Cropping Systems of Central India: An Energy and Economic Analysis

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ABSTRACT. The study attempts to analyze the energy input-output relationship and economic returns of the cropping systems in central India. The data collected from farmers through multistage random sampling techniques, were subjected to descriptive analysis of simple proportions and percentages. Findings reveal that total energy involved in soybean-wheat system (19817 MJ ha^{-1}; renewable 5507 MJ ha^{-1} and non-renewable 14310 MJ ha^{-1}) is much greater than soybean-chickpea (11239 MJ ha^{-1}; renewable 4883 MJ ha^{-1} and non-renewable 6356 MJ ha^{-1}), pigeonpea monocropping (2329 MJ ha^{-1}; renewable 714 MJ ha^{-1} and non-renewable 1616 MJ ha^{-1}), fallow-wheat (13716 MJ ha^{-1}; renewable 2810 MJ ha^{-1} and non-renewable 10906 MJ ha^{-1}) and fallow-chickpea (4445 MJ ha^{-1}; renewable 2526 MJ ha^{-1} and non-renewable 1919 MJ ha^{-1}). The percentage of non-renewable energy is higher than renewable energy inputs. Soybean-wheat (70%) and fallow-wheat

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(78%) systems resorted to more use of non-renewable energy than renewable energy. In soybean-chickpea system share of non-renewable energy is 52%. The energy outputs follow the order: soybean-wheat (70495 MJ ha^{-1}) > fallow-wheat (52084 MJ ha^{-1}) > soybean-chickpea (44485 MJ ha^{-1}) > pigeonpea monocropping (20427 MJ ha^{-1}) > fallow-chickpea (20357 MJ ha^{-1}); energy efficiency is the highest in pigeonpea monocropping (8.76); for other systems it ranged from 3.67 in soybean-wheat to 4.63 in fallow-chickpea system. The net energy of the systems is 50678 MJ ha^{-1} in soybean-wheat, 38368 MJ ha^{-1} in fallow-wheat, 33246 MJ ha^{-1} in soybean-chickpea, 18098 MJ ha^{-1} in pigeonpea monocropping and 15912 MJ ha^{-1} in fallow-chickpea. Though the soybean-wheat system results in highest net energy, its energy productivity (0.269 kg MJ^{-1}) is the lowest and that of fallow-wheat system is 0.288 kg MJ^{-1}. It is comparatively higher for other systems, viz., soybean-chickpea (0.307 kg MJ^{-1}), pigeonpea monocropping (0.643 kg MJ^{-1}) and fallow-chickpea (0.342 kg MJ^{-1}). Further, energy intensity is 3.84 MJ kg^{-1} and 0.887 MJ Rs.$^{-1}$ in physical and economic terms, respectively, in the soybean-wheat system, and are greater than other systems, viz., soybean-chickpea (3.43 MJ kg^{-1} and 0.577 MJ Rs.$^{-1}$), pigeonpea monocropping (1.55 MJ kg^{-1} and 0.243 MJ Rs.$^{-1}$), fallow-wheat (3.59 MJ kg^{-1} and 1.408 MJ Rs.$^{-1}$) and fallow-chickpea (2.96 MJ kg^{-1} and 0.569 MJ Rs.$^{-1}$). But the soybean-wheat cropping system has been found more remunerative in terms of benefit-cost ratio (1.27) owing to its ability to generate the highest return per rupee investment than soybean-chickpea (1.23) and pigeonpea monocropping (1.23). The fallow-based systems are having comparatively better benefit/cost ratio. The investment requirement and also net return is highest for soybean-wheat system, thus is preferred by the large farmers. Farmers are forced to use soybean-chickpea crop rotation whenever there is lack of adequate rainfall during rainy season and irrigation facilities in succeeding winter season. Thus, fallow-chickpea rotation is suitable for extremely poor farmers with no irrigation facilities.

KEYWORDS. Energy, economics, cropping systems, Central India

INTRODUCTION

Agricultural productivity is closely linked with the energy inputs. The measure of energy flow in crop production systems provides a good indicator of the technological aspects of crop production systems in agriculture. For sustainability in energy management the efforts have to be double pronged, firstly efficient use of commercial energies, and secondly harnessing renewable energy sources as supplementary and substituting commercial energy sources. Direct energy inputs to crop production systems are derived from power sources like human, draft animals, engines, tractors, power tillers, and electric motors, etc., required to perform various unit operations as well as indirect energy inputs are in the form of seeds, organic manures, fertilizers, pesticides, growth regulators, etc. Consumption of energy has been increasing at a steady rate to improve productivity in Indian agriculture. But the energy use efficiency is declining consistently (Sharma and Thakur, 1989; Mahendra Pal et al., 1985). The adoption of high yielding varieties, expansion of irrigation facilities, mechanization, and fertilizer-diesel-electricity combination have pushed the demand for commercial energy to a new height.

Research efforts on energetics of cropping systems gathered momentum through the seventies owing to the global fossil fuel crisis and rapidly increasing demand for food. Energy input-output relationships (i.e., energy efficiency, net energy, energy productivity, energy intensity both in physical and economic terms) in cropping systems vary with the crops knitted in a sequence, type of soils, nature of tillage operations, nature and amount of organic manure and chemical fertilizers, plant protection measures, yield levels and biomass production (Baishya and Sharma, 1990; Singh et al., 1997 and Mandal et al., 2002). Among the field crops, legumes involve much less energy expenditure than cereals. In Germany, energy output: input ratios of rape (*Brassica campestris* L.) were generally the highest at intermediate N rates. Since N fertilizers are the major energy inputs, reducing their use and stabilizing yields using organic rather than mineral N would increase net energy yield (Hansen and Diepenbrock, 1994; Aggarwal, 1995). Kadlcek and Cervinka (2000) reported that indirect energy demand of wheat production systems made up 92-94% of total consumption with most energy use associated with the use of fertilizers and agrochemicals on a chernozem soils in the foothills of the White Carpathian Mountains. More energy has been consumed in fertilizer treatments for soybean-chickpea crop sequence compared to control and increasing the levels of nutrients decreased the energy use efficiency and productivity (Joshi et al., 1998). Lagerberg (1999) reported that decreasing the dependency on imported non-renewable resources would enhance the sustainability of the Swedish economy. Energy analysis for Swedish farming systems was also studied by Jansén (2001) and concluded that limited supply of external energy will be a reality for future agriculture as non-renewable energy will be limited. O'Callaghan (1994) reported that N fertilizer accounted for about half the energy supplied by the farmer to a cereal crop.

Seedbed preparation by power tiller (rotavator 2 passes + levelling) and tractor with improved implements (moldboard plough 1 pass + disc harrow 2 passes + levelling) gave higher profit and energy use efficiency than seedbed preparation by other methods. Sowing seeds by drilling in rows gave markedly greater returns and energy output than broadcast sowing (Sharma and Thakur, 1989). Energy consumption was lowest with direct drilling (after rotary tillage to 3-5 cm depth) after winter wheat on sugarbeet root yield, root quality and energy use efficiency on a slightly loamy sandy soil in Poland (Dzienia et al. 1998). In the sandy loam soil of Punjab, India, Gajri et al. (1992) reported that the relative yield of wheat following rice was a curvilinear function of energy use in tillage, applied N and irrigation. Total energy input (fuel, fertilizer and pesticides) to maize (grain and silage) production was about the same for both conventional and no-till production, but no-till production of soybeans required substantially less energy input than did conventional production in Tennessee, USA (Wilhelm, 1992). Moreover, increasing modernization, in general, involves larger input of energy in crop production. It has been studied and observed in rice cultivation (Freedman, 1980) that traditional production practices involve minimum input of energy. In the organic systems in Switzerland, direct and indirect energy use to produce one ton of crop is lower for winter wheat and clover/grass than in the conventional system (Dubois et al., 1999).

The economics of rice-wheat rotation at Ludhiana, Punjab, India was better in terms of energy and cost, it is highly dependent on commercial energy sources (Singh et al., 1989 and Sarkar and Sarkar, 1997). Bora and Dutta (2000) assessed the energy requirement for high yielding autumn rice var. Lachit (TTB 14-1) in India. Castillo (1994) stressed the need for assessment of the potential of crop production systems, their sustainability and rational use of energy in relation to production technologies, the impact of economic recovery and energy use efficiency.

Thus, from the review of the findings of previous researchers it has been felt that energy analyses focused on acceleration of the pace of crop production on one hand and the efficient utilization of farm resources on the other. Also H.T. Odum, in a paper based on modelling (Odum, 1995) states that "As its fuel base declines, the frenzied pulse of the world economy, based on the fuels, bio-mass, and other resources, subsides, returning the system to a more moderate part of the pulse cycle" and there are obvious reasons for studying energy aspects of different cropping systems. According to Giampietro et al. (1992), energy provides a natural focus for comparative studies of physical performance of cropping systems.

The studies conducted by the previous workers primarily emphasized the contribution of different factors of production in agriculture to the total energy consumption. Most of the studies concentrated on the N fertilizer inputs and different tillage aspects for cereal based crop production systems. Moreover, the partitioning of total energy to renewable and non-renewable energy has not been reported so far, which is more important to form future strategies. Further, the previous studies did not consider the size of land holdings of the farmer. In the central ecological niche of India, soybean (*Glycine max* (L.) Merr.) is one of the major cash crops, which covers 80% of its total area in India (Damodaram and Hegde, 2000), and major crop production systems are soybean-wheat (*Triticum aestivum* L.), soybean-chickpea (*Cicer arietinum* L.), pigeonpea (*Cajanus cajan* L.) monocropping, fallow-wheat and fallow-chickpea.

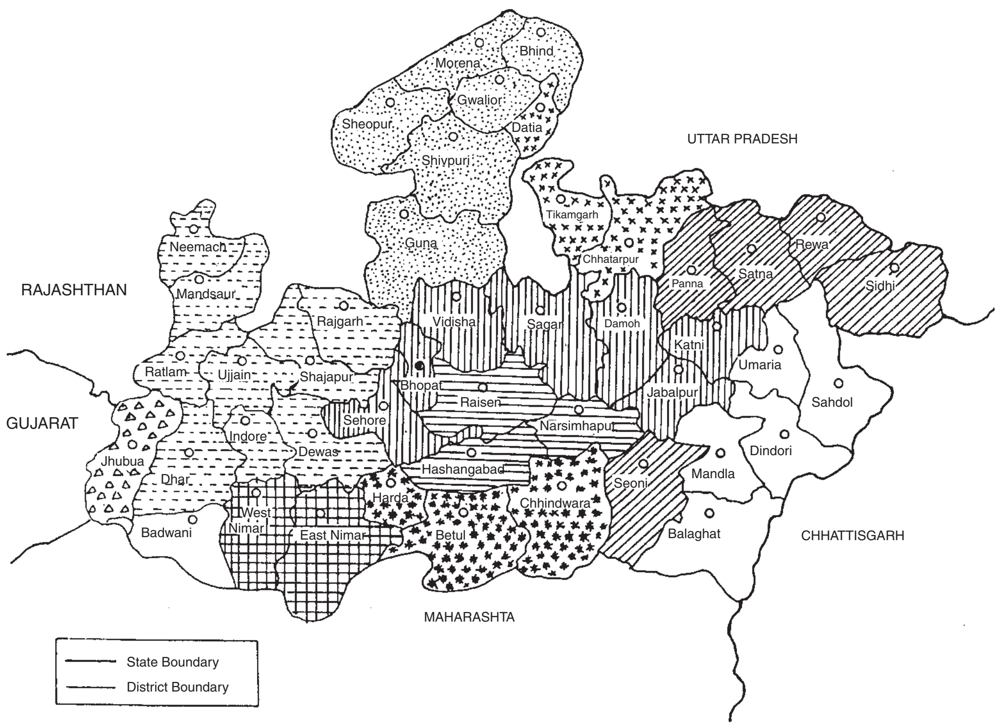
In our study, it was hypothesized that the major crop production systems (soybean-wheat, soybean-chickpea, pegionpea monocropping, fallow-wheat and fallow-chickpea) in central India might differ in terms of energy use (total, renewable and non-renewable), energy output-input relationship and the economics. Consideration of the size of land holdings as a variable was again a unique feature of this study. This kind of study was not conducted so far. The objective of this study was to assess the energy input and output, economic aspects and to compare crop production systems across size of land holdings. An endeavor of this kind will facilitate to bridge the knowledge gap of the farming community, to develop alternative technologies/practices for increasing energy use efficiency and sustaining crop production systems.

METHODOLOGY

The Study Area

The study was conducted in Central Narmada Valley region of India comprising the districts of Raisen, Hoshangabad and Narsinghpur of the state of Madhya Pradesh. The area is surrounded by Sehore, Bhopal, Vidisha, Sagar, Damoh and Jabalpur districts of Vindhyachal Plateau region from west to north, Seoni district of Kaymore Plateau and Satpura Hill region in the east and Betul and Chhindwara districts of Satpura Plateau region in the south (Figure 1). The study area is located between 21.2° to 23.7°N latitude and 75.9° to 77.10° E longitudes. The mean altitude from sea level ranges from 500 to 550 meters. The geographical area of this region is 1,745,00 ha, out of which 1,175,327 ha is under cultivation. The main seasons of this region are dry summer (March to mid-June), wet rainy season (mid-June to September) and winter season (November to February). The mean annual rainfall of this region is about 1300 mm, most of which (80-85%) are received during the month of July to September. The number of rainy days, with rainfall more than

FIGURE 1. Agro-Climatic Zones of Madhya Pradesh



2.5 mm per day, varies between 45 and 50 per year. The predominant soil type of this region is medium to deep black clay soil (Vertisols).

Crops and Crop Management (Land Preparation, Fertilizer, Manure, Seed and Chemicals)

The major crops grown in this region are soybean (469 thousand ha)/pigeon pea (66.7 thousand ha) in rainy season and wheat (461.2 thousand ha)/chickpea (362.6 thousand ha) in winter. The predominant crop production systems viz., soybean-wheat, soybean-chickpea, pigeonpea monocropping, fallow-wheat and fallow-chickpea are analyzed and compared for energy and economic aspects. The practice of keeping fallow in rainy season followed by cultivation of wheat or chickpea in winter season, utilizing the conserved soil moisture or limited irrigation is a common practice in this region. The average fertilizer consumption of this region is 33.03 kg N, 23.73 kg P_2O_5 and 1.62 kg K_2O ha^{-1}. The average cropping intensity (i.e., the ratio between total cropped area in a year and actual net cultivated area expressed in %) of this region is 136%. Farmers of the study area mostly prepare their land with two passes of 35 HP tractor-drawn cultivator, apply farmyard manure once in a year at 5 t ha^{-1} during summer ploughing before rainy season, fertilizer N-P_2O_5-K_2O at 30-60-30 kg ha^{-1} for both soybean and pigeonpea, 120-60-40 kg ha^{-1} for wheat and 20-40-20 kg ha^{-1} for chickpea. They sow seeds with the tractor drawn seed drill with the seed rates of 80, 20, 100 and 75 kg ha^{-1} for soybean, pigeonpea, wheat and chickpea, respectively. They apply phosphamidon 85%EC @ 0.02% for controlling insect-pests.

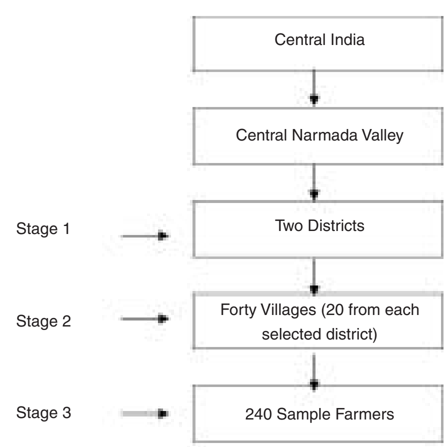
Population Profile

The total population of this region is about 29.29 million with a density of 128 per square km, distributed into 527,625 households with sex ratio of 897 female per 1000 of male. The majority of population (79.48%) residing in the rural areas of this region comprising of 3889 inhabited villages are engaged in agriculture and allied activities. The literacy rate of the rural population is only 43.34%. The total number of main cultivators and agricultural laborers are 382,459 and 360,134, respectively. There are five major categories of farmers in this region. We followed the exactly our national categorization as marginal farmers (having $\leq$ 1 ha of land), small (1 to 2 ha of land), semi-medium (2 to 4 ha of land), medium (4 to 10 ha of land) and large ($\geq$ 10 ha of land). In our study area, 3.11, 10.77, 18.20, 36.74 and 31.19% of total area was occupied by small, semi-medium, medium and large farmers, respectively; and corresponding average farm size was 0.50, 1.34, 2.81, 6.12 and 17.58 ha. About 51.57% of the net sown area is under irrigation facilities.

Sampling Procedure

Multi-stage stratified random sampling technique was adopted for selection of samples for analysis of the study. In the first stage, two districts were selected from the Central Narmada Valley region of India. In the second stages, 40 villages were randomly selected (20 from each district). Finally, 240 farmers were chosen at random maintaining the probability proportional to the number of farmers in each village (Figure 2). After a careful analysis of the study objectives, a suitable questionnaire was developed to collect the primary data for the study. Then the questionnaire prepared for collecting data from the sample farmers by directly interviewing them was first tested with a small group of farmers. The objective of this *pro forma* pre-testing was to enhance the compatibility between the types and patterns of questions to be asked to the farmers and their knowledge level as well as to modify and improve the questionnaire to communicate with the farmers more effectively during personal interview. Necessary modifications were made in the questionnaire to ensure that the important issues in the study were not excluded. Using this validated, pre-tested and modified questionnaire, the primary data were collected for rainy (wet) and winter (dry) season crops through personal interview method from the sample farmers during 1999-2000. Sample was taken randomly at each stage of multistage-stratified random sampling to avoid biasness towards overestimation or underestimation in analysis. This is a standard statistical sampling method used by many researchers.

FIGURE 2. Sampling diagram



Renewable and Non-Renewable Energy and Calculations of Energy Ratios

The energy inputs referred to the both renewable and non-renewable energy. Renewable energy constituted manual, animal/bullock, seed, manure, etc., whereas, non-renewable energy encompassed chemical fertilizer (NPK), tractor, diesel, electricity, lubricants, machinery and agro-chemicals, etc. Total physical output referred to both the grain and by-product yield. These primary data collected on various inputs and management practices for all the crops were used for computation of energy consumption and its various ratios for each crop production systems. The energy output from the economic and by-product yield was also estimated. After threshing in the farmyard the grains were separated by the farmers, and the rest plant parts including husks constituted the byproduct. Thus farmers considered their output as grain and byproduct only. The damage of output was very negligible due to natural calamities and pest. Thus damage or waste is not included. For estimation of energy inputs and outputs (expressed in MJ ha-1) for each item of inputs and agronomic practices, equivalents (Table 1) were utilized as suggested by Mittal and Dhawan (1988), Baishya and Sharma (1990), Panesar and Bhatnagar (1994) and Singh et al. (1997). Superior chemicals are those, which require dilution while application. Energy efficiency, energy productivity and energy intensity were calculated using the following formula as suggested by Mittal and Dhawan (1988), Singh et al. (1997) and Burnett (1982):

$$\text{Energy efficiency} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

$$\text{Net energy (MJ ha}^{-1}\text{)} = \text{Energy output (MJ ha}^{-1}\text{)} - \text{Energy input (MJ ha}^{-1}\text{)}$$

$$\text{Energy productivity (kg MJ}^{-1}\text{)} = \frac{\text{Output (grain + byproduct) (kg ha}^{-1}\text{)}}{\text{Energy input (MJ ha}^{-1}\text{)}}$$

$$\text{Energy intensity (in physical terms, MJ kg}^{-1}\text{)} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Output (grain + byproduct) (kg ha}^{-1}\text{)}}$$

$$\text{Energy intensity (in economic terms, MJ Rs.}^{-1}\text{)} = \frac{\text{Energy output (MJ ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs. ha}^{-1}\text{)}}$$

RESULTS AND DISCUSSION

Crop Production Systems

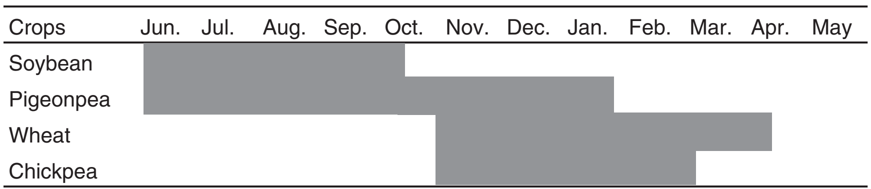
Length of growing period (LGP) of crops is presented in Table 2. Sowing of soybean and pigeonpea coincides with the onset of monsoon rainfall, i.e., dur-

TABLE 1. Energy equivalents for different inputs and outputs

Particulars	Units	Equivalent energy, MJ	Remarks
A. Inputs			
1. Human labor			
(a) Adult man	Man-hour	1.96	
(b) Woman	Woman-hour	1.57	
2. Animals	Bullock-pair/ day	64.56	
3. Diesel	Liter	56.31	Includes cost of lubricants
4. Petrol	Liter	48.23	Includes cost of lubricants
5. Electricity	KWh	11.93	
6. Machinery			
(a) Electric motor	Kg	64.8	
(b) Farm Machinery including self propelled machines	Kg	62.7	
7. Chemical fertilizers			
i) Nitrogen	Kg	60.60	
ii) Phosphate (P_2O_5)	Kg	11.1	
iii) Potash (K_2O)	Kg	6.7	
8. Farmyard manure (FYM)	Kg	0.3	Dry matter
9. Chemicals			
i) Superior chemicals	Kg	120	Require dilution at the time of application
10. Seed	As output of crop production system		
B. Output			
I. Main product			
1. Wheat	Kg	14.7	Dry mass
2. Soybean	Kg	14.7	Dry mass
3. Chickpea	Kg	14.7	Dry mass
4. Pigeonpea	Kg	14.7	Dry mass
II. By product			
1. Straw/stover	Kg	12.5	Dry mass

Source: Mittal and Dhawan (1988), Baishya and Sharma (1990), Panesar and Bhatnagar (1994), Singh et al. (1997)

TABLE 2. Length of growing period (LGP) for different crops



ing mid-June. LGP of soybean extends up to first half of October (i.e., 110-115 days) and that of pigeonpea up to January (i.e., 180-200 days). Pigeonpea varieties are comparatively of long duration. The LGP of pigeonpea extends even after withdrawal of monsoon rainfall (mid-June to September). Thus, the advantage of pigeonpea monocropping is the greater use of land and time and of course, efficient utilization of residual moisture stored in the soil profile. This advantage is accrued by the farmers who follow grow pigeonpea. Land utilization efficiency by pigeonpea monocropping is greater than that of soybean. Sowing of wheat and chickpea start during November and LGP of wheat extends up to mid-April (i.e., 135-140 days) and that of chickpea up to March (i.e., 130-135 days). Chickpea also utilizes the residual soil moisture. Most often wheat needs one pre-sowing irrigation. In the low rainfall year, or in the event of early withdrawal of monsoon, chickpea also needs pre-sowing irrigation for its establishment. Thus, the system as a whole, soybean-wheat and soybean-chickpea occupy the land more number of days than pigeonpea monocropping, fallow-wheat and fallow-chickpea systems.

There are differences in the adoption behavior of cropping systems by different categories of farmers, i.e., different size of land holdings (Table 3). The percentage of farmers adopting soybean-wheat system gradually increased from 6.25% in marginal category to 48.15% in large category. Almost similar is the pattern for soybean-chickpea production system, but the percentage is greater in marginal and small categories, smaller in semi-medium, medium and large categories than for soybean-wheat system. Pigeonpea monocropping is mostly practiced by small (29.82%) and semi-medium (25.49%) farmers, and a very small percentage by large (7.41%) and considerable percentage by marginal (15.63%) and medium (14.63%) size of farms. Soybean-wheat system, particularly the succeeding wheat crop, is input-intensive compared to the other systems, and is practiced by the farmers having greater size of land holdings. It also depends on the availability of irrigation water during the winter season. Wheat needs one pre-sowing and at least one post-sowing supplemental irrigation to achieve economic/profitable return, whereas irrigation water requirement for chickpea is far less than wheat and is normally grown

TABLE 3. Cropping systems followed by different categories of farmers

Cropping systems	Percentage of farmers				
	Marginal (≤ 1 ha)	Small (1-2 ha)	Semi-medium (2-4 ha)	Medium (4-10 ha)	Large (≥ 10 ha)
Soybean-wheat	4 (6.25)	14 (24.50)	17 (33.33)	17 (41.46)	13 (48.15)
Soybean-chickpea	8 (12.50)	15 (26.53)	14 (27.45)	14 (34.15)	11 (40.74)
Pigeonpea monocropping	10 (15.63)	17 (29.82)	13 (25.49)	6 (14.63)	2 (7.41)
Fallow-wheat	20 (31.25)	4 (7.01)	5 (9.80)	4 (9.76)	1 (3.70)
Fallow-chickpea	22 (34.37)	7 (12.24)	2 (3.93)	0 (0.00)	0 (0.00)
Total	64 (100.00)	57 (100.00)	51 (100.00)	41 (100.00)	27 (100.00)

with residual soil moisture or with very less amount of irrigation water (i.e., only one pre-sowing irrigation). It is interesting to note that resource-rich farmers also grow chickpea owing to the fact that almost 50% of their land holding is not having irrigation facilities. Again, the practice of keeping fallow during rainy season is common in the marginal farmers; 31.25% and 34.37% farmers practice fallow-wheat and fallow-chickpea systems, respectively. A very small percentage of farmers having larger size of land holding compared to marginal category, keep their land fallow during rainy season, and no medium and large farmer practice fallowing before sowing of chickpea. It is due to the fact that marginal farmers cannot afford the input costs of two crops in a year. Moreover, though the cropping intensity is reduced, due to fallowing, marginal farmers try to store moisture in the soil profile during the fallow period of rainy season and grow either wheat or chickpea with the residual soil moisture after receding monsoon rain. Thus, irrigation water availability and the investment capacity of farmers mostly determine the cropping system of the study area.

The investment capacity or the purchasing power also governs the input-use behavior of different category of farmers (Table 4). The major inputs for crop production systems are seeds (either through self-produced or market purchased, or both), organic manure, chemicals fertilizers, irrigation, plant protection chemicals and draft power (either through tractor use or bullock use, or both). It reveals that chemical fertilizers (NPK), manure, irrigation and seeds constituted the major share of these inputs. The seed rates are 80, 20, 100 and 75 kg ha^{-1} for soybean, pigeonpea, wheat and chickpea, respectively. The percentage of farmers using self-produced seeds for sowing of crops gradually decrease from 46.65% in marginal category to only 15.73% in large category, i.e., use of self-produced seeds decrease with the increase in size of land hold-

TABLE 4. Distribution of farmers by input use behavior for the crops

Type of input use	Percentage of farmers				
	Marginal ($\leq$ 1 ha)	Small (1-2 ha)	Semi-medium (2-4 ha)	Medium (4-10 ha)	Large ($\geq$ 10 ha)
A. Seed procurement					
a. Self produced	46.65	28.08	17.56	15.97	15.73
b. Purchased from market	23.10	32.23	38.19	45.30	50.38
c. Both self-produced and purchased	30.25	39.69	44.25	38.73	33.89
B. Organic manure	81.14	78.79	53.28	45.62	45.45
C. Fertilizer	87.38	92.74	100.00	100.00	100.00
D. Irrigation	37.62	54.93	82.26	94.90	100.00
E. Plant protection chemicals	4.08	10.23	16.66	33.33	62.38
F. Tractor user	12.83	29.62	62.97	75.72	83.15
G. Bullock user	64.37	42.48	12.21	0.00	0.00
H. Both tractor and bullock user	22.80	27.90	14.82	24.28	16.85

ings. The reverse is the trend for use of market-purchased seeds, ranging from 23.10% in marginal to 50.38% in large category. Thus, the tendency of use of market-purchased seeds increases with the increase in size of land holdings. Application of organic manure, at least once in a year for the cropping system, varies with the farm category. The percentage of farmers decrease towards the large category, 81.14% in marginal and 45.45% in large category. Though the magnitude is higher for manures, the reverse is the trend for chemical fertilizer use. Fertilizer $N\text{-}P_2O_5\text{-}K_2O$ rates are 30-60-30 kg ha^{-1} for both for soybean and pigeonpea, 120-60-40 kg ha^{-1} for wheat and 20-40-20 kg ha^{-1} for chick-pea. Nearly all the semi-medium (100%), medium (100%) and large (100%) farmers apply chemical fertilizers purchased from market, whereas 80-90% of the marginal and small farmers use chemical fertilizers. Similar trend is revealed on the use of irrigation water, plant protection chemicals and tractor power, whereas use of bullock for conducting farm operations is greater in the marginal (64.37%) and small (42.48%) categories; no bullock power is used by medium and large categories. Thus, the size of land holding influences the input-use behavior. Crop production systems in the greater size of land holdings use more of tractor power, chemical fertilizers, irrigation water, plant protection chemicals, and less of organic manure and bullock power. The opposite trend is observed among farmers having smaller size of land holdings.

Energy Use Pattern

Energy consumption (both renewable and non-renewable) differs with the crop production systems (Table 5). Total energy input for soybean-wheat system (19,817 MJ ha^{-1}) is much greater than other systems, i.e., soybean-chickpea (11,239 MJ ha^{-1}), pigeonpea monocropping (2,329 MJ ha^{-1}), fallow-wheat (13,716 MJ ha^{-1}) and fallow-chickpea (4,445 MJ ha^{-1}). Further, the total energy use, though the magnitudes vary in different crop production systems, gradually increases with the increase in size of land holdings in every cropping system, i.e., the lowest total energy is used by marginal category and the highest by large category. Out of this total energy use, the share of non-renewable energy (i.e., chemical fertilizers, diesel, electricity, lubricants, machinery and plant protection chemicals, etc.) is always higher than renewable energy inputs (seeds, manure, human labor, bullock, etc.) for every crop production system. It is found that wheat crop in the system tends to increase non-renewable percent than legumes. Thus, soybean-wheat and fallow-wheat systems resort to more use of non-renewable energy than renewable energy, 70 and 78%, respectively. This is due to the chemical fertilizer use rates. The use of nitrogen, phosphorus and potassium fertilizer is more in wheat than in any other crops in the systems. Thakur and Makan (1997) and Joshi et al. (1998) also reported that main energy input for crop production system was the fertilizer. If both the crop components in the system are legumes as in soybean-chickpea system (52%), non-renewable share of energy is reduced, owing to lower requirement of external nitrogen supply through fertilizers. It is also very important that out of total energy use, percent renewable energy use gradually decrease and percent non-renewable energy use gradually increase with the increase in size of operational holding of the farmers, irrespective of crop production systems of the study area. It reveals that farmers having higher size of land holdings use more of chemical fertilizers, irrigation, plant protection chemicals and tractor power, and adopt mechanized farming. Use of tractor and power tiller reduces the use of both human labor and bullocks on farms, and increases the total energy consumption.

Output of Crop Production Systems and Energy Output-Input Relationship

The physical output per hectare (economic, i.e., grain yield, byproduct, i.e., straw/stover yield) and the energy output per hectare vary with the crop production systems and size of land holding (Table 6). Averaging over the size of land holdings, the economic and the byproduct yield follow the order: soybean-wheat > fallow-wheat > soybean-chickpea > pigeonpea monocropping > fallow-chickpea; the energy outputs also follow the same order and the values

TABLE 5. Total energy consumption for cropping systems in different categories of farmers

Cropping systems	Farmers' category	Total energy (MJ ha^{-1})	Renewable energy		Non-renewable energy	
			(MJ ha^{-1})	%	(MJ ha^{-1})	%
Soybean-wheat	Marginal	13,686	7,146	52	6,540	48
	Small	17,713	6,058	34	11,656	66
	Semi-medium	20,961	5,417	26	15,544	74
	Medium	22,257	4,816	22	17,440	78
	Large	24,468	4,097	17	20,371	83
	Mean	**19,817**	**5,507**	**30**	**14,310**	**70**
Soybean-chickpea	Marginal	7,714	6,011	78	1,703	22
	Small	8,796	5,491	62	3,304	38
	Semi-medium	11,385	4,726	42	6,658	58
	Medium	13,109	4,488	34	8,621	66
	Large	15,190	3,698	24	11,492	76
	Mean	**11,239**	**4,883**	**48**	**6,356**	**52**
Pigeonpea monocropping	Marginal	2,202	1,003	46	1,199	54
	Small	2,232	848	38	1,384	62
	Semi-medium	2,340	619	26	1,721	74
	Medium	2,433	557	23	1,876	77
	Large	2,439	541	22	1,898	78
	Mean	**2,329**	**714**	**31**	**1,616**	**69**
Fallow-wheat	Marginal	9,126	3,393	37	5,732	63
	Small	13,356	3,109	23	10,247	77
	Semi-medium	14,721	2,869	19	11,851	81
	Medium	15,091	2,530	17	12,562	83
	Large	16,289	2,150	13	14,139	87
	Mean	**13,716**	**2,810**	**22**	**10,906**	**78**
Fallow-chickpea	Marginal	3,753	2,858	76	895	24
	Small	4,438	2,542	57	1,896	43
	Semi-medium	5,144	2,178	42	2,966	58
	Medium	-	-	-	-	-
	Large	-	-	-	-	-
	Mean	**4,445**	**2,526**	**59**	**1,919**	**41**

TABLE 6. Physical output (kg ha^{-1}) and energy output (MJ ha^{-1}) for cropping systems in different category of farmers

Cropping systems	Farmers' category	Economic yield (kg ha^{-1})	By-product yield (kg ha^{-1})	Energy output (kg ha^{-1})
Soybean-wheat	Marginal	2,623	2,125	65,121
	Small	2,654	2,368	68,614
	Semi-medium	2,697	2,513	71,058
	Medium	2,767	2,576	72,875
	Large	2,845	2,639	74,809
	Mean	**2,717**	**2,444**	**70,495**
Soybean-chickpea	Marginal	1,446	1,653	41,919
	Small	1,533	1,655	43,223
	Semi-medium	1,630	1,678	44,936
	Medium	1,679	1,683	45,719
	Large	1,729	1,697	46,629
	Mean	**1,603**	**1,673**	**44,485**
Pigeonpea monocropping	Marginal	679	665	18,294
	Small	713	702	19,256
	Semi-medium	782	737	20,708
	Medium	796	772	21,351
	Large	835	820	22,525
	Mean	**761**	**739**	**20,427**
Fallow-wheat	Marginal	1,832	1,782	49,205
	Small	1,936	1,796	50,909
	Semi-medium	1,959	1,878	52,272
	Medium	1,962	1,931	52,979
	Large	2,065	1,976	55,056
	Mean	**1,951**	**1,873**	**52,084**
Fallow-chickpea	Marginal	677	741	19,214
	Small	698	812	20,411
	Semi-medium	759	823	21,445
	Medium	-	-	-
	Large	-	-	-
	Mean	**711**	**792**	**20,357**

are 70,495 MJ ha^{-1}, 52,084 MJ ha^{-1}, 44,485 MJ ha^{-1}, 20,427 MJ ha^{-1} and 20,357 MJ ha^{-1} for soybean-wheat, fallow-wheat, soybean-chickpea, pigeonpea monocropping and fallow-chickpea, respectively. The variation in yield is due to the intrinsic potential of the crops in the sequence and differential input-use behavior. Results also reveal that yield (both economic and byproduct) and obviously the energy output is increased with the increase in size of farm, i.e., from marginal to large category implying that large farmers maintain considerably higher level of productivity compared to small farmers.

The energy efficiency (i.e., the ratio of energy output to energy input) is the highest in pigeonpea monocropping (8.76); for other systems it ranged from 3.67 in soybean-wheat to 4.63 in fallow-chickpea system (Table 7). Comparing the size of land holdings, the energy efficiency gradually decreases towards higher size of farms, except for pigeonpea monocropping, where the trend is reverse; of course the difference between marginal (8.31) and large (9.23) is not very wide. The net energy (i.e., the energy output minus energy input, excluding waste and damage which was negligible) of the systems is 50,678 MJ ha^{-1} in soybean-wheat, 38,368 MJ ha^{-1} in fallow-wheat, 33,246 MJ ha^{-1} in soybean-chickpea, 18,098 MJ ha^{-1} in pigeonpea monocropping and 15,912 MJ ha^{-1} in fallow-chickpea. The net energy also gradually decreases with increase in farm size, except in pigeonpea monocropping and fallow- chickpea systems, where it shows the reverse trend. Though the soybean-wheat system results in the highest net energy, its energy productivity (i.e., kg produced per unit of energy use) is the lowest (0.269 kg MJ^{-1}). Energy productivity of fallow-wheat system (0.288 kg MJ^{-1}) is also low. It is comparatively higher for other systems, such as soybean-chickpea (0.307 kg MJ^{-1}), pigeonpea monocropping (0.643 kg MJ^{-1}) and fallow-chickpea (0.342 kg MJ^{-1}). It reveals that wheat crop in the system involves highest energy inputs and results in highest output also, but the energy efficiency and energy productivity are lower. Mittal and Dhawan (1989) and Mandal et al. (2002) also found the similar pattern. Energy productivity also follows the same trend as the energy efficiency with respect to size of land holdings. Further, energy intensity, both in the physical terms (i.e., energy required to produce one unit of output, MJ kg^{-1}) and in economic terms (i.e., energy consumed per rupee of investment, MJ $Rs.^{-1}$) are 3.84 MJ kg^{-1} and 0.887 MJ $Rs.^{-1}$, respectively, for the soybean-wheat system, and are greater than other systems; such as, soybean-chickpea (3.43 MJ kg^{-1} and 0.577 MJ $Rs.^{-1}$), pigeonpea monocropping (1.55 MJ kg^{-1} and 0.243 MJ $Rs.^{-1}$), fallow-wheat (3.59 MJ kg^{-1} and 1.408 MJ $Rs.^{-1}$) and fallow-chickpea (2.96 MJ kg^{-1} and 0.569 MJ $Rs.^{-1}$). Except for pigeonpea, the increase in farm size leads to gradual increase in the energy intensity in both terms for the crop production systems. Thus, it indicates that inclusion of wheat crop in the system, particularly in the larger size farms, the system becomes more energy intensive, less energy efficient and less energy

TABLE 7. Energy input-output relationship for cropping systems

Cropping systems	Farmers' category	Energy efficiency (output-input ratio)	Net energy (MJ ha^{-1})	Energy productivity (kg MJ^{-1})	Energy Intensity	
					(MJ kg^{-1})	(MJ $Rs.^{-1}$)
Soybean-wheat	Marginal	4.76	51,435	0.347	2.88	0.741
	Small	3.87	50,901	0.284	3.53	0.826
	Semi-medium	3.39	50,097	0.249	4.02	0.929
	Medium	3.27	50,618	0.240	4.17	0.926
	Large	3.06	50,341	0.224	4.46	1.013
	Mean	**3.67**	**50,678**	**0.269**	**3.84**	**0.887**
Soybean-chickpea	Marginal	5.43	34,205	0.402	2.49	0.493
	Small	4.91	34,427	0.362	2.76	0.481
	Semi-medium	3.95	33,551	0.291	3.44	0.575
	Medium	3.49	32,610	0.256	3.90	0.626
	Large	3.07	31,439	0.226	4.43	0.711
	Mean	**4.17**	**33,246**	**0.307**	**3.43**	**0.577**
Pigeonpea monocropping	Marginal	8.31	16,092	0.610	1.64	0.253
	Small	8.63	17,024	0.634	1.58	0.233
	Semi-medium	8.85	18,368	0.649	1.54	0.242
	Medium	8.78	18,919	0.645	1.55	0.244
	Large	9.23	20,085	0.678	1.47	0.243
	Mean	**8.76**	**18,098**	**0.643**	**1.55**	**0.243**
Fallow-wheat	Marginal	5.39	40,080	0.396	2.53	0.980
	Small	3.81	37,554	0.279	3.58	1.395
	Semi-medium	3.55	37,552	0.261	3.84	1.511
	Medium	3.51	37,888	0.258	3.88	1.527
	Large	3.38	38,766	0.248	4.03	1.626
	Mean	**3.93**	**38,368**	**0.288**	**3.59**	**1.408**
Fallow-chickpea	Marginal	5.12	15,461	0.378	2.65	0.511
	Small	4.60	15,973	0.340	2.94	0.588
	Semi-medium	4.17	16,301	0.308	3.25	0.609
	Medium	-	-	-	-	-
	Large	-	-	-	-	-
	Mean	**4.63**	**15,912**	**0.342**	**2.96**	**0.569**

productive. This may be explained by the higher rates of chemical fertilizers, irrigation and increased mechanization by the larger size farms.

Economic Appraisal

Soybean is comparatively more investment intensive because of organic manure application to soybean for the sequence, summer ploughing during dry season and spraying of insecticide. Wheat is also the investment intensive crop followed by chickpea and pigeonpea because of higher rates of chemical fertilizers and irrigation water requirement. As a consequence, the cost of cultivation for soybean-wheat system is the highest (Rs. 22,140) followed by soybean-chickpea (Rs. 19,201), fallow-wheat (Rs. 9,705), pigeonpea monocropping (Rs. 9,598) and fallow-chickpea (Rs. 7,777) (Table 8). The cost of cultivation also increases with increase in size of farms. The soybean-wheat cropping system is mostly preferred on the larger farms which can invest more in farming business due to the highest investment requirement and net return of soybean-wheat cropping system (Rs. 5,837). Kathiresan et al. (1999) also reported that a maximum net return of Rs. 10,131.00 per hectare was obtained from soybean cultivated with application of enriched farmyard manure with a benefit-cost ratio of 2.65, and Kewat and Pandey (2001) obtained a benefit-cost ratio of 1.96 from cultivation of soybean where farmers control weeds by hand weeding twice at 20 and 40 days after sowing. However, the investment efficiency is the highest in the case of marginal and small farms, which obtain higher income per rupee of investment as is evidenced from higher benefit/cost ratio. Farmers of all categories opt for soybean-chickpea crop rotation wherever there is inadequate rainfall during rainy season and lack of irrigation facilities in subsequent winter season for cultivation of wheat crop.

The low investment requirement of soybean-chickpea cropping system makes it favorable for adoption by the marginal and small farmers who have low investment capacity. The farmers which neither have adequate funds to invest in farming business nor the irrigation facilities for raising two crops mostly favor pigeonpea monocropping, fallow-wheat and fallow-chickpea systems. But the soybean-wheat cropping system is more remunerative in terms of benefit-cost ratio (1.27) owing to its ability to generate higher return per rupee investment than soybean-chickpea (1.23) and pigeonpea monocropping (1.23). The fallow-based systems have better benefit/cost ratio. The cost of production for wheat in Madhya Pradesh during 1998-99 was Rs. 10,260.22 per hectare with a benefit-cost ratio of 1.18 and Rs. 8050.90 per hectare for pigeonpea during 1997-98 with a benefit-cost ratio of 1.13 (Fertilizer Statistics, 2000-2001). Therefore, the soybean-wheat cropping system bears promise to provide higher income generation and the maintenance of sustainable cereal-legume crop rotation system whereas soybean-chickpea and

TABLE 8. Economic analyses of different cropping systems under farmers' categories

Cropping systems	Farmers' category	Cost of cultivation (Rs. ha^{-1})	Net return (Rs. ha^{-1})	Benefit/cost ratio
Soybean-wheat	Marginal	18,481	8,133	1.44
	Small	21,443	5,860	1.27
	Semi-medium	22,566	5,584	1.25
	Medium	24,047	4,792	1.20
	Large	24,162	4,815	1.20
	Mean	**22,140**	**5,837**	**1.27**
Soybean-chickpea	Marginal	15,640	5,615	1.36
	Small	18,268	4,070	1.22
	Semi-medium	19,812	3,833	1.19
	Medium	20,929	3,799	1.18
	Large	21,356	3,970	1.19
	Mean	**19,201**	**4,258**	**1.23**
Pigeonpea monocropping	Marginal	8,715	2,061	1.24
	Small	9,564	1,541	1.16
	Semi-medium	9,682	2,339	1.24
	Medium	9,985	2,367	1.24
	Large	10,043	2,893	1.29
	Mean	**9,598**	**2,240**	**1.23**
Fallow-wheat	Marginal	9,308	4,292	1.46
	Small	9,575	4,053	1.42
	Semi-medium	9,743	3,939	1.40
	Medium	9,881	3,885	1.39
	Large	10,019	3,805	1.38
	Mean	**9,705**	**3,995**	**1.41**
Fallow-chickpea	Marginal	7,341	2,580	1.35
	Small	7,551	2,697	1.36
	Semi-medium	8,440	2,213	1.26
	Medium	-	-	-
	Large	-	-	-
	Mean	**7,777**	**2,497**	**1.32**

$1 = Rs. 46.68

monocropping of pigeonpea, and fallow-wheat rotation are suitable for farmers with low resource endowments in dry farming techniques. The fallow-chickpea rotation is only suitable for extremely poor farmers with no irrigation facilities. Shivakumar (2001) obtained a maximum net return of Rs. 8,432.00 per hectare from cultivation of chickpea with a benefit-cost ratio of 1.78, and Ashok Kumar et al. (2002) reported a maximum net return of Rs. 9,117.00, 4,487.00 and 7,732.00 per hectare from cultivation of wheat, pigeon pea and chickpea, respectively with a benefit-cost ratio of 2.45, 3.16 and 2.20.

SUMMARY AND CONCLUSIONS

1. The crop production systems in central India, viz., soybean-wheat, soybean-chickpea, pegionpea monocropping, fallow-wheat and fallow-chickpea are analyzed in relation to the energy (renewable and non-renewable) input and output and in economic terms. The implications of variable energy use in different categories of land holdings are also outlined. Energetics in the crop production systems enable to identify the effective and sustainable cropping system in different farm size with respect to energy use, energy efficiency, energy intensity and energy productivity.
2. The length of growing period reveals that soybean-wheat and soybean-chickpea occupy land the more number of days than pigeonpea monocropping, fallow-wheat and fallow-chickpea systems. Thus land utilization efficiency is more in the soybean-wheat and soybean-chickpea systems.
3. The adoption of soybean-wheat system is increased towards greater land holdings, but the adoption of soybean-chickpea system is greater in small land holdings than soybean-wheat system. Pigeonpea monocropping is mostly practiced by the small and marginal category.
4. Input use pattern is different with the category of farmers. Use of self-produced seeds is greater in marginal and small land holdings than the large, whereas the opposite trend is observed for market-purchased seeds, i.e., large farmers use more of market purchased seeds than the self-produced. Nearly every farmer having greater than 2 ha of land and 80-90% farmers having land holding less than 2 ha apply fertilizer-NPK. Similar trend is revealed for irrigation water and plant protection measures.
5. The total energy input to the soybean-wheat cropping system is much greater than soybean-chickpea, pigeonpea monocropping, fallow-wheat and fallow-chickpea; and the share of non-renewable (i.e., chemical fertilizers, diesel, electricity, lubricants, machinery and plant protection chemicals, etc.) to the total energy input is greater than renewable en-

ergy inputs (seeds, manure, human labor, bullock, etc.) in every cropping system. Thus, the systems involving wheat as a component crop resort to greater use of non-renewable energy input compared to legume-based systems. Further, the soybean-wheat system is more energy intensive (both in physical, i.e., MJ kg^{-1} and economic basis, i.e., MJ $Rs.^{-1}$), less energy efficient and less energy productive, especially in large land holdings.

6. The cost of cultivation for soybean-wheat system is higher than other systems; it increases with increase in size of farms. Thus large farmers who can invest more in farming opt for soybean-wheat cropping system in their land holdings where irrigation water is provided to wheat. Further the investment efficiency is greater in case of marginal and small farms, which obtain higher income per rupee of investment as is evidenced from higher benefit/cost ratio.
7. Farmers of all categories opt for soybean-chickpea cropping system wherever there are inadequate irrigation facilities during winter season for cultivation of wheat crop. Moreover, as investment requirement is low for soybean-chickpea cropping system, the marginal and small farmers adopt it. Therefore, the soybean-wheat cropping system bears promise to provide higher income generation and the maintenance of sustainable cereal-legume crop rotation system whereas soybean-chickpea and monocropping of pigeonpea, and fallow-wheat rotation are suitable for farmers with low resource endowments in dry farming techniques.
8. Thus, soybean-chickpea required less energy input but gave the highest energy efficiency among the systems, especially under limited irrigation. In the present era of energy crisis, soybean-chickpea system could be popularized for the benefit of small and marginal farmers and in unirrigated lands of the large farmers, especially in the central ecological niche of Indian subcontinent.

Planning is needed to develop systematic energy optimizing management practices to generate energy efficient and remunerative crop production systems. As the chemical fertilizers are non-renewable and energy-intensive resources, supplementation of plant nutrients through renewable resources like farmyard manure, green manures, etc., would increase net bioenergy yield. Integrated nutrient management systems and the recycling of biomass for saving non-renewable inputs such as chemical fertilizers, management of non-monetary energy inputs such as splitting of fertilizer application and timely sowing are needed to sustain the energy efficient production systems. Thus farmers' awareness of the use of non-renewable energy inputs in the present day situation of global fossil-fuel crisis should be an important prerequisite for continuation of the soybean-wheat cropping systems. Energy-use needs to be sustainable in economic terms also. The analysis of cropping systems cautions for increasing trend of non-renewable energy use on larger size farm holdings. The short-term advantage of greater yields using high levels of fossil fuel-derived inputs need to be balanced against the long-term costs of depleting a scarce and non-renewable energy resource.

REFERENCES

Aggarwal, G. C. 1995. Fertilizer and irrigation management for energy conservation in crop production. *Energy* (Oxford) *20* (8): 771-776.

Ashok Kumar, Sharma, S. K. and Vashist, G. D. 2002. Profitability, risk and diversification in mountain agriculture: Some policy issues for slow growth crops. *Indian J. Agril. Econ. 57* (3): 356-365.

Baishya, A. and Sharma, G. L. 1990. Energy budgeting of rice-wheat cropping system. *Indian J. Agron. 35* (1,2): 167-177.

Bora, P. K. and Dutta, P. K. 2000. Assessment of energy requirement in the cultivation of autumn rice. *Annals of Biology 16* (1): 21-23.

Burnett, M. 1982. Energy analysis of three agro-eco systems. In: Stuart B. Hill (Ed.), Paper presented at Second International Conference on Basic Techniques in Ecological Farming held during 1-5 October at IFO, Montreal, Basel: Birkhauser, pp. 183-195.

Castillo, I. 1994. The regional response to the greenhouse issue: Latin America and the Caribbean. *International J. Global Energy Issues 6* (1-2): 28-36.

Damodaram, T. and Hegde, D. M. 2000. Oilseed situation: A Statistical Compendium, Directorate of Oilseed Research (ICAR), Hyderabad, India.

Dubois, D., Gunst, L., Fried, P. M., Stauffer, W., Spiess, E., Mader, P., Alfoldi, T., Fliessbach, A., Frei, R. and Niggli, U. 1999. DOC trial: Yields and energy use efficiency. *Agrarforschung 6* (2): 71-74.

Dzienia, S., Piskier, T., Wereszczaka, J. and Bien, E. 1998. Productivity of sugarbeet under different tillage systems. Proc. 5th Intl. Symposium, Warsaw, Poland. 24-25 Sept. 1998. pp.115-119.

Fertilizer Statistics. 2000-2001. The Fertilizer Association of India, New Delhi-110067, India.

Freedman, S. M. 1980. Modification of traditional rice production practices in developing world: An energy efficiency analysis. *Agroecosystem 6*: 129-146.

Gajri, P. R., Arora, V. K. and Prihar, S. S. 1992. Tillage management for efficient water and nitrogen use in wheat following rice. *Soil Till. Res. 24*:167-182.

Giampietro, M., Cerretelli, G. and Pimentel, D. 1992. Assessment of different agricultural production practices. *Ambio 21*: 451-459.

Hansen, F. and Diepenbrock, W. 1994. Agronomic aspects of energy and nitrogen balance in rape cropping. *Fett Wissenschaft Technologie 96* (4): 129-136.

Jansén, J. 2001. Energy analysis of early, mid and late 20th century Swedish farming systems: A local society case study. *J. Sustainable Agriculture 17* (4): 9-25.

Joshi, O. P., Billore, S.D. and Bundela, V.P.S. 1998. Fertilizer management in soybean-chickpea crop sequence. *J. Oilseeds Res. 15* (1): 118-122.

Kadlcek, L. and Cervinka, J. 2000. Demand of energy of tillage by cultivation of winter wheat on silt loams. *Zemedelska Technika. 46* (1): 7-9.

Kathiresan, G., Manickam, G. and Gnanamurthy, P. 1999. Effect of enriched farmyard manure and time of gypsum application on growth and yield of soybean (*Glycine max*). *J. Oilseeds Res. 16* (2): 348-349.

Kewat, M. L. and Pandey, Jitendra. 2001. Effect of pre-emergence herbicides on weed control in soybean (*Glycine max*). *Indian J. Agron. 46* (2): 327-331.

Lagerberg, C. 1999. Energy analysis of the resource use in greenhouse crop production and of the resource basis of the Swedish economy. *Acta Universitatis Agriculturae Sueciae Agraria.* No. 191, p. 31.

Mahendra Pal, Singh, K.A., Saxena, J.P. and Singh, H.K. 1985. Energetics of cropping systems. *Indian J. Agron. 30* (2): 1-L(xi).

Mandal, K.G., Saha, K.P., Ghosh, P.K., Hati, K.M. and Bandyopadhyay, K.K. 2002. Bioenergy and economic analysis of soybean-based crop production systems in central India. *Biomass and Bioenergy 23* (2002): 337-345.

Mittal, J. P. and Dhawan, K. C. 1988. Research Manual on Energy Requirements in Agricultural Sector, ICAR, New Delhi, pp. 20-23.

Mittal, J. P. and Dhawan, K. C. 1989. Energy parameters for raising crops under various irrigation treatments in Indian agriculture. *Agriculture, Ecosystems and Environment 25* (1): 11-25.

O'Callaghan, J. R. 1994. Resource utilization and economy of soil tillage in crop production systems. *Soil Till. Res. 30* (2-4): 327-343.

Odum, H. T. 1995. Tropical forest systems and the human economy. In: Lugo, A.E., Lowe, C. (Eds.) Tropical Forests: Management and Ecology, Springer Verlag, New York.

Panesar, B. S. and Bhatnagar, A. P. 1994. Energy norms for inputs and outputs of agricultural sector, In: Energy Management and Conservation in Agricultural Production and Food Processing: USG Publishers and Distributors, Ludhiana, pp. 5-16.

Sarkar, Apurba and Sarkar, A. 1997. Energy-use patterns in sub-tropical rice-wheat cropping under short term application of crop residue and fertilizer. *Agriculture, Ecosystems and Environment 61* (1): 59-67.

Sharma, R. S. and Thakur, C. L. 1989. Economic and energy factors in soybean cultivation. *Indian J. Agron. 34* (3): 337-340.

Shivakumar, B. G. 2001. Performance of chickpea (*Cicer arietinum*) varieties as influenced by sulphur with and without phosphorus. *Indian J. Agron. 46* (2): 273-276.

Singh, M. K., Pal, S. K., Thakur, R. and Verma, U. N. 1997. Energy input-output relationship of cropping systems. *Indian J. Agril. Sci. 67* (6): 262-264.

Singh, Surendra, Singh, M.P., Rana, R.S., Mittal, V.K. and Bakshi, Rupa. 1989. Energy and cost requirements for cultivation of rice (*Oryza sativa*)-wheat (*Triticum aestivum*) and maize (*Zea mays*)-wheat rotations. *Indian J. Agril. Sci. 59*(9): 558-560.

Thakur, C. L. and Makan, G. R. 1997. Energy scenario of Madhya Pradesh (India) agriculture and its future requirements. *Energy Conversion and Management 38* (3): 237-244.

Wilhelm, L. R. 1992. Farm energy inputs for crop production. Tennessee Farm and Home Science, No. 161, 4-13.

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