there is limited scope for expanding the area under cultivation in South Asia, there is an urgent need to further intensify land use and increase productivity of cereal systems to meet this growing demand (Dobermann et al., 2003a,b).

The total land area of Bangladesh is about 14.84 Mha (million hectares), of which 3.74 Mha (25% of the total) is not available for agriculture due to use for urban areas, industrial buildings, rural homesteads, roads and other infrastructure. The net area of Bangladesh for crop cultivation declined to 7.84 Mha in 2011 from 8.85 Mha in 1985 (BBS, 2012). On the other hand, due to an increase in annual cropping on the same piece of land, sometimes as much as a four-fold increase, the total harvested crop area increased by 14.95 Mha between 1985 and 2011 (BBS, 2012). Therefore, to meet the food demands of an increasing population, crop rotation may include a range of cropping options from mono-cropping to multiple crops depending on the ecological conditions of the area. These crop rotations would not only provide staple food to millions of people but would also affect the livelihood and health of both rural and urban populations.

A crop production system with high yield targets is not sustainable unless balanced nutrient inputs are supplied to soil to counteract the negative effect caused by the removal of nutrients by crops (Dobermann et al., 2002; Dobermann et al., 2003a, 2003b; Khurana et al., 2008; Pasuquin et al., 2014). Intensive cropping with modern varieties, leaching of nutrients by monsoon rains, and acid and light textured soil also favor micronutrient deficiency in Bangladesh soil. Consequently, zinc (Zn) and boron (B) deficiency are frequently reported in some soils and crops, and sandy and acid soils are more likely to show a deficiency of micronutrients than clay soils (Jahiruddin et al., 1994; Bhuiyan et al., 2011; Akter et al., 2012).

Crops cannot be sustainably produced by the exclusive use of chemical fertilizers nor can higher crop yield be obtained by using organic manure alone (Hossain et al., 2016). Hua et al. (2015) noticed that phosphorous (P) was available in soil for a sustained period of time when farmyard manure rather than crop straw was incorporated into the soil. However, long-term or excessive use of farmyard manure to increase crop yield is not sustainable and may risk P environmental pollution. This risk can be attenuated by incorporating crop residues into soil without compromising crop productivity (Hua et al., 2015). Sustainable crop production is also possible through the integrated use of organic manure and chemical fertilizers (Dobermann et al., 2002, 2003a,b). Soil organic matter determines sustainable soil fertility and productivity (Baruah and Baruah, 2015). Continuous use of organic materials such as crop residues, green manure (GM) and animal manure strongly influence soil productivity and nitrogen (N) dynamics in the soil-plant system (Leite et al., 2011; Chauhan et al., 2012; Hossain et al., 2016). The inclusion of legume crops as GM or grain legumes in a crop rotation are more beneficial than a simple crop rotation (Singh et al., 2011; Gathala et al., 2013; Hossain et al., 2016) and hold promise in organic agriculture (Sarkar et al., 2004; Singh et al., 2014). Legumes that are used in crop rotation are not only responsible for biological nitrogen fixation, but may also improve nutrient availability and soil structure, reduce the incidence of disease and promote mycorrhizal colonization (Wani et al., 1995; Cupina, 2014).

The present system of fertilizer application in Bangladesh is mostly based on the nutrient requirement of individual crops and ignores the carry-over effect of organic or inorganic fertilizer applied to the preceding crop. It is known that some fertilizers have a considerable residual effect on the next crop and may extend to as many as two or three crops. Organic or inorganic sources of nutrients applied to a preceding crop can benefit the next crop

Table 1
Treatment details in P–M–R crop rotation in three locations: HYG; high yield goal, MYG; moderate yield goal, IPNS; integrated plant nutrient system, STB; soil test based, FP; farmers' practice, CON; control (without fertilizers).

Locations	Treatments	Potato							Mungbean							T. *Aman* rice						
		CD ($t\ ha^{-1}$)	N ($kg\ ha^{-1}$)	P	K	S	Zn	B	CD ($t\ ha^{-1}$)	N ($kg\ ha^{-1}$)	P	K	S	Zn	B	CD ($t\ ha^{-1}$)	N ($kg\ ha^{-1}$)	P	K	S	Zn	B
Bogra (AEZ-25)	HYG	00	198	44	194	24	6.0	1.2	0	24	40	48	24	3	1.2	0	80	16	44	12	2.0	0
	MYG	00	140	34	138	18	4.5	0.9	0	20	36	40	20	2	1.0	0	56	12	32	8.0	1.5	0
	IPNS	10	168	38	170	18	6.0	1.2	5	9.0	37	36	21	3	1.2	5	65	13	32	9.0	2.0	0
	STB	00	169	38	180	19	6.0	1.0	0	20	34	44	18	3	1.0	0	67	14	41	9.0	2.0	0
	FP	00	98	17	92	00	00	00	0	7.0	6.0	5.0	00	0	00	0	40	9.0	11	00	00	0
	CON	00	00	00	00	00	00	00	0	00	00	00	00	0	00	0	00	00	00	00	00	0
Joydebpur (AEZ-28)	HYG	00	198	44	194	24	6.0	1.2	0	24	40	48	24	3	1.2	0	80	16	44	12	2.0	0
	MYG	00	140	34	138	18	4.5	0.9	0	20	36	40	20	2	1.0	0	56	12	32	8.0	1.5	0
	IPNS	10	168	38	170	18	6.0	1.2	5	9.0	37	36	21	3	1.2	5	65	13	32	9.0	2.0	0
	STB	00	171	40	164	22	5.0	1.0	0	20	36	40	22	2	1.0	0	68	15	37	11	2.0	0
	FP	00	97	16	91	00	00	00	0	6.0	5.0	4.0	00	0	00	0	39	7.0	12	00	00	0
	CON	00	00	00	00	00	00	00	0	00	00	00	00	0	00	0	00	00	00	00	00	0
Jessore (AEZ-11)	HYG	00	198	44	194	24	6.0	1.2	0	24	40	48	24	3	1.2	0	80	16	44	12	2.0	0
	MYG	00	140	34	138	18	4.5	0.9	0	20	36	40	20	2	1.0	0	56	12	32	8.0	1.5	0
	IPNS	10	168	38	170	18	6.0	1.2	5	9.0	37	36	21	3	1.2	5	65	13	32	9.0	2.0	0
	STB	00	167	37	181	23	6.0	1.0	0	20	31	44	23	3	1.0	0	66	13	41	12	2.0	0
	FP	00	99	18	93	00	00	00	0	7.0	6.0	4.0	00	0	00	0	41	8.0	13	00	00	0
	CON	00	00	00	00	00	00	00	0	00	00	00	00	0	00	0	00	00	00	00	00	0