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Intensification and diversification increase land and water productivity and profitability of rice-based cropping systems on the High Ganges River Floodplain of Bangladesh

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ABSTRACT

In the High Ganges River Floodplain of Bangladesh, rice-based cropping systems with lower tillage, labor and irrigation water requirement and higher productivity and profitability are needed. To explore options for achieving this, a replicated cropping system experiment was conducted at Jessore to evaluate cropping system intensification with varying degrees of tillage and rice residue retention. Four cropping systems/establishment methods (CSE) were compared: CSE1: T.*boro*-T.*aman* (soil puddling and transplanting of both rice crops); CSE2: CTwheat-CTmungbean-T.*aman* (wheat and mungbean sown using a power tiller-operated seeder, PTOS, with full tillage (CT) and sowing in a single pass); CSE3: CTwheat-CTmungbean-CTDS*aman* (all crops sown using a PTOS with full tillage, dry seeded (DS) *aman*); CSE4: STwheat-STmungbean-STDS*aman* (all sown using a PTOS with strip tillage (ST)). Two levels of *aman* residue retention (removed; partial retention) were compared in sub-plots. Water was ponded on the T.*boro* fields from transplanting until shortly before harvest, while all *aman* crops were grown using safe alternate wetting and drying (AWD) water management.

System productivity (rice equivalent yield, REY) of all wheat-mungbean-*aman* systems was significantly higher than that of the T.*boro*-T.*aman* system in the first and fourth years and when averaged over the four years (by 10% or 1.3 t ha^{-1}). This was due to higher prices paid to farmers for mungbean and wheat, which more than offset their lower grain yields in comparison with T.*boro* yield. Irrigation input was lower, by 62–83%, in the wheat-mungbean-*aman* systems than the T.*boro*-T.*aman* system. The wheat-mungbean-*aman* systems were also economically superior to the T.*boro*-T.*aman* system in terms of higher gross margin (by 26%), net return (double) and benefit cost ratio (1.1 *vs* 1.0) due to both higher returns and lower cost of production. The total labor requirement of all systems was similar; however, it was more evenly distributed throughout the year in the triple cropping systems. Productivity of the wheat-mungbean-*aman* systems with T.*aman* and DS*aman* was similar, despite significantly higher yield of wheat (by 10% or 0.4 t ha^{-1}) following DS*aman*, as this was countered by a consistent trend (non-significant) for lower yield of the DS*aman* than T.*aman*. However, gross margin of the systems with DS*aman* was 5% higher than with T.*aman* due to lower cost of production of the former. Changing from puddling and transplanting to dry seeding of *aman* reduced total irrigation input to the triple cropping system by 238–879 mm (32–65%) over the four years. Establishment of wheat in 40 cm of standing *aman* residues using the PTOS was excellent with both full and strip tillage. Partial *aman* residue retention gave significantly higher (by 0.8–0.9 t ha^{-1}) system yield than residue removal from the second year onwards, due to consistent trends for higher yields of all crops (significant in the case of wheat and mungbean). There were no significant differences between the use of CT and ST in the wheat-mungbean-*aman* system for any of the measured parameters.

The results suggest that intensification from T.*boro*-T.*aman* to a wheat-mungbean-*aman* system can increase system productivity and profitability and reduce irrigation requirement, and that replacement of T.*aman* with DS*aman* in the triple cropping system can be done with reduced irrigation input, increased wheat yield, and little effect on rice yield. Furthermore, tillage for all three crops can be reduced to strip tillage with no adverse effects

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on productivity or profitability. Long term studies are needed to determine the full impacts of the changes in crop intensification, establishment method, tillage and residue management on soil properties, irrigation requirement and crop performance.

1. Introduction

Rice is the staple food for the people of Bangladesh, contributing 95% of the total food grain consumed (BBS, 2011), about two-thirds of the total calorie supply and half of the total protein intake of an average person (Begum and D'Haese, 2010). About 75% of the total cropped area and over 80% of the total irrigated area is planted to rice. Wheat is the second most important cereal, and contributes 7% of the total output of food cereals (Hossain and Teixeira da Silva, 2013). The predominant cropping systems in Bangladesh are: (1) T.*boro* −T.*aman* (puddled transplanted winter rice, fully irrigated, followed by puddled transplanted monsoon rice, predominantly rainfed), and (2) wheat–T.*aman*, which occupy 2.4 and 0.5 Mha, respectively (Ladha et al., 2003; Dawe et al., 2004; Bhuiyan et al., 2004).

In the past few decades, high food production growth rates (rice 2.3%*p.a*, wheat 3%*p.a.*) have kept pace with population growth as a result of the introduction of high yielding varieties and increased inputs, and the development of ground water irrigation which enabled a 5-fold increase in the area of T.*boro* production (BBS, 2013). However, yields of rice and wheat have now almost stagnated (Ahmed, 2004). With the population increasing at 1.47% *p.a.* (BBS, 2013), and the gradual decrease (0.08 Mha or 1% *p.a.*) in the area of cultivable land due to increasing industrialization and urbanization (Planning Commission, 2009), the challenge of ensuring future calorific food security continues.

Malnutrition is also a major problem in Bangladesh; for example, 88% of the populations suffer from protein deficiency (Kabir et al., 2005). At present, only 0.25 Mha (3% of the total cultivable land area) are under pulse cultivation, producing 0.23 Mt *p.a.* Pulses such as mungbean have two and three times the protein content of wheat and rice, respectively. Mungbean also contains essential micronutrients, especially Zn, Fe, and essential amino acids (especially lysine), that are lacking in rice and wheat. Therefore, there is a need to intensify and diversify cropping systems by including legumes.

The current T.*boro*-T.*aman* and wheat-T.*aman* cropping systems are not sustainable because of decreasing profitability due to increasing labor and tillage costs, increasing agricultural labor scarcity, groundwater depletion, and declining soil fertility. Production costs of the T.*boro*–T.*aman* system increased by about 55% during 1996–2006 (BRRI, 2007a,b), mainly due to increased input costs, especially labor and irrigation and comparatively low in seed, fertilizer, fuel and pesticides.

The high tillage and labor requirements for rice production are due to the practices of puddling and transplanting. The soil is initially cultivated (usually 1–2 passes) under moist or dry conditions using a rotary tiller powered by a 2-wheel tractor (2-WT), and is then soaked with water and tilled while flooded (usually two passes), and then levelled. In addition to the high financial cost of burning fuel, large amounts of the greenhouse gas CO_2 are generated. Bangladesh is one of the most vulnerable countries in the world to climate change and sea level rise because much of her territory is located on low lying deltas (IPCC, 2007; Sarwar, 2005; Alam, 1996). Transplanting is very labor intensive; labor for all operations from seedbed preparation to transplanting accounts for nearly one third of the total cost of production (Rashid et al., 2009). Furthermore, labor is often not available on time, resulting in late establishment and reduced yield of both rice and subsequent crops in the rotation. In addition, transplanting often leads to back damage in older farmers (Hussain, 2005).

In the main T.*boro* producing areas of Bangladesh, farmers withdraw large amounts of ground water for T.*boro* cultivation which has led to lowering of ground water tables (Shamsudduha et al., 2009), land subsidence and formation of cracks and sinkholes. The lowering of the water table increases irrigation cost through higher cost of pumping, and the need to deepen tubewells and install more expensive pumps. Furthermore, in some areas such as south-western Bangladesh, high use of ground water has led to the accumulation of heavy metals in the ground water, especially arsenic (Dhar et al., 1997; Christopher and Haque, 2012; DPHE, 2000). As a result, a lot of arsenic is being brought into the food chain through irrigated (T.*boro*) rice cultivation (FAO, 2007; Rahman et al., 2008; Panaullah et al., 2009).

Thus the rice–rice and rice-wheat systems as currently practised are not sustainable. Alternative practices are needed which will reduce the cost of production, increase land, labor, water and energy productivity, and reduce adverse environmental effects. One potential way of achieving this is to switch to conservation agriculture (CA) practices with reduced or zero tillage, residue retention and crop diversification (Hobbs et al., 2008). For rice-wheat systems, this could potentially be achieved by changing from: (1) puddled transplanted rice (PTR) to non-puddled dry seeded rice (DSR), (2) continuously flooded rice to alternate wetting and drying (AWD) water management, (3) conventional to reduced tillage in wheat, (4) inclusion of a legume in the rotation, and (5) retention of crop residues. Inclusion of legumes in the rice-wheat rotation could also bring other benefits including disruption of cycles of weeds and diseases that occur in cereal monoculture (Chauhan et al., 2012), and soil fertility benefits (Bhuiyan, 2004; IFPRI, 2009) due to the potential of legumes to add nitrogen to the cropping system. It has been estimated that growing mungbean adds about 25–40 kg N ha^{-1} to the soil (Ali, 1992; Ahlawat et al., 1998), which can make a small contribution to the N requirement of high yielding rice-wheat cropping systems (Timsina and Connor, 2001).

Given the above, a four-year cropping system experiment was implemented to evaluate the effects of changing from: (1) the conventional T.*boro*-T.*aman* system to a conventional practice wheat-mung-T.*aman* system, and (2) changing from the conventional wheat-mung-T.*aman* system to the same system using CA. The experiment was designed to enable separation of the effects of *aman* establishment method, tillage, and *aman* residue retention. This paper presents the findings on system performance in terms of yield, irrigation amount and its productivity, and profitability.

2. Materials and methods

2.1. Site description

The experiment was conducted over four years on the experimental farm of the Regional Agricultural Research Station of Bangladesh Agricultural Research Institute at Jessore (23°11′ N, 89°14′ E and 16 m ASL). The climate in this region is subtropical monsoon with average annual rainfall at Jessore of 1590 mm, 90% of which falls from June to October (Fig. 1a), the period of growth of the *aman* crop. Monthly average maximum temperature ranges from 26 °C in January to 36 °C in April, while monthly average minimum temperature ranges from 11 °C in January to 24 °C in April (Fig. 1b). Monthly mean daily solar radiation ranges from 13 MJ $m^{-2}d^{-1}$ in January to 22 MJ m^{-2} d^{-1} in April/May (Fig. 1c). The soil at the experimental site was a calcareous brown clay loam of the High Ganges River Floodplain (BARC, 2012), with clay content declining from 38% in the topsoil to 26–28% at 60–120 cm (Table 1). Bulk density was 1.4–1.5 g cm^{-3} throughout the profile, apart from a slightly denser layer at 20–25 cm. The topsoil (0–15 cm) was slightly alkaline (pH 7.7)