Energy for Sustainable Development 28 (2015) 115–121

Contents lists available at ScienceDirect

Energy for Sustainable Development

Energy efficiency and economics of rice cultivation systems under subtropical Eastern Himalaya

S. Mandal [a,d], Somnath Roy [b], Anup Das [a,*], Ramkrushna G.I. [a], R. Lal [c], B.C. Verma [a], Arvind Kumar [a], R.K. Singh [a], Jayanta Layek [a]

[a] ICAR Research Complex for NEH Region, Umiam, Meghalaya 793103, India
[b] National Bureau of Plant Genetic Resources, Regional Station, Umiam, Meghalaya 793103, India
[c] Carbon Management and Sequestration Centre, Ohio State University, Columbus, USA
[d] Central Institute of Agricultural Engineering, Bhopal, India

ARTICLE INFO

Article history:
Received 11 January 2015
Accepted 5 August 2015
Available online 2 September 2015

Editor: Jones Daniel B.

Keywords:
Energy efficiency
Cultivation system
Mechanization
Resource conservation technology

ABSTRACT

In the northeastern region (NER) of India (eastern Himalayas), rice (*Oryza sativa*) is grown in ~70% of cultivated land. Therefore, the identification of energy-efficient rice cultivation system is important to food security and sustainable intensification (SI). Thus, six rice cultivation systems, composed of conventional direct seeded (CT-DSR), conventional transplanted (TRP), no-till (NT) DSR, NT-TRP, system of rice intensification (SRI), and mechanized TRP, were evaluated for their energy and cost efficiency. Results showed that land preparation, application of chemical fertilizers, farm yard manure, and seeding and/or transplanting operations consumed >80% of energy input in all rice cultivation systems. Energy input was the highest in mechanized TRP (15371 MJ ha^{-1}) and the lowest in NT-DSR (9162 MJ ha^{-1}). Average grain yield obtained was the highest under SRI (4.72 Mg ha^{-1}), followed by CT-TRP (4.34 Mg ha^{-1}), mechanized TRP (4.23 Mg ha^{-1}), and NT-TRP (3.52 Mg ha^{-1}). Grain and biomass output energy was the highest in SRI system (148811 MJ ha^{-1}), followed by that for the conventional TRP and mechanized TRP. The NT-DSR system was the most energy-efficient rice cultivation practice (output–input ratio: 11.00), whereas mechanized TRP was the least energy efficient (output–input ratio: 8.6). The lowest energy input (2900 MJ Mg^{-1}) per unit of grain yield was recorded for the SRI system. Both the input–cost and the benefit–cost ratio in mechanized TRP were lower than that under SRI.

Introduction

Energy is one of the most important inputs in agricultural production process and is expended in every step starting from land preparation to value addition (Devasenapathy et al., 2009). Production, formulation, storage, distribution, and application of inputs are dependent on energy based on fossil fuel consumption which emits CO_2 and other greenhouse gases (GHGs) into the atmosphere (Lal, 2004; Sørensena et al., 2014). Energy use efficiency (EUE) of a cropping system depends on a range of factors such as soil type, tillage operation, fertilizers application, plant protection measures, harvesting, threshing operations, and grain and biomass yield (Baishya and Sharma, 1990; Clemens et al., 1995; Singh et al., 1997). Energy consumption in Indian agriculture is increasing day by day with the introduction of new agricultural machineries and other inputs (Das, 2012). However, the use of new machinery in agriculture and adoption of reduced tillage methods can reduce the energy need by 18–83% in different cultivation practices (Sørensen and Nielsen, 2005).

In the NER of India, rice (*Oryza sativa*) is the most important cereal crop cultivated on about 3.5 million ha (Mha), with a total production of 12.6 teragrams (Tg $= 10^{12}$ g $=$ 1 million Mg) comprising 7.7% and 9.5%, of Indias rice area and production, respectively (NEDFI, 2010). Rice is an energy-intensive crop, and a major component of its use is through use of fertilizer and farm yard manure (FYM) along with land preparation. The use of mineral fertilizers and pesticides increases yields in the conventional cropping system but simultaneously also increases the energy inputs in rice cultivation (Dalgaard et al., 2001; Hatirli et al., 2006). The per capita energy availability in the NER region is rather low compared to that for other parts of India. Therefore, the identification of energy-efficient rice cultivation system is necessary, particularly in the context of climate change, as the major share of total energy need in agricultural production system is non-renewable in nature (Sartori et al., 2005). The cost of cultivation is equally important for the resource-poor farmers of this region. Higher cost of cultivation relative to the returns from rice cultivation is a major concern among the rice farmers (Das et al., 2014). Mechanization of cultivation system involves higher amount of energy expenditure but reduces cost of cultivation (Mandal et al., 2002). Further, the mechanization ensures timeliness of agricultural operations, while increasing both

* Corresponding author. Tel.: +91 364 2570257.
E-mail address: anup_icar@yahoo.com (A. Das).

http://dx.doi.org/10.1016/j.esd.2015.08.002
0973-0826/

the productivity and net returns over those performed by manual labor or draft animals. Therefore, it is important to identify an efficient rice cultivation system in terms of the EUE and the cost. The present study was undertaken with the objective to identify the energy- and cost-efficient cultivation system for sustainable rice production in the energy-deficient NER of India. The hypothesis tested was that rice cultivation practice which requires less tillage and inputs saves energy and reduces cost of cultivation.

Methodology

Experimental site and climate

Experimental data for different agronomic practices were obtained various inputs used and outputs of six rice cultivation systems. These systems included conventional direct seeded (DSR), conventional transplanted (TRP), NT-DSR, NT-TRP, system of rice intensification (SRI), and mechanized TRP (Table 1). These experiments were conducted in lowland and upland Agronomy and Agricultural Engineering research farms of the Indian Council of Agricultural Research (ICAR) Complex for the North Eastern Hill (NEH) Region, located at Umiam, Meghalaya, India. These data were obtained from field experiments conducted for five consecutive rainy seasons (June–November 2006–2010). The research farm is located at 25°30′ N latitude and 91°51′ E longitude, at an elevation of 950 m (lowland) and 961 m (upland) above mean sea level. The experimental site falls under a per-humid subtropical climate, with the average minimum and maximum temperature during cropping season ranging from 7.8 °C to 20.5 °C and from 20.5 °C to 24.5 °C, respectively (Fig. 1). The patterns of rainfall and temperature during the cropping seasons of 2005 to 2011 are presented in Fig. 2. The relative humidity of the experimental period varied between 53.46% and 79.71%. Soil of the experimental site is classified as Typic

Table 1
Details of management practices, inputs used, and outputs in different rice cultivation systems.

	Conventional		No-till		SRI[a]	Mechanized
	DSR[b]	TRP[c]	DSR	TRP	TRP	TRP
A. Inputs						
1. Land preparation						
Ploughing and levelling						
Power tiller with rotavator (h ha^{-1})	15.8	23.6	0	0	23.6	27.3
Diesel (l ha^{-1})	31.6	47.2	0	0	47.2	54.6
Human (male-h ha^{-1})	15.8	23.6	0	0	23.6	27.3
Rectification of ridges (male-h ha^{-1})	34.8	36	0	0	33	0
2. Seeding/transplanting						
Seed (kg ha^{-1})	58.6	44.4	58.8	45.8	8.1	67.2
Nursery raising (female-h ha^{-1})	0	87.6	0	91.8	64.8	92.4
Direct sowing (female-h ha^{-1})	69	0	145.2	0	0	0
Manual transplanting (female-h ha^{-1})	0	145.2	0	174	162	0
Machine transplanting						
Transplanter (h ha^{-1})	0	0	0	0	0	6.4
Diesel (l ha^{-1})	0	0	0	0	0	7.68
Human (male-h ha^{-1})	0	0	0	0	0	6.6
3. Water management (male-h ha^{-1})	12	31.2	12	31.8	43.2	29.4
4. Fertilizer and manure application						
FYM (t ha^{-1})	5	5	5	5	10	5
Application of FYM (female-h ha^{-1})	48	48	48	48	72	48
Nitrogen (N) (kg ha^{-1})	60	64	60	60	80	80
Phosphorus (P_2O_5) (kg ha^{-1})	60	60	60	60	60	60
Potassium (K_2O) (kg ha^{-1})	40	40	40	40	30	40
Fertilizer application (female-h ha^{-1})	18	18	18	18	18	18
5. Weeding						
Cono-weeding (male-h ha^{-1})	0	0	0	0	60.6	61.8
Hand weeding (female-h ha^{-1})	288	210	349.2	260.4	60.6	61.8
Cono weeder (h ha^{-1})	0	0	0	0	60.6	61.8
6. Pesticide application						
Herbicide (l ha^{-1})	0	0	1.5	1.5	0	0
Insecticide (l ha^{-1})	1.5	1.5	1.5	1.5	1.5	1.5
Knapsack sprayer (h ha^{-1})	24	24	36	36	18	0
Power sprayer(h ha^{-1})	0	0	0	0	0	8
Petrol (l ha^{-1})	0	0	0	0	0	8
Human (male-h ha^{-1})	24	24	36	36	18	8
7. Harvesting						
Reaper (h ha^{-1})	0	0	0	0	0	6.1
Diesel (l ha^{-1})	0	0	0	0	0	7.32
Human (male-h ha^{-1})	61.8	73.4	61.2	72	70.2	6.1
Human (female-h ha^{-1})	62	71	65	67	70	0
8.Threshing						
Pedal thresher (h ha^{-1})	80.4	114	78	111.6	140.4	0
Engine operated thresher (h ha^{-1})	0	0	0	0	0	9.2
Diesel (l ha^{-1})	0	0	0	0	0	22.8
Human (male-h ha^{-1})	42	60	36	60	72	30
Human (female-h ha^{-1})	38.4	54	42	51.6	68.4	24
B. Outputs						
1. Rice grain (kg ha^{-1})	3144	4342	3012	3524	4720	4230
2. Straw (kg ha^{-1})	4180	5528	4518	4542	6354	5573

[a] System of rice intensification.
[b] Direct-seeded rice.
[c] Transplanted rice.