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Energy budgeting for designing sustainable and environmentally clean/safer cropping systems for rainfed rice fallow lands in India

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A B S T R A C T

Efficient utilization of rice (*Oryza sativa* L.) fallow (~11.6 million hectares) systems can accelerate the growth of Indian agriculture. But, bringing more area under cultivation is an energy-demanding process and a source of gaseous emissions in the era of climate change. Hence, development of environmentally sustainable cropping systems require for efficient use of rice-fallow lands for sustainable productivity. Therefore, the present study was conducted with the objective to identify sustainable and environmentally safer cropping systems with low global worming potential (GWP) and low energy requirement for rice fallow land of India. Seven diverse crops (e.g., toria (*Brassica campestris* var. toria), lentil (*Lens culinaris*), field pea (*Pisum arvense*), garden pea (*Pisum sativum* L.), green gram (*Vigna radiata*), black gram (*Vigna mungo*) and maize (*Zea mays*)) were introduced in rice-fallow system by adopting no-till (NT) production technology to develop sustainable and environmentally cleaner production systems in a subtropical climate of Tripura, India. All these rice-based cropping systems were evaluated on the basis of the energy requirements and system productivity. Results indicated that rice had the highest energy input followed by that for maize and the least for lentil. System productivity regarding equivalent rice yield was the highest in rice–garden pea system. The relative amount of energy input in all cropping systems involved 44–54% for chemical fertilizers, 13–17% for land preparation, 12–15% for diesel and 11–14% for labor. Total energy input of 28,656 MJ per hectare (MJ/ha) was the highest for rice–maize and the lowest of 22,486 MJ/ha for rice–lentil systems. The highest system productivity and the highest energy productivity were obtained for the rice–garden pea system. The GWP was lower for legume-based than that for cereal and oilseed-based cropping systems. The lowest GWP of 7.97 Mg CO_2e/ha per yr was observed for the rice-lentil cropping system and the highest GWP of 8.39 Mg CO_2e/ha per yr for the rice-maize cropping system. The rice-vegetable pea and rice-lentil cropping systems also had low greenhouse gas emission intensity. The rice–pea and rice–lentil cropping systems are recommended for the region because of their low energy requirement, high energy and system productivity and low GWP. These systems are suited for the efficient utilization of rice fallow lands of eastern India to sustain productivity while adapting and mitigating the climate change.

1. Introduction

Despite the focus on industrialization, agriculture remains a dominant sector of the Indian economy both regarding contribution to gross domestic product (17.4%) as well as a source of employment to millions across the country (Economic Survey, 2015). About 68% population of the country depends on agriculture for their livelihood. Therefore, growth in the agricultural sector is of paramount importance. Furthermore, agriculture is also essential to achieving the Sustainable Development Goals (SDGs) adopted by the United Nations General Assembly in September 2015. Important among SDGs are reductions in poverty, hunger,

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and other deprivations but also cleaner and safer environment along with a dignified life for all (UN, 2015). Therefore, the Government of India has extended the National Food Security Mission (NFSM) to eliminate hunger and achieve food and nutritional security. In this regards, new targets have been established for the additional production of food grains of 25 Tg comprising of 10 Tg of rice, 8 Tg of wheat, 4 Tg of pulses and 3 Tg of coarse cereals by the end of 2017 (NFSM, 2014). In addition, these targets also help in increasing the per capita protein intake. According to the National Sample Survey (NSS) of India, the average consumption of pulses increased in rural India between 2004–05 and 2011–12 from 22 gm to 26 gm/capita. But this is less than 70 per cent of the norm of 40 gm/person/day (UN, 2016). Achieving the additional food and make the country nutritional secure requires intensification of existing agriculture production system by increasing the cropping intensity. Further, intensification also requires the adoption of high yielding varieties, the input of cost-effective chemical fertilizers and irrigation facilities, and to expand cultivation to uncultivated fallow land. With little, if any additional land area available for food grain production; utilization of fallow land especially that associated with the rice-based system is a novel option for enhancing and sustaining the agricultural production (Laxmipathi Gowda et al., 2013). Efficient and sustainable utilization of rice-fallows can meet the ever increasing requirements for food and nutrition (Laxmipathi Gowda et al., 2013).

In India, rice is grown on 44.6 million ha (Mha), of which about 11.65 Mha (comprising of 79% of the total rice fallows in South Asia) remains fallow during winter (post–rainy season) after the harvest of *Kharif* (summer season) rice (Subbarao et al., 2001). As much as 82% of the rice-fallow system in India is practiced in states of Madhya Pradesh, West Bengal, Uttar Pradesh, Chhattisgarh, Bihar, Jharkhand, Orissa and North East India (Yadav et al., 2015). These fallow lands are having diverse climatic and soil conditions, and are suitable for growing a range of crops during the post-rainy–season (Yadav et al., 2015; Ashoka et al., 2017). Some short duration crops of pulses can be grown successfully after harvest of rice with efficient utilization of residual soil moisture (Ali and Kumar, 2009). The multitude gaps of knowledge related to the advantages of legumes and its long-term positive effect on soil functions and behavior in various types of soils as well as understanding to management practices are in increasing demand (Meena and Meena, 2017). Further, the popularization of short duration high yielding rice varieties can facilitate vacating of the rice fields early in September–October and pave the way for transforming the traditional rice–fallow into double cropping system. The double cropping system is based on the inclusion of cool season pulses, oil seeds, and a range of other crops. However, selection of suitable rice-based cropping systems (e.g., location-specific short duration varieties) is critical because both intensification and extensification of rice-fallow require a high input of energy. Inputs of fertilizer and irrigation, being energy-intensive, are sources of greenhouses gasses (GHG) in agroecosystems (Pishgar-Komleh et al., 2012).

Agriculture is an important source of GHG emissions (Smith et al., 2007; Meena et al., 2017), and is the second highest contributor (17.6%) of the total GHGs in India (Sahai et al., 2011). The agriculture indirectly accounts for another 9% of GHG emissions because it consumes one-fourth of the country's electricity output. Therefore, agriculture is considered one of the main source of GHG emission in India (Jat et al., 2016). Thus, bringing more area under cultivation may exacerbate the contribution of agriculture sector to GHGs emissions. Principal contributors to GHGs emissions in agriculture in India are high energy consumption through the use of fertilizer, irrigation, machinery, diesel and pesticides (Mandal et al., 2015; Jat et al., 2016). Thus, improving the energy use efficiency of agriculture in India can reduce GHG emissions while making farming cleaner and safer enterprise (Pishgar-Komleh et al., 2012).

Adoption of best management practices (BMPs), that can reduce energy use, GHG emissions and global warming potential (GWP) in rice-based cropping systems. Important among BMPs are no-till (NT), diversified crop rotation, short duration high yielding rice varieties and reduced rates of fertilization especially N fertilizer (Mosier et al., 2005, 2006; Robertson et al., 2000). Tillage, irrigation, and fertilization are the primary consumers of energy and contributors of GHG emissions because these farm operations use fossil fuel and electricity (Pratibha et al., 2015; Soni et al., 2013). Thus, reducing the fossil fuel consumption by reducing or eliminating tillage operations is a promising option for reducing GHG emissions (Lal, 2003**;** Soni et al., 2013). Choice of those crops and cropping systems is also pertinent which can be grown with NT and low rate of irrigation and fertilizers.

Therefore, environmentally and economically sustainable cropping systems are needed to replace the rice-fallow systems in North Eastern Region of India (Babu et al., 2014). Such a system must be based on the knowledge of energy budget, GWP, and the need for inputs of water and fertilizers in diverse crops (Yadav et al., 2013). However, the consumption of energy and GWP increase with the inclusion of two or more crops in the cropping sequences (Chaudhary et al., 2009). Therefore, a proper understanding of the relationship between energy and crops is important to achieving intensification of cropping system (Tuti et al., 2012). Energy consumption and GHGs emissions are closely linked (Mi et al., 2016). Therefore, increasing energy efficiency with technological changes can save energy and reduce emissions of GHGs (Pishgar-Komleh et al., 2012; Meena et al., 2017a). Thus, the overall goal of the present study was to develop the energy-efficient cropping system for rice fallow, to advance the food and nutritional security, reduce GHG emission and improve the environment. Specific objectives of this study were to identify sustainable and environmentally safer cropping systems with low GWP and low energy requirement for rice fallow land of India. The experiment was designed to test the hypotheses that adoption of NT, low-input requiring, short duration crops will have less energy input and GWP than conventional long duration and high-input requiring crops. Thus, unutilised fallow lands can be used for food production with minimal use of energy and low GWP.

2. Materials and methods

2.1. Experimental site and climate

The experiment was conducted during 2012–13 and 2013–14 at Indian Council of Agricultural Research (ICAR) Research Complex for North Eastern Hill Region, Tripura Centre, Lembucherra, Tripura (W), India. The site is located at $23^{0}54'24.02''$ N and $91^{0}18'58.35''$E at an altitude of 52 m ASL (meter above sea level). The long-term average annual rainfall of the region is 2200 mm; however, rainfalls of 1990 and 2055 mm were received during 2012–13 and 2013–14, respectively. The monthly distribution of rainfall and temperature are depicted in Fig. 1. The soil (*Typic Kandihumults*) of the experimental field was sandy loam in texture, and the baseline analysis of soil samples from 0 to 150 mm depth indicated 7.2 g/kg of soil organic C, 292.0 mg/kg of available nitrogen (N), 9.5 mg/kg available phosphorus (P) and 295.5 mg/kg available potassium (K), and pH of 5.1 (1: 2.5, soil and water ratio) (Prasad et al., 2006).

2.2. Experimental details

The seven cropping systems studied were: rice (*Oryza sativa* L)–toria (*Brassica campestris* var. toria) (R–T), rice–lentil (*Lens*