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Energy auditing of a maize–wheat–greengram cropping system under conventional and conservation agriculture in irrigated north-western Indo-Gangetic Plains

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ABSTRACT

This study evaluated energy requirements and input-output energy relationship in a maize-wheat-greengram cropping system under conventional and conservation agriculture. Conventional tillage with flat bed (CTF) and raised bed (CTB) and zero tillage with flat bed (ZTF) and raised bed (ZTB) were supplemented with crop residue management viz., no residue (CON), wheat residue in maize crop (WR), maize residue in wheat crop (MR) and wheat + maize residue in both maize & wheat crops (WMR). Results showed that ZTB (89170 MJ/ha) consumed 8% lower input energy than CTF. ZTB saved 91% and 38% energy in land preparation and irrigation, respectively. The output and net energy return were significantly higher with ZTF (387235 MJ/ha; 295397 MJ/ha), which were 2.0% higher than ZTB. Energy ratio and productivity were significantly higher with ZTB. WMR contributed the highest input and output energy and lowered energy ratio and productivity. Reduced energy ratio and energy productivity can be ignored as it returned to soil to improve its quality. Surface retained residues had better effect on crop productivity. With this view, ZTB with WMR was better and would be a substitute of the conventional agricultural system for adoption in maize-wheat-greengram cropping system in the irrigated north western Indo-Gangetic Plains.

1. Introduction

Maize (*Zea mays* L.) –wheat [*Triticum aestivum* (L.) emend Fiori & Paol] is the third most important cropping system, grown on about 1.83 million ha in India, contributing nearly 3% to the national food production after rice–wheat (32%) and rice–rice (5%) systems [1,2]. The north-western part of the Indo-Gangetic Plains (IGP) is characterised by relatively large farm size, better irrigation facility and the highest degree of farm mechanization with rice–wheat system. Energy is one of the most valuable inputs in farming and should be significantly high in order to feed and to meet other socio-economic goals of expanding population. Crop yields and food supplies are directly linked to energy. In Indian agriculture, animate (human and animal) and fuel energy is predominantly used starting from land preparation to harvesting of crops. But human power is becoming less available due to migration towards cities, consequently it accounts more costly. Similarly animal powers have reduced due to increase of mechanical power. Various forms of input energy (physical/mechanical, fertilizer, pesticides etc.) should be sufficiently available for its efficient use [3]. Energy balances are used for the environmental assessment of agriculture, because they indicate intensity and environmental effects of production system [4,5]. Advancement of mechanization in modern conventional agriculture requires more fossil fuel energy. Now it has been realized that conventional agriculture is not very energy efficient and is detrimental to the air, water and soil environment. In recent years, the rice–wheat system has been suffering from a production fatigue and several economic and ecological problems. Huge quantities of crop residue are produced in cereal – cereal production systems. Crop residue is a source of renewable energy, generally considered as non-commercial as thought to be freely available. Though in India, crop residue is considered as an economic item for which it is to be paid. These are used as animal feed,

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thatching homes and domestic fuels. Large portion of unused crop residues are burnt in the fields with intention to clear the left-over straw and stubble for sowing of the succeeding crops, particularly in the combine-harvested rice–wheat system. This is because of tractor requires more oils for ploughing fields and to incorporate crop residues well in soil. Burning of residues in IGP has drawn the attention to the researchers and planners as this practice has several adverse impacts on productivity of soil and environment. Based on estimates taken from grain production and grain to straw ratios (cereals) indicates of total crop residue production in India is about up to 350 million tonnes of which one-third is available for recycling by soil incorporation or surface retention. The estimated crop residue produced in IGP covered under rice – wheat system (10 million ha) is about 126 million tonnes of which 42 million tonnes is available for recycling with estimated fertilizer replacement value of about Rs. 3.6 billion/year and 525×10^{15} J/year (525 Peta J/year) in terms of renewable energy for soil improvement. Sustainability of a system depends on productivity, energy and other resources-use efficiency, soil and environment quality and socio-economic feasibility. With the aim of conserving resources, improving input-use efficiency and sustaining productivity, conservation agricultural system has emerged. The concept of conservation agriculture was developed in USA during 1970s as a result of primarily steep increase of fuel price therefore, to cut down expenses on tillage machinery. This involves minimum soil disturbance, providing a soil cover through crop residue or other cover crops and following efficient crop rotation [6]. Zero tillage (ZT) technique is an ecological approach for soil surface management and seed bed preparation resulting in less energy requirement, less weed problem, better crop residue management and higher or equal yield [7]. Conservation agricultural practices save fossil fuel due to restricted tractorisation of the field and improves the soil productivity in long term by continue retention of crop residues on soil surface.

Globally, conservation agriculture is being practised in about 125 million ha [8]. In India, its adoption as ZT is initiated in late 1980s and still conservation agriculture is in initial phases as largely being adopted in wheat of rice–wheat system of IGP [9], which is not truly conservation agriculture as the practice is being undertaken in wheat crop, leaving rice with conventional method. ZT technology resulted in 5–6% increase in yield due to early emergence. Tillage system carried in one crop have influence considerably the performance of succeeding crops grown in the system and depends on the soil type and climatic condition [10]. Experiences from several locations in IGP showed that with its ZT technology, farmers were able to reduce diesel consumption by 50–60 L/ha [11]. In terms of energy, ZT technology can save energy by about 3000 MJ/ha due to less fuel consumption. Conventional tillage practice involves multiple passes of tractor for ploughing, harrowing, planking and seeding. Conventional rice–wheat system required higher energy due to intensive field preparations, whereas ZT required least energy leading to higher output: input energy ratio [12]. Conventional tillage practice in maize and wheat involves 6–8 tillage operations, consumes 25–30% of the total operational energy [13]. Continuous tillage in both rainy (*kharif)* and winter (*rabi)* season was found to have ill effects on the soil health and high energy requirement [14]. Resource conservation technology like raised-bed planting saves irrigation water [15] and labour consumption without sacrificing productivity [16,17]. Fresh raised-bed was found beneficial in maize and wheat, saving water and higher yield and net returns despite higher cost of cultivation [18]. These reports indicate that conservation agriculture system requires the least energy in farm operation compared to other systems but may not be applicable in all cases. Energy should be considered as a critical aspect for a nation development as it is needed in industries, infrastructure development, agriculture including processing and packaging, transportation, power generation and irrigation projects, education and health services, domestic use and other services. Developed countries realized energy crisis due to conventional mechanised agricultural practices much earlier than the developing countries. A scientific assessment is needed to reduce input energy in land preparation, fertilizers and agro-chemicals application and irrigation to enhance energy use efficiency of these operations with conservation agriculture system. The crop residue whether it is incorporated in soil by conventional tillage or retained on the soil surface by zero tillage, was not taken deliberately for energy analysis as reported in various literature. Though huge amount of energy is retained in the residue contributed from various energy resources during production. It is fact that its recycling improves the soil quality and useful to the environment. In developing countries like India crop residues are being used for feeding cattle, thatching house and as domestic fuel. We thought crop residues should be considered as input energy in intensive sequential cropping system where, residue produced of preceding crop is left intentionally and utilised as input to succeeding crop. This is our contribution to existing literature on the energy relation analysis in changing farming pattern which also includes crop residues as input energy.

The objectives of this study were to audit energy utilization pattern and its input – output relation in conventional and conservation agricultural practices and to find out the most productive and energy efficient tillage and residue management practice in an irrigated maize (rainy season) –wheat (winter season) – greengram (summer season) system.

2. Materials and methods

2.1. Site and climate

The field experiment was conducted on a fixed lay-out/site during rainy, winter and summer seasons of 2011–12 and 2012–13 at the ICAR-Indian Agricultural Research Institute, New Delhi, India. The soil was sandy loam. New Delhi has a sub-tropical semi-arid climate with hot dry summer in May & June and severe cold winter in December & January. The average annual rainfall in the region is 650 mm with 80% rainfall, received during rainy season from July to September. The total annual rainfall in 2011–12 and 2012–13 was about 583 and 668 mm, respectively.

2.2. Experimental details

The experiment was conducted in a split plot design on a fixed layout with 16 treatment combinations of tillage, crop establishment and residue management. The four main plot treatments comprised of conventional tillage–flat bed (CTF), conventional tillage–raised bed (CTB), zero tillage–flat bed (ZTF) and zero tillage–raised bed (ZTB). The four residue management treatments in sub-plots comprised of no crop residue control (CON), 2.5 t wheat residue/ha (WR) in maize crop, 2.5 t maize residue/ha (MR) in wheat crop, and 2.5 t/ha wheat residue in maize + 2.5 t/ha maize residue in wheat (WMR). Crop residues were incorporated through tillage in CTF and CTB, but retained on the soil surface in ZTF and ZTB treatments. On this layout, previously cotton (rainy season) – wheat (winter season) system was adopted for three years (2008–2011) with the same 16 treatment combinations, but with cotton residue in place of maize residue. The cropping system was changed to maize – wheat – greengram since June 2011 in order to attain higher crop & system productivity with better soil health through inclusion of a legume crop in rotation. In conventional tillage (CT), ploughing was done with a tractor-drawn disc plough