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Research paper

Energy use and efficiency in selected rice-based cropping systems of the Middle-Indo Gangetic Plains in India

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ABSTRACT

The use and cost of energy in agriculture have increased, making it necessary to make current agricultural practices more energy efficient. To do this, the prevailing systems must be thoroughly analysed. Studies have focused on assessing the energy performance of individual crops, but notably few studies have investigated different cropping systems. This paper aims to assess the energy performance of the two most used cropping systems of the Indo-Gangetic plains in India, namely Paddy rice–Wheat (PW) and Paddy rice–Potato (PP). The PW system was more energy efficient with Energy Use Efficiency (EUE) of 6.87 ± 1.7 compared to 3.61 ± 0.58 for the PP system. Higher Energy Efficiency Ratio (EER_M) (3.94 ± 1.30) and Specific Energy(4.39 ± 2.06) (SE) were reported for the PW system, compared to 2.62 ± 0.47 and 2.15 ± 0.35 respectively for the PP system. Fertiliser use accounted for the highest input energy consumption in both systems, accounting for 58% and 51% of the energy consumed in PW and PP systems respectively, followed by fuel, seeds and electricity. The net income from the PP system (2295.7 ± 457.4 USD.ha^{-1}.yr^{-1}) was higher than that from the PW system (1555.4 ± 856.6 USD.ha^{-}1.yr^{-1}). The higher return of PP system was attributed to higher yield and better market price for the potato produce. There were no significant differences reported for various energy and economic parameters within different farm sizes in the PP system. However, for PW system, small farms were energy efficient while larger farms were economically efficient.

1. Introduction

Both energy use and costs are ever-increasing in the agricultural sector. Since the green revolution and the promotion of high-input, mechanised, irrigated cropping systems, agriculture uses much energy, directly and indirectly, owing to its many production activities, inputs and requirements: land preparation, tillage, fertilisers and agrochemicals (manufacturing and application), irrigation (pumping), harvesting and the likes. Therefore, increased energy efficiency has become a key objective for both farmers and policy-makers; however, on-going efforts fall short of harnessing the complete economic potential of energy use in agriculture (World Energy Outlook, 2012). From this perspective, the agricultural sector has an important role as both a consumer and a producer of energy. The final products and major by-products of cropping systems contribute to a large amount of nutritive energy for human and animal populations. Several of the crop's by-products may potentially be used as biomass, which may be turned into renewable energy. The growing worldwide demand of energy by the agricultural sector to meet the food demand of more than 7 billion people results in detrimental effects on the environment and the health of the farmers. If the energy in agricultural sector is used judiciously, it will not only reduce the environmental impacts in terms of green house gases (GHG) emissions and other hazardous effects but will also lead to a desirable sustainable form of agriculture (Schroll, 1994; Dalgaard et al., 2001; Nasso et al., 2011). A higher input of energy accounts for higher energy costs, which significantly reduces the net return of the farms and is a challenging issue for the policy makers. In many advanced agricultural systems, an increase in yield is clearly the result of an augmented energy input that is directly related to the use of improved mechanised tools and the introduction of high-yield crop varieties. In most developing nations, agriculture is the mainstay of the economy and a source of employment for a large proportion of the population. Mechanisation reduces human drudgery, ensures timeliness of farm related activities and increases farm output in terms of productivity. In these countries, in addition to the expansion of arable land, increase in total production is also required, which occurs via the use of efficient machinery for farm operations and proper water, chemicals and weed management practices (Faidley, 1992).

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To know more about the energy input and output relationship in the agricultural sector, it is necessary to take account of the proper use of various energy sources, the cost of energy usage and its impacts on the environment (Jones, 1989). To meet the increasing food demand of the ever increasing population of the world, the world's production capacity is expected to increase two folds by 2050 (FAO, 2008) and energy use will be a prime factor in this transformation as the amount of arable land will either decrease or will remain constant.

In Indian agriculture, there is a huge diversity of agro-ecological diversity in soil, rainfall, temperature and cropping systems. To meet the need for operational energy and reduce the share of animate power, the contribution of mechanical energy increased substantially, which directly resulted in increased use of fossil fuels, mainly diesel. The use of mechanical energy in operational energy increased from a very low value of 11% in 1970–71 to a very high contribution of 76% in 2000–01 (Kulkarni, 2010).

Paddy rice-based cropping systems are most common to the middle Indo-Gangetic plains of the Indian subcontinent, which covers an area of 9.64 Mha (Gangwer et al., 2005). The major crops grown in rotation with rice (*Oryzasativa L.*) are wheat, potato, mustard, pulses, maize and other legumes. India is a major paddy rice-producing nation and accounts for approximately 21% of the total white rice production (Ministry of Statistics and Program Implementation, 2012). The middle Indo-Gangetic plains in India cover the states of Uttar Pradesh, Bihar and West Bengal, the major areas of rice production in India. Paddy rice-wheat (PW) and Paddy rice-potato-fallow (PP) are two cropping systems that are extensively practised by farmers of this region; such systems require very high inputs in terms of agricultural machinery, pesticides, fertilisers and other agro-chemicals (Singh and Chancellor, 1975).

The key drivers of energy use in the agricultural sector in India are agricultural production, the extent of arable land used for crop production and the penetration of efficient technologies, such as irrigation facilities and improved mechanisation means (Chaudhary et al., 2009). Currently, cropping systems are increasing their energy inputs; therefore, there is a need to ascertain the efficiency of the system in terms of energy use. In this context, it is imperative to thoroughly budget the energy use of the widely followed cropping systems to identify the processes and systems that are most energy consuming and can be replaced with other low input-energy-consuming practices, in order to conserve energy and achieve sustainable cropping systems (Hatirli, 2006). The farm size distribution in Indian farming households has gone to a major shift, with the percentage of marginal, small and small & marginal categories witnessing an increase while the semi-medium, medium and large farm sizes witnessing a continuous decrease, after the post-independence period (Dev, 2012). There has always been a lot of debate on the economic and environmental performance of smaller farms as compared to larger farms. The study also intends to report the performance of marginal, small and medium farms, in terms of energy indicators and eco-efficiency.

There have been several studies to assess the energy performance of different crops and cropping systems in Upper Indo-Gangetic Plains (Singh et al., 1990; Nassiri and Singh, 2009). However, there are a limited number of studies assessing the key energy indicators and economic performance of cropping systems in the middle Indo-Gangetic plains (Mittal et al., 1992; Tripathi et al., 2013). Therefore, to assess key energy indicators, such as Energy Use Efficiency (EUE), Energy Efficiency Ratio (EER_M) (in terms of the yield of main products) and Specific Energy (SE) of the two most followed cropping systems (Paddy rice–wheat and paddy rice–potato–fallow) in the middle Indo-Gangetic plains of India, this study was conducted along with the calculation of the eco-efficiency indicator in terms of ratio of economic creation to ecological destruction (Saling et al., 2002). The Paddy Rice–Potato–Fallow and paddy rice-wheat systems are henceforth termed as PW and PP systems, respectively in the current study.

Table 1
Average farm sizes in the study areas.
Source: Dev (2012).

State (State Capital)	Farm size classification (ha)		
	Marginal	Small	Medium
Bihar (Patna)	0.30	1.21	5.24
Uttar Pradesh (Allahabad)	0.40	1.41	5.57

2. Materials and methods

The energy analysis presented here compares the energy indicators EUE, EER_M and SE of the two systems as well as their eco-efficiency in terms of economic return per unit of energy consumption. The two systems selected are PW and PP, which are among the most used cropping systems in the middle Indo-Gangetic plains of India. Energy fluxes in the two selected cropping systems were estimated using crop inputs for resource utilisation and biomass production for the crop year 2012–2013. The mechanical energy dissipated in mechanical operations and energy consumed in other activities, such as irrigation, transportation and other inputs, were estimated from on- and off-farm energy inputs.

The actual values of all the inputs used were calculated based on the results of a survey of the target area. Data was collected from the two important districts in the middle Indo-Gangetic plains, namely Patna and Allahabad, through direct face-to-face interviews with the farmers using the two cropping systems during the period of December–January 2013. The sample size was calculated by the formula given by Yamane (1967) and a total of 51 and 48 farmers engaged in the PW (mainly in Patna) and PP (mainly in Allahabad) cropping systems, respectively, were interviewed in the selected areas. This was based on the number of farming households following a particular cropping system in a particular village of the study areas. Table 1 provides the average farm size classification in the study areas.

2.1. Site description

The selected sites for the study were Patna and Allahabad, two cities in the middle Indo-Gangetic plains of India. Allahabad is situated at 24°47' N latitude and 81°19' E, longitude while the latitudinal and longitudinal coordinates for Patna are 25°36'N and 85°7'E. Both areas are drained by the river Ganges and have similar alluvial soil profiles. Both sites have a humid sub-tropical climate with a hot summer from the end of March to early June. South-eastern monsoons prevail from the end of June to early October, and winter lasts from the middle of November to February. Both areas are characterised by three seasons, hot dry summer, cool dry winter and warm humid monsoon. The mean annual temperature for the Allahabad and Patna regions for 2011 was 25.9 °C and 25.8 °C, respectively, and for 2012, it was 26.4 and 26.2 °C, respectively. The mean annual precipitations for the two areas for 2011 were 1188.7 mm and 915.9 mm, and for 2012 the values were 1227.4 mm and 945.4 mm, respectively. In both areas, farmers practice rainfed as well as irrigated farming, depending on the monsoon season.

In both the areas, Paddy-rice is grown in *Kharif* (monsoon; July–October) season while wheat and potato are grown in *Rabi* (winter; October–March) season. Both the cropping systems, PW and PP, have a lot of diversity in terms of various management practices, in both the areas. Most of the pre-harvest processes (tillage, seeding, weed management, irrigation etc.) are mechanised and inorganic fertilisers are preferred over the organic ones. Manual method of harvesting for paddy-rice and wheat, is usually employed, as the farm sizes are not suitable for large harvesting machines, with a