Agropedology 2019, 29 (02), 107-118
doi.org/10.47114/j.agroped.2019.dec4

Energy Utilization Patterns for Sustainable Crop Production in the Semi-Arid Vertisols of India

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Abstract: In semi-arid regions, the amount of rainfall and its distribution governs not only output levels but also influences uses and pattern of energy-inputs. Current study analyzes the role of energy and economic indicators to identify a suitable crop under different rainfall situations in rainfed areas of southern India. For this study, ten years data on production of rainfed sorghum and chickpea were analyzed with help of an array of energy and economic indicators like net energy, energy efficiency, specific energy, energy productivity, energy intensity and human labor profitability. The results of the study show that the share of non-renewable energy (80% in normal rainfall years) was remarkably higher than renewable energy in production of both the crops. Deficient rainfall led to decline in the consumption of energy inputs by 19.6 and 5.7%, and consequently resulted in a reduction of output energy by 48.6 and 63.4% in comparison to normal rainfall in case of sorghum and chickpea cultivation, respectively. Further, energy efficiency scores were found to decline to an extent of 1.95 and 1.29 under deficient rainfall situations from the levels of 3.06 and 3.32 obtained under sorghum and chickpea production under normal rainfall conditions, respectively. The computed values of benefit: cost ratio and energy efficiency suggest that chickpea is the more suitable rainfed crop as compared to sorghum in the semi-arid Vertisols of Karnataka.

Key words: *Vertisols, chickpea, deficient rainfall, energy indicators, sorghum, semi-arid region.*

Introduction

Agriculture has become an increasingly energy intensive sector in the last half-century with much of it attributable to increased use of energy inputs. Traditional low energy farming has been replaced by modern energy-intensive systems demanding higher use of chemical fertilizers and pesticides (Chaudhary *et al.* 2006). Much greater energy is required for the production as compared to on-farm application of these inputs (Dyer and Desjardins 2006). Although agricultural production is positively correlated with these energy inputs (Baruah and Dutta 2007), the latter have adversely affected the environment (Ghorbani *et al.* 2011) by deteriorating water and land resources and through increased emission of greenhouse gases (Lal 2004; IPCC 2006; Ozkan *et al.* 2007). The short-term yield advantage using high levels of fossil fuel-derived inputs must be balanced against the long-term costs of non-renewable energy depletion (Franzluebbers and Francis 1995).

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Energy use is one of the key indicators for evaluating sustainable agricultural practices (Streimikiene *et al.* 2007; Kizilaslan 2009), Energy efficiency (EE) enhancement not only helps in improving competitiveness through cost reduction but also minimizes energy related environmental pollution, and contributes towards sustainable development (Jonge 2004; Esengun *et al.* 2007; Nagesha 2008). Further, a scientific analysis of energy consumption helps in effective planning of energy strategies and policies (Lianga *et al.* 2007) since it provides information on both non-renewable energy utilization and climate change burdens linked to crop production. Most importantly, it is not biased by the artificial changes in the prices of inputs and outputs as is the case with economic analysis (Jones 1989). Energy indicators express aspects or consequences of the production and use of energy and provide a clear picture of the whole system, including inter-linkages and trade-offs among various dimensions of sustainable development, as well as the long-term implications of current decisions and behavior. Changes in the indicator values over time mark progress or lack of it towards sustainable development. Among different indicators, energy efficiency is considered as an essential component of short- and medium-term climate change mitigation options (Morita *et al.* 2001; Fisher 2007).

Chickpea and sorghum are among the top principal major crops cultivated in the state of Karnataka, and the major crops of the semi-arid regions of the state, accounting for about 11.6 and 9.7%, respectively of the gross cropped area (10.3 million ha) of the state (2018-19 data, compiled from https://www.aps.dac.gov.in/APY/Public_Report1.aspx). About 16% of the national area and 7.7% of the total chickpea production is shared by the state. Similarly, the contribution of the state to the national area and production of sorghum is 25 and 32%, respectively (https://www.aps.dac.gov.in/APY/Public_Report1.aspx). Rainfall uncertainty and occurrence of low to medium intensity droughts every alternate year makes Karnataka as one of the most drought prone states of India (Kumar *et al*. 2016). An analysis of 100 years rainfall data revealed that the frequency of 'below-normal rainfall' in arid, semi-arid and sub-humid regions is 54 to 57%, while severe and rare droughts occurred once in every eight to nine years (Mondal *et al.* 2014). Thus, the farmers cultivating sorghum and chickpea face complete to partial yield losses under deficient rainfall situations which results not only in financial loss but also in the waste of input energy, as most of the energy-consuming cultivation practices are completed with the hope of receiving a fairly well distributed rainfall during the cropping season.

Against this background, we attempted to assess the pattern and levels of energy consumption during the cultivation of sorghum and chickpea and changes in output levels under deficient and normal rainfall years. The specific objectives of the study are (a) to examine the share of different inputs for crop production; (b) assesses the extent of input utilization in different cultural operations during production, and (c) to identify the most suitable crop between sorghum and chickpea which performs better in terms of energy and economic efficiency in the region.

Materials and Methods

Study area

The analysis was carried out using 10 years (2002-2011) data on production of rainfed sorghum and chickpea recorded at the Research Farm of the Research Centre of the ICAR-Indian Institute of Soil and Water Conservation, Bellary, Karnataka, (15º 09' N; 76º 51' E) at an elevation of 445 m above msl (mean sea level). Annual average rainfall is 501 mm received in 32 rainy days with high variability (184 to 949 mm per year). The soils are classified as Vertisols (black cotton soils) which are highly dispersible due to the high exchangeable sodium percentage (varying from 3 to 21%) leading to unstable soil structure. The clay content varies from 32 to 55% in soils and the predominant clay mineral is montmorillonite which gives these soils the characteristic swell-shrink feature. This leads to formation of cracks that may be 5-10 cm wide and up to 45 cm deep leading to increased loss of soil moisture. Droughts of moderate intensity are quite frequent and region often experiences no to poor rainfall during cropping season leading to complete failure of crops or poor (with decline up to 70% in some years) yield. The seasonal rainfall during the study period and the corresponding yields of rainfed sorghum and chickpea are given in fig. 1 which depicts the fluctuations in seasonal rainfall and variability in production of rainfed sorghum and chickpea. The importance of seasonal rainfall can be realized by the fact that even a small downward deviation leads to high yield loss of both the crops. The extent of yield fluctuations in sorghum was more conspicuous and relatively higher than chickpea, which shows that chickpea is relatively more drought tolerant and stable in terms of assured production.

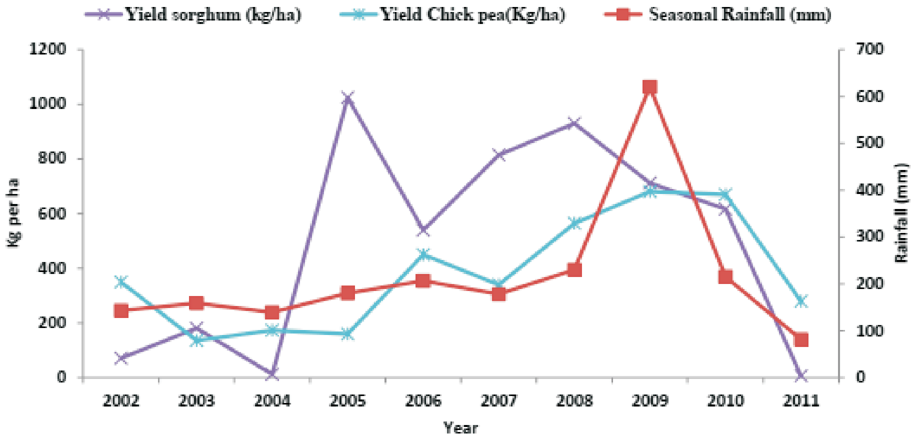

Fig. 1. Variations in seasonal rainfall, yield of sorghum and chickpea during the study period (2002-2011)

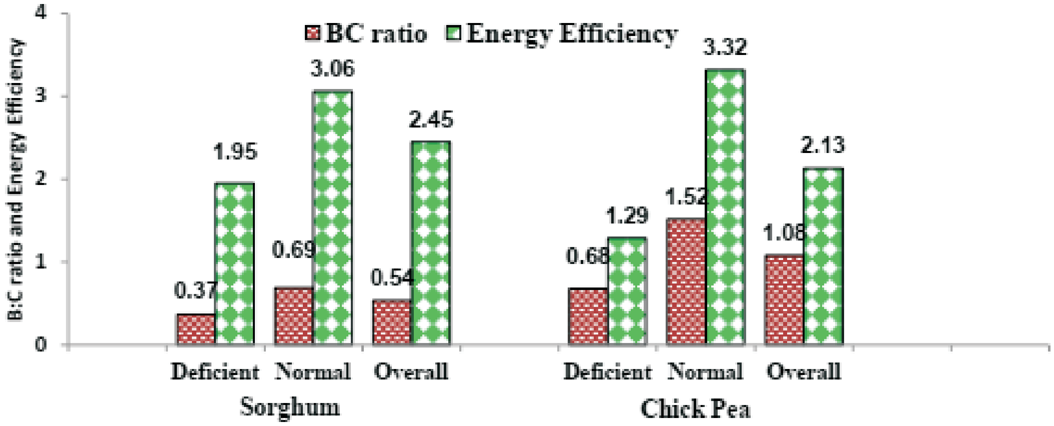

Fig. 2. Comparisons of benefit: cost ratio and energy efficiency of sorghum and chickpea cultivation under different rainfall situations

Data

Data on all the inputs *viz.,* human labor (male and female), bullock labor, farm machinery hours, diesel consumption, fertilizers and chemicals (pesticides and insecticides) used in the production of sorghum and chickpea cultivation were compiled. These inputs were then converted into energy equivalents using standard conversion factors (Table 1). For understanding the dynamic interactions among level of input energy, output energy and rainfall, the data set was categorized into two groups representing deficient and normal rainfall years. A particular year was categorized under deficient or normal rainfall groups as defined by equations 1 and 2, respectively.

$$R_i = \{(-0.19) * (R_T)\} \quad (1)$$

$$R_i > \{(-0.19) * (R_T)\} \quad (2)$$

Where R_i is the seasonal (September to November) rainfall (mm) received during the i^{th} year (i = 2002 to 2011) and R_T is the long-term seasonal rainfall (1982-2011).

Based on the above equations, the years 2003, 2004, 2005, 2007 and 2011 are deficient rainfall years, while 2006, 2008, 2009 and 2010 were categorized as normal years (Table 2).

Table 1. Energy equivalents for different inputs and outputs in agricultural production

Particulars	Unit	Equivalent energy (MJ)	Source
Labour			
Adult man	Man-hour	1.96	Ghosh *et al.* (2006)
Woman	Woman-hour	1.57	Ghosh *et al.* (2006)
Bullocks (Body weight 352-450 kg)	Pair-hour	10.10	Devasenapathy *et al*. (2009)
Chemical fertilizer			
Nitrogen	kg	60.60	Devasenapathy *et al.* (2009); Ghosh *et al.* (2006)
Phosphate (P_2O_5)	kg	11.1	Devasenapathy *et al.* (2009)
Potash (K_2O)	kg	6.7	Ghosh *et al.* (2006)
Farmyard manure (FYM)	kg	0.3	Devasenapathy *et al.* (2009)
Machinery	hours	62.70	Devasenapathy *et al.* (2009)
Seed (Sorghum + chickpea)	kg (dry mass)	15.2	Kitani (1999)
Output			
Sorghum	kg (dry mass)	14.7	Fisher *et al*. (2007)
Chick pea		14.7	Mandal *et al.* (2002)
By product			
Sorghum	kg (dry mass)	12.5	Fisher *et al.* (2007)
Chick pea		12.5	Mandal *et al.* (2002)

Table 2. Rainfall situation in the study area

Year	Annual rainfall	Deviation	Seasonal rainfall	Deviation	Category
	(mm)	(%)	(mm)	(%)	
2002	432.6	-12.3	142.9 (33)	-42.8	Deficient
2003	272.6	-44.8	158.6 (58)	-36.5	Deficient
2004	383.7	-22.3	139.1 (36)	-44.3	Deficient
2005	526.2	6.6	180.0 (34)	-27.9	Deficient
2006	364.9	-26.1	206.6 (57)	-17.2	Normal
2007	474.1	-3.9	178.0 (38)	-28.7	Deficient
2008	607.4	23.1	229.9 (38)	-7.9	Normal
2009	998.3	102.3	620.5 (62)	148.5	Normal
2010	627.2	27.1	215.3 (34)	-13.8	Normal
2011	325.0	-34.1	81.3 (25)	-67.4	Deficient

Notes: Average annual and seasonal rainfalls are 493.52 and 249.66 mm based on the average of last 30 years data (1982-2011) and figures in parentheses are the percentage to total annual rainfall. Data Source: various annual reports of ICAR-IISWC, RC, Ballari (Karnataka).

Energy use analysis

Drawing upon literature on energy analysis, especially crop production, some well-defined energy indicators *viz.,* net energy, energy efficiency, specific energy, energy productivity, energy intensity and human labor profitability were computed for drawing meaningful conclusions on energy use patterns by the selected crops under different rainfall situations. The following indicators were computed using the equations 3 through 14.

A. Total input energy $(E_T) = (E_D + E_I)$ or $(E_R + E_N)$ (3),

Where, E_D is the direct energy required to perform various tasks related to crop production processes such as land preparation, irrigation, intercultural operations, threshing, harvesting and transportation of agricultural inputs and farm produce (Singh 2000) and directly used at farms and on fields (Banaeian and Zangeneh 2011). The term E_I denotes indirect energy which comprises of energy used in the manufacture, packaging and transport of fertilizers, pesticides and farm machinery (CAEEDAC 2000). The terms E_R and E_N represent renewable (human labor, bullock labor and seed) and non-renewable (liquid fuel, fertilizers, pesticides, insecticides and farm machinery) energy, respectively. All energy terms are expressed in MJ ha^{-1}.

A. Direct energy $(E_D) = E_H + E_{BL} + E_{LF}$ (4)

B. Indirect energy $(E_I) = E_S + E_F + E_C + E_{FM}$ (5)

C. Renewable energy $(E_R) = E_H + E_{BL} + E_S$ (6)

D. Non-renewable energy $(E_{NR}) = E_{LF} + E_F + E_C + E_{FM}$ (7)

Where, E_S, E_H, E_{LF}, E_{FM}, E_{BL}, E_F and E_C are energy from seeds, human labour, liquid fuel, farm machinery, bullock labour, fertilizers and chemicals (pesticides and insecticides), respectively.

E. Net energy (NE) $= E_O - E_T$ (8)

Where, E_O and E_T are the total output and input energy, respectively expressed in MJ ha^{-1}

F. Energy use efficiency (EE) $= \frac{E_0}{E_T}$ (9)

G. Energy productivity $= \frac{Y_g}{E_T}$ (10)

Where, Y_g = grain yield (kg ha^{-1}) and E_T = total input energy (MJ ha^{-1})

H. Specific energy (SE) $= \frac{E_T}{Y_g}$ (11)

I. Energy profitability $= \frac{E_T}{Gross\ income\ (INR\ ha^{-1})}$ (12)

J. Energy intensity (EI) $= \frac{E_0}{E_H}$

To judge the financial viability of crop production, Benefit: Cost (B: C) ratio was computed and compared between crops. For our study, it was calculated as a ratio of 'gross income from crop' to 'variable cost of cultivation'.

Results and Discussion

Share of different inputs in total energy consumption for sorghum and chickpea production

The share of different inputs consumed in the production of sorghum and chickpea is depicted in table 3. Overall, the total energy input for sorghum and chickpea production was 5714 and 7303 MJ ha^{-1}, respectively. Fertilizers and liquid fuel were the major inputs accounting for about 61% of total energy required for sorghum production, whereas in case of chickpea around 55% of total input-energy was contributed through pesticides and liquid fuel. Increased consumption of bullock labour (163 and 183 MJ ha^{-1} in case of sorghum and chickpea cultivation, respectively) was observed under normal rainfall, which can primarily be attributed to additional intercultural operations required for weed management and soil mulching. A decline by 19.6 and 5.7% in consumption of total energy occurred under sorghum and chickpea cultivation, respectively during years of deficient rainfall as compared to normal rainfall. Under deficient rainfall, the highest reduction in energy consumption for sorghum crop occurred in the form of pesticide (864 MJ ha^{-1}) followed by fertilizer application (248 MJ ha^{-1}) and utilization of human labour (180 MJ ha^{-1}). In case of chickpea, chemical (646 MJ ha^{-1}) followed by fertilizer application (95 MJ ha^{-1}) showed the highest decline in energy utilization under deficient rainfall situations.

Table 3. Share of different energy inputs in cultivation of sorghum and chickpea crops

Category	Labour	BL	FM	LF	Fertilizer	Seed	Chemicals	Total
				Sorghum				
Deficient	674	501	411	1575	1765	148	133	5207
	(12.9)	(9.6)	(7.9)	(30.3)	(33.9)	(2.8)	(2.6)	(100)
Normal	854	338	441	1678	2013	153	997	6474
	(13.2)	(5.2)	(6.8)	(25.9)	(31.1)	(2.4)	(15.4)	(100)
Pooled	746	436	423	1616	1864	150	479	5714
	(13.1)	(7.6)	(7.4)	(28.3)	(32.6)	(2.6)	(8.4)	(100)
				Chickpea				
Deficient	449	385	454	1760	1202	822	2060	7132
	(6.3)	(5.4)	(6.4)	(24.7)	(16.9)	(11.5)	(28.9)	(100)
Normal	473	202	449	1609	1297	825	2706	7561
	(6.3)	(2.7)	(5.9)	(21.3)	(17.2)	(10.9)	(35.8)	(100)
Pooled	459	311	452	1700	1240	823	2318	7303
	(6.3)	(4.3)	(6.2)	(23.3)	(17.0)	(11.3)	(31.7)	(100)

Notes: Figures in parentheses are percent to total energy consumed in corresponding category. BL, FM and LF stand for bullock labour, farm machinery and liquid fuel. Average situation over the period of 10 years has been shown under 'pooled' category. The sum of figures in parentheses may be not 100 in a particular row because of rounding of figures to one decimal point.

Energy-use pattern in different cultural operations

Perusal of data in table 4 reveals that major part of total input-energy in case of sorghum is consumed during fertilizer application (34.8%) followed by land preparation (22.5). During deficient rainfall years, intercultural operations in sorghum consumed 158 MJ ha^{-1} higher input energy as compared to that consumed during normal rainfall years. Further, as expected, there was a drastic reduction (919 MJ ha^{-1}) in consumption of energy due to pesticide application which may partly be ascribed to fewer incidences of pests and disease and partly to reluctance of the farmer to spend on pesticides due to the high probability of obtaining lesser yield in a deficient rainfall year. Interestingly, around 66.1% of the total input-energy was consumed up to the time of sowing of sorghum during normal years, which increased to 71.2% during rainfall deficit years. This implies that 71.2% (3707 MJ ha^{-1}) of the total energy would already have been consumed prior to sowing without any clue about the rainfall to be received during the rest of the growing period.

Highest energy consumption in case of chickpea was recorded under plant protection activity followed by land preparation with an extent of around of

30.6% and 24.6% of the total energy consumption, respectively. Around 53.4% of total required energy goes into production process till the time of sowing, which increased to 54.7% during deficient rainfall years. In either case the energy requirement for chickpea cultivation prior to sowing is less than that for sorghum cultivation. Thus, chickpea cultivation is relatively less energy-risky than sorghum, as far as the amount of energy being put at stake prior to sowing is concerned.

Table 4. Pattern of energy utilization in different cultural operations during cultivation of sorghum and chickpea

Category	Land Preparation	Sowing	Fertilizer application	Intercultural operations	Plant protection	Harvesting & Threshing	Total
				Sorghum			
Deficient	1287	498	1922	703	299	498	5207
	(24.7)	(9. 6)	(36.9)	(13.5)	(5.7)	(9.6)	(100)
Normal	1290	512	2082	545	1218	827	6474
	(19.9)	(7.9)	(32.2)	(8.4)	(18.8)	(12.8)	(100)
Pooled	1288	504	1986	640	667	630	5714
	(22.5)	(8.8)	(34.8)	(11.2)	(11.7)	(11.0)	(100)
				Chick pea			
Deficient	1754	850	1296	552	2185	495	7132
	(24.6)	(11.9)	(18.2)	(7.7)	(30.6)	(6.9)	(100)
Normal	1738	845	1316	315	2795	548	7561
	(23.0)	(11.2)	(17.5)	(4.2)	(37.0)	(7.2)	(100)
Pooled	1748	848	1305	457	2429	516	7303
	(23.93)	(11.61)	(17.87)	(6.3)	(33.3)	(7.1)	(100)

Notes: Figures in parentheses are percent to total energy consumed in corresponding category. Average situation over the period of 10 years has been shown under 'pooled' category. The sum of figures in parentheses may be not 100 in a particular row because of rounding of figures to one decimal point.

Direct, Indirect, Renewable, Non-renewable and Output Energy

The type and levels of energy required for agricultural production process will determine whether the food production system will be able to meet the twin goals of future food security and environmentally sustainable agricultural production (FAO 2012). To obtain insights about the kind of energy inputs being used in the production process of the selected rainfed crops, total input energy was grouped into indirect and direct pools. Average computed values of direct and indirect energy were 2798 and 2916 MJ ha^{-1}, respectively for sorghum whereas the values were 2470 and 4833 MJ ha^{-1}, respectively for chickpea production (Table 5). Higher indirect energy was consumed in case of chickpea (66.2%) cultivation than that of sorghum (51.0%). Under deficient rainfall years, consumption of direct and indirect energy in case of sorghum came down by 120 and 1147 MJ ha^{-1}, respectively as compared to that under normal rainfall conditions. The fall in the amount of direct energy is mainly attributed to less number of laborers required for harvesting and threshing. On the other hand, reduction in indirect energy can be attributed to lesser use of chemicals fertilizers. In case of chickpea cultivation, deficient rainfall resulted in increased consumption of indirect energy to an extent of 310 MJ ha^{-1}. However, a reduced utilization of direct energy to the tune of 739 MJ ha^{-1} was estimated.

Overall renewable energy consumption was computed as 1332 and 1593 MJ ha^{-1} whereas the amounts of 4382 and 5710 MJ ha^{-1} in terms of non-renewable energy were required for production of sorghum and chickpea, respectively (Table 5). Further, the share of non-renewable energy for sorghum cultivation is around 75 and 80% under deficient and normal rainfall situations, respectively. Similarly, in chickpea production non-renewable energy accounted for 77% and increased by 3% under normal rainfall conditions. The proportion of non-renewable input energy is very high in case of both crops, which creates the potential for greater substitution with renewable energy inputs. The total energy output in case of sorghum was 10162 and 19779 MJ ha^{-1} during deficient and normal rainfall years, respectively, implying a decline by 48.6% under the former situation. The contribution of grain (main product) and straw (by-product) to the total output energy of sorghum production were 47.4 and 52.6%, respectively. Similarly, realized output energy in case of chickpea was 9199 MJ ha^{-1} under deficient rainfall, which is 63.4% less than that obtained under normal rainfall situations (Table 5).

Table 5. Direct, indirect, renewable and non-renewable energies and output energies (MJ ha^{-1})

Particular	**Sorghum**			**Chickpea**		
	Deficient	Normal	Pooled	Deficient	Normal	Pooled
Direct energy (E_D)	2750 (52.8)	2870 (44.3)	2798 (49.0)	2594 (36.4)	2284 (30.2)	2470 (33.8)
Indirect energy (E_I)	2457 (47.2)	3604 (55.7)	2916 (51.0)	4538 (63.6)	5277 (69.8)	4833 (66.2)
Renewable energy (E_R)	1323 (25.4)	1345 (20.8)	1332 (23.3)	1656 (23.2)	1500 (19.8)	1593 (21.8)
Non-renewable energy(E_N)	3884 (74.6)	5129 (79.2)	4382 (76.7)	5476 (76.8)	6061 (80.2)	5710 (78.2)
Energy output (main product) (E_M)	4643	9639	6641	3403	8338	5377
Energy output (by product) (E_B)	5519	10140	7367	5796	16788	10192
Total output energy (E_O)	10162	19779	14008	9199	25126	15569

Note: Figures in parentheses denote percentage

Energy indicators in sorghum and chickpea production

Average values of energy efficiency (EE) scores were 2.45 and 2.13 in sorghum and chickpea production, respectively (Table 6). During normal rainfall years, EE scores were 3.06 and 3.32 for sorghum and chickpea production, which declined to 1.95 and 1.29, respectively under deficient rainfall situations. While this indicates that sorghum performs relatively better than chickpea under deficient rainfall situations in terms of energy efficiency, under normal rainfall situations, chickpea cultivation is more energy efficient than sorghum. The computed average net energy values in case of sorghum and chickpea were 8294 and 8266 MJ ha^{-1}, respectively. Under deficient rainfall situations, drastic reductions occurred in the value of net energy the tune of to 62.8 and 88.2% in comparison to that realized under normal rainfall years. However, comparison under deficient rainfall situations reveals that net energy consumption in sorghum (4955 MJ ha^{-1}) was higher than that in chickpea (2067 MJ ha^{-1}) cultivation.

Values of energy productivity, defined as the units of physical output (main product) obtained per unit of input energy, were computed as 0.08 and 0.05 kg MJ^{-1} in case of sorghum and chickpea production, respectively. These scores imply that one unit of input-energy produces 80 and 50 grams of sorghum and chickpea, respectively. Energy productivity declined by 40 and 62.5%, respectively under sorghum and chickpea during deficit rainfall years. The overall average scores of specific energies were 12.65 and 19.97 MJ kg^{-1} in sorghum and chickpea production, respectively. A comparison of specific energy scores suggests that under deficient rainfall situations, sorghum and chickpea require 1.67 and 2.31 times, respectively more energy to produce one unit of main product (grain as output) that that required under normal rainfall conditions. The comparison also shows that sorghum consumes less input energy to produce one unit of output irrespective of rainfall condition. Energy profitability, defined as the net energy gains from the investment made per unit of input energy were computed as 1.45 and 1.13 for sorghum and chickpea cultivation, respectively. When normal rainfall was received, energy profitability scores for sorghum and chickpea cultivation were 2.2 and 8.0 times higher than that realized under deficient rainfall situation. From energy profitability point of view, sorghum crop performed better than chickpea in deficient rainfall situation but chickpea outperformed sorghum during the years of normal rainfall.

Energy intensity is a measure of the amount of energy it takes to produce an INR's (Rupees) worth of economic output, or conversely the amount of economic output that can be generated by one standardized unit of energy. A low value of economic energy intensity indicates that relatively lower quantity of energy enables a relatively higher amount of economic value (King 2010). In general, the values of energy intensities were 1.35 and 0.94 for sorghum and chickpea, respectively indicating that sorghum requires around 1.44 times more input energy than chickpea to produce output worth of one INR. Human profitability, obtained from total output energy divided by human labor energy (Tabatabaeefar *et al.* 2009), was almost 1.8 times higher in chickpea (33.92) production than in case of sorghum production (18.78).

Table 6. Energy and economic indicators in sorghum and chickpea production.

Indicator	Sorghum			Chickpea		
	Deficient	Normal	Pooled	Deficient	Normal	Pooled
Energy efficiency	1.95	3.06	2.45	1.29	3.32	2.13
Net energy (MJ ha^{-1})	4955	13305	8294	2067	17565	8266
Energy productivity (kg MJ^{-1})	0.06	0.10	0.08	0.03	0.08	0.05
Specific energy (MJ kg^{-1})	16.49	9.87	12.65	30.81	13.33	19.97
Energy profitability (MJ ha^{-1})	0.95	2.06	1.45	0.29	2.32	1.13
Energy intensity (MJ ha^{-1}/ INR ha^{-1})	2.23	0.91	1.35	1.64	0.58	0.94
Human energy profitability	15.08	23.16	18.78	20.49	53.12	33.92
Variable cost (INR ha^{-1})	6326	10214	7881	6354	8541	7227
Gross Revenue (INR ha^{-1})	2335	7091	4237	4349	12999	7809
Gross Margin (INR ha^{-1})	-3990	-3122	-3644	-2005	4459	581
BC ratio	0.37	0.69	0.54	0.68	1.52	1.08

Decision making based on energy use efficiency and economic viability of production

While recommending a suitable crop that is environmentally and economically sustainable, due emphasis must be given to the profit realized by farmers as well as minimization of energy losses. Here, we have used two proxy indicators, namely, energy efficiency and B: C ratio (benefit: cost ratio) for environmental sustainability and economic efficiency, respectively. Gross margin (difference between gross revenue minus variable cost) was negative under all the rainfall situations for sorghum cultivation. However, chickpea cultivation seems economically more promising than that of sorghum registering a positive gross margin under overall (INR 581 ha^{-1}) and normal rainfall (INR 4459 ha^{-1}) situations (Table 6). Based on energy use efficiency, it can be said that both the crops are suitable across the rainfall situations having EE score of more than one. The BC ratio in case of sorghum cultivation was less than one across all rainfall situations, resulting in financial losses, at least in the short-run, based on the prevailing input and output prices (Fig. 2). With BC ratio and EE to the tune of 1.52 and 3.32, respectively, chickpea outperformed sorghum (BC ratio, 0.69 and EE, 3.06) under normal rainfall situations on both economic (BC ratio for sorghum) and environmental fronts. However, across all rainfall situations, sorghum was found to be relatively better on the environmental front, with an EE of 2.45, while chickpea was found to be economically viable with a BC ratio of 1.08.

Conclusions

Growing concerns of climate change and ever-increasing cost of fossil fuels, synthetic fertilizers and chemicals (pesticides and insecticides) necessitates the identification of suitable crops/cropping systems which are viable on both economic and environmental fronts. There is also a need to understand and optimize various crop production energy inputs for higher energy and economic efficiency. We attempted to understand the pattern and extent of energy utilization for two important crops of semi-arid region under deficient rainfall situations with help of energy and economic indicators. The results of the study show that synthetic fertilizers and liquid fuels consume a major chunk of input energy are in sorghum cultivation, while plant-protection chemicals and liquid fuels are the major energy inputs in chickpea production. Consumption of input-energy and production of output energy declined during deficit rainfall years as compared to that obtained during normal rainfall years. Share of non-renewable was remarkably higher than renewable energy for both crops, which provides an opportunity to substitute the former with eco-friendly management practices like conservation tillage, sorghum+chickpea intercropping, INM (integrated nutrient management) and IPM (integrated pest management). Further, energy efficiency scores obtained under normal rainfall conditions were higher than that obtained under deficient rainfall situations. With appropriate *in situ* moisture conservation measures like contour bunds, ridges and furrows and application of manures/mulches, the energy use efficiency of the crops can be enhanced, especially under deficient rainfall condition. On the basis of BC ratio and energy efficiency, chickpea is advocated as the more promising rainfed crop over sorghum.

References

Banaeian, N. and Zangeneh, M. (2011). Study on energy efficiency in corn production of Iran. *Energy* **36**, 5394-5402.

Baruah, D.C. and Dutta, P.K. (2007). An investigation into the energy use in relation to yield of rice (*Oryza sativa*) in Assam, India. *Agriculture, Ecosystems and Environment* **120**, 185-191.

CAEEDAC (The Canadian Agricultural Energy End-Use Data and Analysis Centre). (2000). A descriptive analysis of energy consumption in agriculture and food sector in Canada. Final Report, Canada. www.usask.ca /agriculture /caedac /pubs/ processing.

Chaudhary, V.P., Gangwar, B. and Pandey, D.K. (2006). Auditing of energy use and output of different cropping systems in India. *Agricultural Engineering International: The CIGR E-Journal* **8**, 1-13.

Devasenapathy, P., Senthil, K.G. and Shanmugam, P.M. (2009). Energy management in crop production. *Indian Journal of Agronomy* **54**, 80-90.

Dyer J.A. and Desjardins, R.L. (2006). Carbon dioxide emissions associated with the manufacturing of tractors and farm machinery in Canada. *Biosystem Engineering* **93**, 107-118.

Esengun, K., Gündüz, O. and Erdal, G. (2007). Input-output energy analysis in dry apricot production of Turkey. *Energy Conversion and Management* **48**, 592-598.

FAO (Food and Agriculture Organization of UNO. (2012). Energy-smart food at FAO: An Overview. (FAO: Rome). pp. 66. (http://www.fao.org/docrep/ 015/an913e/an913e.pdf. 2012).

Fisher, B.S., Nakicenovic, N., Alfsen, K.CorfeeMorlot, J., de la Chesnaye, F., Ch. Hourcade, J., Jiang, K., Kainuma, M., La Rovere, E., Matysek, A., Rana, A., Riahi, K., Richels, R., Rose, S., van Vuuren, D. and

Warren, R. (2007). Issues related to mitigation in the long term context. In 'Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change' (Eds. B. Metz, O. R. Davidson, P. R. Bosch, R. Dave and L. A. Meyer) pp. 171-250. (Cambridge University Press: Cambridge).

Franzluebbers, A.J. and Francis, C.A. (1995). Energy output: input ratio of maize and sorghum management systems in eastern Nebraska. *Agriculture, Ecosystems and Environment* **53**, 271–278.

Ghorbani, R., Mondani, F., Amirmoradi, S., Feizi, H., Khorramdel, S., Teimouri, M., Sanjani, S., Anvarkhah, S. and Aghel, H. (2011). A case study of energy use and economical analysis of irrigated and dry land wheat production systems. *Applied Energy* **88**, 283–288.

Ghosh, P.K., Mohanty, M., Bandyopadhyay, K.K., Painuli, D.K. and Misra, A.K. (2006). Growth, competition, yield advantage and economics in soybean/ pigeon pea intercropping system in semi-arid tropics of India I. Effect of sub soiling. *Field Crops Research* **96,** 80–89.

IPCC (Intergovernmental Panel on Climate Change). (2006). 2006 IPCC guidelines for national greenhouse gas inventories. In 'Energy' (Eds. H.A.S. Eggleston, L. Biennia, K. Miwa, T. Negara and K. Tanabe), National Greenhouse Gas Inventories Programme. (IGES: Japan).

Jones, M.R. (1989). Analysis of the use of energy in agriculture approaches and problems. *Agricultural Systems* **29**, 339-355.

Jonge, A.M. (2004). Eco-efficiency improvement of a crop protection product: The perspective of the crop protection industry. *Crop Protection* **23**, 1177-1186.

King, C.W. (2010). Energy intensity ratios as net energy measures of United States energy production and expenditures. *Environmental Research Letters* **5**, 044006.

Kitani, O. (1999). 'CIGR handbook of agricultural engineering-Volume V: Energy and biomass engineering'. (Eds. O. Kitani, T. Jungbluth, R.M. Peart and A. Ramdani) pp. 310-322. (American Society of Agricultural and Biological Engineers, St. Joseph: Michigan).

Kizilaslan, H. (2009). Input–output energy analysis of cherries production in Tokat. Province of Turkey. *Applied Energy* **86**, 1354–1358.

Kumar, S., Raizada, A., Biswas, H., Srinivas, S. and Mondal, B. (2016). Assessment of vulnerability to climate change: A case study. *Indian Journal of Soil Conservation* **44**, 314-320.

Lal, R. (2004). Carbon emission from farm operations. *Environment International* **30**, 981–990.

Lianga, Q.M., Fana, Y. and Wei, Y.M. (2007). Multi–regional input–output model for regional energy requirements and CO_2 emissions in China. *Energy Policy* **35**, 1685-1700.

Mandal, K., 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**, 337-345.

Mondal, B., Loganandhan, N. and Raizada, A. (2014). Meteorological drought and coping strategies by small and marginal farmers in semi-arid Karnataka. *Indian Journal of Soil Conservation* **42**, 54-61.

Morita, T., Robinson, J., Adegulugbe, J., Alcamo, J., Herbert, D., La Rovere, E., Nakicenovic, N., Pitcher, H., Raskin, P., Riahi, K., Sankovski, A., Sokolov, V., de Vries, B. and Zhou, D. (2001). Greenhouse gas emission mitigation scenarios and implications. In 'Climate Change 2001: Mitigation. Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change'. (Eds. B. Metz, O. Davidson, R. Swart and J. Pan) pp. 115-166. (Cambridge University Press: Cambridge).

Nagesha, N. (2008). Role of energy efficiency in sustainable development of small–scale industry clusters: An empirical study. *Energy for Sustainable Development* **12**, 34-39.

Ozkan, B., Fert, C. and Karadeniz, F. (2007). Energy and cost analysis for greenhouse and open-field grape production. *Energy* **32**, 1500–1504.

Singh, J.M. (2000). On farm energy use pattern in different cropping systems in Haryana, India. International Institute of Management, University of Flensburg, Germany. (Ph. D. Thesis).

Streimikiene, D., Klevas, V. and Bubeliene, J. (2007). Use of EU structural funds for sustainable energy development in new EU member states. *Renewable and Sustainable Energy Reviews* **11**, 1167–1187.

Tabatabaeefar, A., Emamzadeh, H., Varnamkhasti, M.G., Rahimizadeh, R. and Karimi, M. (2009). Comparison of energy of tillage systems in wheat production. *Energy* **34**, 41-45.