Energy, economics, and water use efficiency of chickpea (*Cicer arietinum* L.) cultivars in Vertisols of semi-arid tropics, India

S. L. Patil*, P. K. Mishra, N. Loganandhan, M. N. Ramesha and S. K. N. Math

Central Soil and Water Conservation Research and Training Institute, Research Centre (ICAR), Bellary 583 104, India

Pulses play a major role in providing overall prosperity to the small and marginal farmers through nutritional security by meeting their dietary protein requirements and improving production base through conservation of natural resources. Inclusion of pulses in the cropping system as a crop rotation improves soil fertility and crop productivity of cereals and oil seeds. Chickpea is one of the important pulses cultivated in Vertisols during winter season. We examined chickpea cultivars for energy use efficiency, economics, physiological efficiency and water use efficiency (WUE) under different rainfall situations for their sustainable yield and overall profit, in Vertisols of semi-arid tropics of South India. Results revealed that low input energy and high grain and stover yields of cultivars result in higher total output energy and net benefit energy. Higher dry matter efficiency of 0.702 was observed with medium-duration cultivar, whereas WUE was higher in short-duration cultivar followed by medium-duration cultivar. We conclude that medium-duration cultivar and short-duration cultivar are more suitable for the SAT region in terms of greater energy benefits, higher income per unit area, physiological efficiency and water use efficiency. Thus short-duration cultivar could be cultivated during normal to above normal rainfall years and during normal to drought years in winter season on residual soil moisture in Vertisols medium-duration cultivar for higher energy efficiency and economics.

Keywords: Chickpea, cultivars, dry matter, economics, energy, water use efficiency.

THE changing farm input subsidy regime of the government, capricious climatic conditions, diminishing agricultural labour force and energy availability are forcing farming practices to be more efficient in the use of energy and costly inputs for long-term ecological sustainability[1–5]. Tillage is a primary land preparation activity which consumes most of the energy input in the farming practices[5–8]. Any reduction in tillage practices saves resources, time and money to the farmers thereby improving farm profitability[7–10]. On account of globalization of agriculture through implementation of WTO and IPR, pulses now play a major role in providing overall prosperity to the small and marginal farmers through nutritional security by meeting their dietary protein requirements. Besides improving production base through conservation of natural resources, inclusion of pulses in the cropping system as a crop rotation improves soil fertility and crop productivity of cereals and oil seeds[11,12]. In addition, pulses fetch high net returns to farmers though value addition and lower the cost of production[12,13]. Production of high protein value foods plays an important role in solving our nutrition problem[13]. India is the largest producer of pulses in the world. Among the developing countries, India alone produces nearly 25% of the global share[14]. Being an inseparable ingredient in the diet of the vast majority of the population and mainstay of sustainable crop production, pulses continue to be an important component of the rainfed agriculture since time immemorial. In India, about a dozen pulse crops, namely chickpea, pigeon pea, mung bean, urd bean, lentil, field pea, lathyrus, cowpea, common bean, moth bean, horse gram and rice bean are cultivated on 22.47 m ha area under varied agro-ecological conditions. Pulse production in India has fluctuated widely between 13 and 15 mt, with no significant growth trend between 1991 and 2010. The latest estimates indicate that the present production of pulses is 14.66 mt, with productivity of 637 kg ha^{-1}. Stagnant growth in pulses production compared to population growth rate of 1.44% has led to progressive decline in per capita availability of pulses in India, i.e. 41.6 g in 1991 to 34 g in 2010. In India, pulses supply the protein (25.3–28.9%) needs of marginal and poor farmers as well as animal daily diet. Assuming a moderate requirement of 50 g pulses $capita^{-1}$ day^{-1} with 10% additional need for seeds, feed, wastage, etc., the ever-growing Indian population requires nearly 32 mt by 2030, which necessitates annual growth rate of 4.2% in production. To meet the projected pulse requirement, productivity needs to be enhanced to 1361 kg ha^{-1} or about 3.0 m ha additional area has to be brought under pulses besides reducing the post-harvest losses. In order to improve production and productivity, different varieties have been released and evaluated by various agricultural research institutions for different traits[13], but they have scarcely evaluated cultivars for potential energy benefits in the semi-arid tropics (SAT) region.

Agriculture has a close relation with energy, economics and environment, which are mutually dependent[7,15]. Energy is a crucial input in agricultural production. Continuously rising prices, increasing proportion of commercial energy in the total energy input to agriculture and the growing scarcity of commercial energy sources such as fossil fuels, have necessitated more efficient use of these sources for different crops[16,17]. Agriculture uses large quantities of locally available non-commercial energies such as seed, manure and animate energy, and commercial energies directly and indirectly in the form of diesel, electricity, fertilizer, plant protection, chemicals, irrigation

---

*For correspondence. (e-mail: slpatil64@gmail.com)

water, machinery, etc. Efficient use of these helps achieve greater production, and productivity which in turn contribute to economy, profitability and competitiveness of agricultural sustainability among rural folk[16–19].

Energy in agriculture is an important input for crop production and processing of produce for value addition[18]. The relation between agriculture and energy is very close. Agriculture itself is an energy user and energy supplier in the form of bio-energy. At present, productivity and profitability of agriculture depend on energy consumption[18,19]. Energy use in agriculture has escalated due to increasing population, limited supply of arable land and improved standard of living. In all sections of society, these factors have encouraged an increase in energy inputs to maximize yields, minimize labour-intensive practices, or both[20].

Of late, with more use of fossil fuels through mechanization and chemicals, i.e. fertilizers, pesticides and weedicides, including electricity for irrigation, the energy use in agricultural production has become more intensive leading to substantial increase in food production. However, greater intensive energy use has produced more human health and environment problems, and hence efficient use of inputs has become important in terms of sustainable agricultural production[21]. Energy auditing is one of the most common approaches to assess energy efficiency and environmental impact of the production system. It enables the researchers to calculate the output–input ratio, relevant indicators for energy and energy use patterns in agricultural productivity[22]. The energy audit provides sufficient data to the established functional forms to study the relationship between energy input and output. Estimating these functional forms is useful to determine elasticity of inputs on yield and production[22]. The best way to lower the environmental hazard of energy use is to increase the energy use efficiency[20]. Energy input–output analysis is usually used to evaluate the efficiency and environmental impacts of agricultural production systems. Earlier many studies were conducted on the agricultural energy flow such as dry apricot production in Turkey[20], tomato[22], sugar beet[23], greenhouse vegetable[24], some field crops and vegetables in Turkey[25,26], soybean, maize and wheat in Italy[27], soybean production system[28], oilseed rape in Germany[29] and greenhouse cucumber in Iran[30]. In general, different varieties of a crop also require energy inputs at varying levels in different production zones.

Hence it is essential to cultivate energy-efficient, high-yielding varieties of suitable pulses under changing climatic scenario to meet the protein requirement of poor and marginal farmers and animals in the arid and semi-arid regions and to mitigate possible global warming. Since 2005, the area under chickpea cultivated during postrainy season on residual soil moisture in Vertisols of South India, has increased steeply. Therefore, it is vital to evaluate cultivars not only for their productivity but also how they respond physiologically with improved water use efficiency (WUE) and produce more energy output with greater profit under different rainfall situations. In fact, information on the performance of cultivars in terms of energy use efficiency, economics, physiological efficiency and WUE is scarce in Vertisols of SAT in South India and elsewhere in the world. Thus we evaluated chickpea cultivars for their performance in terms of energy benefits, physiological efficiency, WUE and economics.

During winter seasons of 2007–08 and 2008–09, a field experiment was conducted at our institute on Vertisols of SAT, South India. The experiment was conducted on deep black soils that are derived from granite, gneiss and schist. These soils belong to the Bellary series and are classified as Typic-Pellusterts. The infiltration rate of soils is low (0.9 mm h^{-1}) with 1.20 mg m^{-3} bulk density[31]. The soil pH is 8.3 and electrical conductivity is 0.14 dS m^{-1} (ref. 32). The soils are low in organic carbon (3.5 g kg^{-1})[18] and available N (165 kg ha^{-1})[33], medium in available P (24 kg as P_2O_5 ha^{-1})[34] and high in available K (570 kg as K_2O ha^{-1})[35]. The study was replicated thrice in randomized block design with eight cultivars, including a local control (A1) that is generally cultivated by the farmers in this region. All study plots were once deep ploughed and twice harrowed prior to sowing during 2007–08, whereas the same plots were thrice harrowed prior to sowing during 2008–09. Each study plot measured $6.8 \text{ m} \times 5.4 \text{ m} = 36.72 \text{ m}^2$. Seeds were manually sown by dibbling at a depth of 5 cm and at 45 × 10 cm spacing. The weeds were controlled through bullock-drawn implements as well as manually. The recommended rate of N at 25 kg ha^{-1} and P_2O_5 at 50 kg ha^{-1} for the Bellary region was applied in each plot at sowing. Recommended plant protection measures were adopted for timely control of pests and diseases.

Cultivars were sown on 22 October 2007 and harvested from 4 to 25 January 2008, whereas during 2008, the crop was sown on 21 October and harvested from 8 to 27 January 2009 at physiological maturity. Plants from each net plot were harvested and sun-dried for 10 days. The seeds were separated from the pods and weighed along with stover. Cultivars were grouped into short duration (<80 days), medium duration (80–90 days) and long duration (>90 days) based on the number of days for attaining physiological maturity.

The consumptive use (CU) was worked out[36]. WUE is determined by dividing the seed yield by CU and expressed as kg ha^{-1} mm^{-1}. The cost of cultivation was worked out based on the cost that existing for human labour, bullock pair and hourly hire of tractors, pesticide and fertilizer cost that existed during winter (*rabi*) season of 2012 and the market rates that existed for sale of individual varieties during February 2013. Rates of each variety were arrived at based on the market rate quoted by 10 wholesale buyers in the District Agricultural

Produce Market Committee, Bellary and average of 10 buyers was considered as selling price of the individual variety.

Days to 50% flowering and 50% pod formation were recorded in each plot when 50% plants were at flowering and pod formation stage from the sowing date. The dry matter efficiency (DME) is the ratio of harvest index to the duration of crop[37] and is calculated using the formula

$$\text{Dry matter efficiency} = \frac{\text{Economic yield}}{\text{Total biological yield}} \times \frac{100}{\text{Duration of crop/variety}}.$$

Total energy input and output in different cultivars was estimated based on the information on energy inputs of various operations from primary tillage up to harvest of cultivars, including the output in terms of grain and stover yields. These data were entered into Excel spreadsheets and then energy indicators were calculated (Tables 1 and 2). The energy calculations like energy use efficiency (EUE), energy productivity (EP), agrochemical energy ratio (AER), specific energy (SE) and net energy were worked out using the following formulae[22,26,38,39]

$$\text{Energy ratio or energy use efficiency} = \frac{\text{Total energy output (MJ ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})},$$

$$\text{Energy productivity (kg MJ}^{-1}) = \frac{\text{Chickpea grain yield (kg ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})},$$

$$\text{Agrochemical energy ratio} = \frac{\text{Input energy from agrochemicals (MJ ha}^{-1})}{\text{Total input energy (MJ ha}^{-1})},$$

$$\text{Specific energy (MJ kg}^{-1}) = \frac{\text{Total energy input (MJ ha}^{-1})}{\text{Chickpea grain yield (kg ha}^{-1})},$$

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

Energy flow in the cultivation of chickpea cultivars on black soils under rainfed situations during winter seasons was analysed in four groups as direct and indirect as well as non-renewable and renewable energy resources. The direct energy includes human labour and diesel fuel and indirect energy accounts for the energy content in seeds, fertilizers, pesticides and machinery[19]. Non-renewable energy consists of diesel, chemicals, fertilizers and machinery, while renewable energy includes human labour and seeds[30,38].

Variables were analysed and least significance difference (LSD) test was carried out for analysed mean square errors using MSTAT package. Significance and non-significance difference between any pair of cultivars derived using the procedure provides for a single LSD value[40].

Twenty-one per cent higher rainfall1 (607.4 mm) received during 2008 as against 56 years mean annual rainfall (501 mm) of the region resulted in better vegetative growth and delay in 50% flowering (42.3 days), 50% pod formation (50.1 days) and maturity at 84.5 days compared to a drought year of 2007 with 474.1 mm (95%) rainfall resulting in early 50% flowering (40.5 days), 50% pod formation (49.2 days) and early maturity at 80.7 days after sowing (Table 3). There was no significant difference in DME and WUE among the years; however, higher DME of 0.658 was observed during drought year of 2007 and is attributed to lesser duration of crop. Higher WUE of 6.52 kg ha^{-1} mm^{-1} observed during above-normal rainfall year of 2008 compared to drought year of 2007 is attributed to better utilization of soil moisture for greater economical yield (Table 3).

Cultivars that matured late could produce flowers and pods late compared to early maturing cultivars. Of the eight cultivars, BGD72 was the late maturing variety whereas KAK2 matured early compared to the rest of the cultivars evaluated. The drought-tolerant cultivar ICCC37 showed significantly higher DME during a drought year of 2007, whereas high-yielding variety BGD103 showed higher DME during 2008 under above-normal rainfall situation with higher mean DME. The high-yielding variety JG11 showed significantly higher WUE of 7.02 kg ha^{-1} mm^{-1} during the drought year (2007), whereas BGD103 showed higher WUE of 7.53 kg ha^{-1} mm^{-1} during the wet year (2008). Overall, cultivars BGD103 and JG11 showed high grain yields of 1662 and 1688 kg ha^{-1} with better utilization of soil moisture, and thus higher

Table 1. Energy equivalents of input and output in agricultural systems

Input and output	Energy equivalents (MJ)	Reference
Inputs		
Human labour – men (h)	1.96	38
Human labour – women (h)	1.57	47
Machinery (h)	64.8	47
Diesel fuel (l)	51.33	38
Pesticides (l)	120.0	47
Seed (kg)	25.0	47
Output		
Grain chickpea (kg)	25.0	47
Stover chickpea (kg)	10.0	47

Table 2. Energy equivalents of input and output in chickpea production systems

Quantity (input and output)	Quantity per unit area (ha)	Total energy equivalents (MJ ha^{-1})	Percentage of total energy
Inputs			
Human labour – men	177	346.92	7.09
Human labour – women	359	563.63	11.53
Bullock pair	48	484.80	9.91
Total		1395.35	28.53
Machinery	6.86	444.65	9.17
Chemical fertilizers	100	1080.00	22.28
Pesticides	6	120.00	14.85
Seed	50	1250.00	25.78
Total energy input		4890.00	100.00
Output			
Grain chickpea	1490.8	37270	73.53
Stover chickpea	1342.0	13420	26.47
Total energy output		50690	100.00
Output – input energy ratio			
Main product	–	7.69	–
Total output	–	10.47	–
Other energy indicators			
Energy use efficiency	10.35		
Specific energy (MJ kg^{-1})	3.38		
Energy productivity (kg MJ^{-1})	0.304		
Agrochemical energy ratio (%)	36.81		
Net energy (MJ kg^{-1})	45,800		

WUE of 7.20 and 7.18 kg ha^{-1} mm^{-1}, respectively. This indicates that these cultivars are suited for cultivation under different rainfall situations in the SAT Vertisols during post-rainy (winter) season (Table 3).

Table 2 shows the energy input and output, total energy equivalents and percentage of different inputs from total energy consumption in chickpea production systems. Results indicate that nearly 177 men, 359 women, 48 bullock and 6.86 machinery power hours were used for production of chickpea per hectare. Chemical fertilizer, pesticide and seed application rates in chickpea production were 100 kg ha^{-1}, 6 l ha^{-1} and 50 kg ha^{-1} respectively.

Total energy consumption for various practices adopted for chickpea cultivation was calculated as 4890 MJ ha^{-1} (Table 2). Similarly, in Iran, the total energy input for chickpea was 5880 MJ ha^{-1} and the higher share of energy input was for various field operations[41]. In contrast, among the pulses, i.e. bean, lentil, irrigated and dryland chickpea, the dryland chickpea required lower energy of 2630 MJ ha^{-1} for production[42]. The greater shares of input energy were observed for human and bullock pair (28.53%), as majority of operations were done with this force. Seed is the major input cost in chickpea cultivation and it contributes to 25.78% of energy consumed followed by chemical fertilizer (22.28%) and pesticides (14.85%), as these inputs are required for higher grain and stover production in chickpea. Asakereh *et al.*[43] reported that total input energy in organic and conventional lentil is 5062 and 6196.5 MJ ha^{-1} respectively. Results of this study also indicated that more energy was utilized for different field operations using through bullock, human and machinery.

The average grain and stover yields of eight cultivars over two years were 1490.8 and 1342 kg ha^{-1} respectively. According to energy equivalents, energy output of grain and stover are 37,270 and 13,420 MJ ha^{-1} respectively, and hence the total energy output of this study is 50,690 MJ ha^{-1} (Tables 2 and 4). Asakareh *et al.*[43] reported 10,739.2 and 12,694.6 MJ ha^{-1} as the output energy for organic and non-organic lentil respectively, while and Salami and Ahmadi[41] reported a value of 5880 MJ ha^{-1} for chickpea. Analysis of output–input energy for grain was 7.69 and total output was 10.47, indicating that greater output of energy for input of energy was observed for chickpea in Vertisols of South India under rainfed conditions during winter season due to higher yields compared to the energy used for production (Table 2).

Energy use efficiency of the studied chickpea fields was calculated as 10.35 (Table 2) as against 3.04 as a lower value[38]; 1.04 as reported by Salami and Ahmadi[41] from Iran, and 2.12 and 2.05 observed for organic and non-organic lentil respectively by Asakereh *et al.*[43]. Energy use efficiency in the present study was higher and it

Table 3. Physiological characteristics and water use efficiency of chickpea cultivars

	Days to 50% flowering			Days to 50% pod formation			Days to physiological maturity			Dry matter efficiency			Water use efficiency (kg ha^{-1} mm^{-1})		
Chickpea cultivar	2007–08	2008–09	Mean	2007–08	2008–09	Mean	2007–08	2008–09	Mean	2007–08	2008–09	Mean	2007–08	2008–09	Mean
Year	40.5	42.3	41.4	49.2	50.1	49.7	80.7	84.5	82.6	0.658	0.621	0.640	6.16	6.52	6.34
SEm ±		0.3			0.15			0.26			0.07			0.11	
LSD ($P = 0.05$)		1.3			0.64			1.10			n.s.			n.s.	
Short duration															
KAK2	36.7	38.3	37.5	42.7	45.3	44.0	74.0	79.3	76.7	0.696	0.632	0.664	5.37	5.37	5.37
BGD103	38.7	39.3	39.0	47.7	48.3	48.0	76.0	80.7	78.3	0.706	0.641	0.674	6.87	7.53	7.20
Medium duration															
BGD1105	40.3	39.3	39.8	49.0	48.7	48.8	78.0	84.0	81.0	0.652	0.621	0.636	5.20	6.74	5.97
BGD128	39.0	39.7	39.3	49.3	48.7	49.0	79.3	83.3	81.3	0.596	0.592	0.594	5.73	5.91	5.82
ICCC37	41.0	41.7	41.3	50.0	49.0	49.5	80.0	83.0	81.5	0.770	0.634	0.702	6.95	6.29	6.62
JG11	38.0	41.3	39.7	49.7	49.3	49.5	81.0	83.7	82.3	0.633	0.626	0.630	7.52	6.84	7.18
A1	38.0	42.0	40.0	49.3	49.7	49.5	82.0	84.3	83.2	0.655	0.634	0.645	6.47	6.44	6.45
Long duration															
BGD72	52.3	57.0	54.7	56.0	62.0	59.0	95.3	97.7	96.5	0.559	0.591	0.575	5.20	7.05	6.13
SEm ±	1.6	0.6	1.2	0.6	0.7	0.6	1.0	1.2	1.1	0.048	0.370	0.035	0.33	0.58	0.16
LSD ($P = 0.05$)	4.8	1.8	2.5	1.9	2.0	1.3	2.9	3.5	2.1	0.14	n.s.	0.085	0.99	1.77	0.34
CV	6.7	5.3	6.1	5.2	4.2	5.1	5.0	4.3	4.1	12.5	10.1	11.2	9.2	15.5	6.3

is attributed to higher grain and stover yield (Figure 1). The specific energy recorded in the present study was 3.38 MJ kg^{-1}, while it was 7.55 MJ kg^{-1} in Iran[38]. This clearly indicates that less energy was used in Bellary to produce 1 kg of chickpea grain compared to Iran. The energy productivity recorded at Bellary (0.304 kg MJ^{-1}) was high compared to that at Iran (0.13 kg MJ^{-1}), clearly indicating that higher grain yield consuming one MJ energy at Bellary compared to Iran (Table 4). More use of agrochemicals, i.e. fertilizers and pesticides in chickpea production resulted in higher agrochemical energy ratio of 36.81 compared to only 1.74 observed in Iran. This was attributed to lesser use of chemicals for production of chickpea. Compared to India, in Iran limited amounts of chemical fertilizers and pesticides were applied for chickpea production (Table 2).

Direct energy inputs in chickpea production are only 28.53% compared to higher indirect energy inputs of 49.38%, whereas renewable energy inputs were slightly higher, i.e. 54.10% compared to non-renewable energy inputs of 45.90% (Table 5). These results clearly indicate that human and bullock input energy were used less compared to input energy of seeds, pesticides and machinery for chickpea production. Further, it is observed that renewable energy input used in this study is more compared to non-renewable energy inputs like diesel, fertiliser, pesticides and machinery. In contrast, non-renewable energy like diesel fuel and direct energy inputs are used more for chickpea production in Iran[38] and developed countries.

Higher input energy used in normal year of 2008–09 compared to drought year of 2007–08 was attributed to higher grain and stover yield in normal rainfall situation. Further, significantly greater total energy output of 55,361 MJ ha^{-1} was produced during a normal year compared to lower energy output of 46,019 MJ ha^{-1} during a drought year and thus resulted is higher net energy benefit of 9186 MJ ha^{-1} during 2008–09 over 2007–08 (Table 4). Even the energy use efficiency of 11.23 and energy productivity of 0.329 kg MJ^{-1} were higher during a normal year compared to lower energy use efficiency of 9.46 and energy productivity of 0.279 kg MJ^{-1} during a drought year. During below-normal rainfall year, more energy of 3.66 MJ is utilized to produce 1 kg chickpea grain yield compared to lower energy of 3.10 MJ utilized for the production of 1 kg grain yield during normal rainfall year. These results indicate that less energy was utilized for more energy production, as 1 MJ energy produced higher chickpea grain yield during normal year compared to a drought year.

Cultivars that showed higher yields, i.e. JG11 (medium duration) and BGD103 (short duration) during both years of study and in the pooled data, consumed more labour for harvesting, trashing and transportation resulting in more energy consumption. High total energy output of 55,269 MJ ha^{-1} was produced by JG11 and this was significantly superior over other cultivars evaluated during the drought year, whereas during normal year, BGD103 produced higher energy output of 59,686 MJ ha^{-1} compared to other cultivars. In the pooled data high energy of

Table 4. Evaluation of chickpea cultivars through energy calculations

Chickpea cultivar	Total energy input (MJ ha^{-1})			Total energy output (MJ ha^{-1})			Net energy benefit (MJ ha^{-1})			Energy use efficiency			Energy productivity (kg MJ^{-1})			Specific energy (MJ kg^{-1})		
	2007–08	2008–09	Mean	2007–08	2008–09	Mean	2007–08	2008–09	Mean	2007–08	2008–09	Mean	2007–08	2008–09	Mean	2007–08	2008–09	Mean
Year	4,857	4,923	4,890	46,019	55,361	50,690	41,162	50,438	45,800	9.46	11.23	10.35	0.279	0.329	0.304	3.66	3.10	3.38
SEm±		–			804			804			0.16			0.006			0.056	
LSD ($P = 0.05$)		–			3,460			3,460			0.63			0.022			0.225	
Short duration																		
KAK2	4,813	4,857	4,835	42,297	47,901	45,099	37,484	43,044	40,264	8.79	9.85	9.32	0.245	0.279	0.262	4.10	3.64	3.87
BGD103	4,895	4,968	4,932	48,882	59,686	54,284	43,987	54,718	49,352	9.98	12.01	11.00	0.309	0.364	0.337	3.26	2.76	3.06
Medium duration																		
BGD1105	4,805	4,923	4,864	41,614	55,275	48,445	36,809	50,352	43,581	8.66	11.21	9.94	0.238	0.330	0.284	4.22	3.06	3.64
BGD128	4,833	4,892	4,863	42,310	53,356	47,833	37,477	48,464	42,970	8.75	10.90	9.83	0.261	0.306	0.284	3.86	3.30	3.58
ICCC37	4,898	4,911	4,904	48,228	52,810	50,519	43,330	47,899	45,615	9.83	10.75	10.29	0.311	0.321	0.316	3.27	3.13	3.20
JG11	4,929	4,948	4,938	55,269	57,636	56,453	50,340	52,688	51,515	11.21	11.64	11.43	0.335	0.348	0.342	2.99	2.91	2.95
A1	4,873	4,938	4,906	47,535	57,953	52,744	42,662	53,015	47,838	9.75	11.73	10.74	0.292	0.341	0.317	3.42	2.98	3.20
Long duration																		
BGD72	4,805	4,945	4,875	42,017	58,272	50,144	37,212	53,327	45,269	8.74	11.74	10.24	0.239	0.345	0.292	4.21	3.05	3.63
SEm±	–	–	–	2,096	4170	2,282	2,096	4,170	2,282	0.40	0.76	0.36	0.014	0.029	0.015	0.16	0.30	0.15
LSD ($P = 0.05$)	–	–	–	6,357	n.s.	6,920	6,357	n.s.	6,920	1.20	n.s.	1.10	0.041	n.s.	0.044	0.50	n.s.	0.45
CV	–	–	–	7.9	13.0	11.6	14.2	21.1	19.1	7.2	11.8	10.4	8.4	14.3	12.4	7.8	12.9	11.3

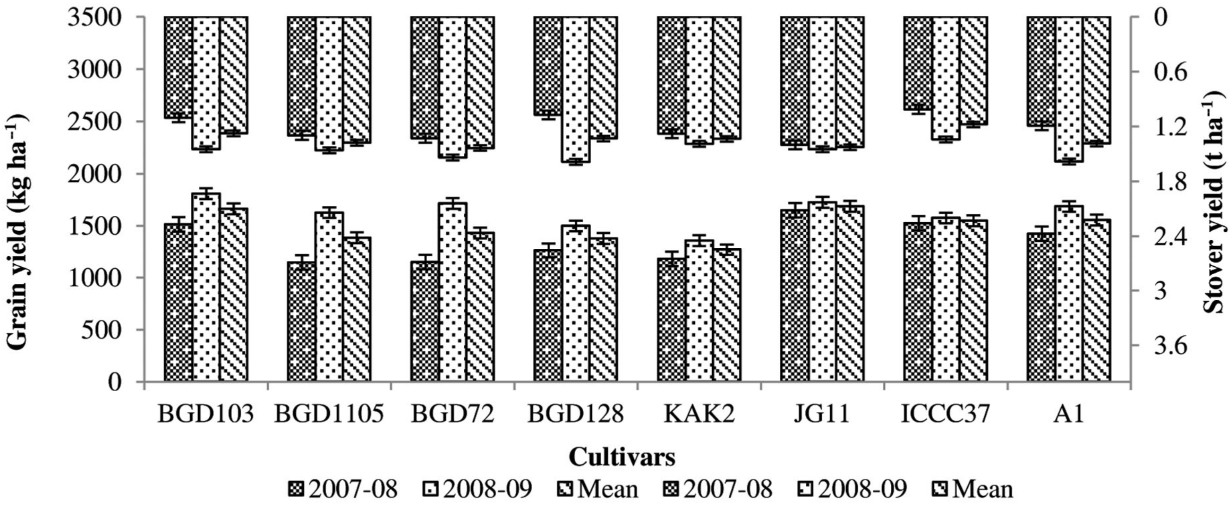

Figure 1. Grain and stover yields of chickpea cultivars under varying rainfall situations.

Table 5. Total energy input in the form of direct, indirect, renewable and non-renewable energy for chickpea production (MJ ha^{-1})

Indicator	Quantity	Percentage
Direct energy[a]	1395.35	28.53
Indirect energy[b]	2414.61	49.38
Renewable energy[c]	2645.35	54.10
Non-renewable energy[d]	2244.61	45.90
Total energy input	4890.00	100.0

[a]Includes human labour, bullock pair, [b]Includes seeds, pesticides, machinery; [c]Includes human labour, seed; [d]Includes diesel, pesticides, fertilizers, machinery.

56,453 MJ ha^{-1} was produced by JG11 followed by 54284 MJ ha^{-1} by BGD103. Similar to total energy output, the net energy output was high for JG11 (51,515 MJ ha^{-1}) and BGD103 (49,352 MJ ha^{-1}) in the pooled data and during both years of study. The other cultivars that also showed slightly lower net energy compared to JG11 include A1, ICCC37, and BGD72, as these exhibited high yield and were also drought-tolerant.

Cultivar JG11 showed significantly higher energy use efficiency of 11.21 during 2007–08, whereas during 2008–09, BGD103 showed greater energy use efficiency of 12.01 compared to other cultivars evaluated (Table 4). Higher energy use efficiency of 11.43, 11.00 and 10.74 was shown by JG11, BGD103 and A1, respectively over other cultivars evaluated in the pooled data. Higher energy use efficiency was shown by all the cultivars evaluated in this study compared to lower energy use efficiency in other studies[38,41,42]. This was attributed to higher grain yield with lower energy use (Table 4). The trend in energy productivity was similar to the energy use efficiency with JG11 recording higher energy productivity of 0.335 kg MJ^{-1} during drought year and BGD103 recording higher energy productivity of 0.364 during normal years. Both these cultivars used lesser energy for production of 1 kg grain yield of chickpea compared to other cultivars. Higher energy productivity was observed for chickpea at Bellary compared to Iran[38]. At Bellary, lesser energy was used for the production of 1 kg chickpea grain. Lower specific energy of 2.99 and 2.76 MJ was utilized for producing 1 kg of JG11 and BGD103 cultivars during drought and normal rainfall year respectively, compared to rest of the cultivars evaluated in this study. This clearly indicates that these cultivars consume lesser energy for higher grain and stover yield and net energy. This confirms that these cultivars are suitable for Vertisols and its associated soils of SAT in South India.

To assess any production system, it is finally the economics of the system which plays a major role for its acceptance by the farmers. Suitability of cultivars for any region depends on their performance in terms of grain and stover yield and market price under different rainfall situations.

Higher gross returns of Rs 65,909 ha^{-1}, net returns of Rs 43,885 ha^{-1} and B : C ratio of 1.99 during 2008–09 compared to significantly lower gross and net returns and B : C ratio of Rs 55,106 ha^{-1}, Rs 33,350 ha^{-1} and 1.53, respectively during 2007–08 have been attributed to higher grain and stover yield during 2008–09. The higher yields during 2008–09 were attributed to 21% higher rainfall over normal rainfall in the region, thus producing 20 and 22% higher grain and stover yield respectively (Figure 1 and Table 6).

High-yielding short-duration cultivar BGD103, during normal rainfall year of 2008–09 showed higher grain yield of 1809 kg ha^{-1} and stover yield of 1.45 t ha^{-1} compared to other cultivars evaluated, thus resulting in higher gross returns of Rs 78,425 ha^{-1}, net returns of Rs 56,216 ha^{-1} and B : C ratio of 2.53. During the drought year of 2007–08, the performance of medium

Table 6. Economics of chickpea cultivars

	Cost of cultivation (Rs ha^{-1})			Gross returns (Rs ha^{-1})			Net returns (Rs ha^{-1})			B : C ratio		
Chickpea cultivar	2007–08	2008–09	Mean	2007–08	2008–09	Mean	2007–08	2008–09	Mean	2007–08	2008–09	Mean
Year	21,756	22,025	21,891	55,106	65,909	60,508	33,350	43,885	38,618	1.53	1.99	1.76
SEm+		–			1,988			1,940			0.08	
LSD (*P* = 0.05)		–			8,554			8,348			0.35	
Short duration												
KAK2	21,581	21,760	21,671	48,598	55,830	52,214	27,018	34,069	30,543	1.25	1.56	1.41
BGD103	21,914	22,209	22,062	65,412	78,425	71,919	43,498	56,216	49,857	1.98	2.53	2.26
Medium duration												
BGD1105	21,546	22,027	21,787	48,327	67,851	58,089	26,781	45,823	36,302	1.24	2.08	1.66
BGD128	21,663	21,899	21,781	52,669	63,151	57,910	31,006	41,252	36,129	1.43	1.88	1.66
ICCC37	21,925	21,976	21,950	59,192	61,780	60,486	37,268	39,804	38,536	1.70	1.81	1.75
JG11	22,050	22,126	22,088	71,291	74,538	72,915	49,240	52,412	50,826	2.23	2.37	2.30
A1	21,825	22,086	21,956	51,896	61,742	56,819	30,071	39,656	34,864	1.38	1.79	1.59
Long duration												
BGD72	21550	22,115	21,832	43,464	63,959	53,712	21,914	41,845	31,880	1.02	1.88	1.45
SEm ±	–	–	–	2,808	5,497	3,086	2,736	5,352	3,005	0.12	0.23	0.13
LSD (*P* = 0.05)	–	–	–	8,517	16,675	6,320	8,299	16,236	6,155	0.36	0.70	0.27
CV	–	–	–	8.8	14.5	12.5	14.2	21.1	19.1	13.5	20.1	18.1

duration cultivar JG11 was better with higher grain (1650 kg ha^{-1}) and stover (1.40 t ha^{-1}) yields with higher gross (Rs 71,291 ha^{-1}), and net returns (Rs 49,240 ha^{-1}) and B : C ratio of 2.23 compared to other cultivars evaluated (Figure 1 and Table 6). Even in the Thal desert of Pakistan, the cost of cultivating a hectare of chickpea was computed to be Rs 14,879 with a net income of Rs 21,653 and B : C ratio was 2.46 : 1, thus indicating chickpea as the most potential winter pulse crop[44]. Pooled analysis results also indicated that medium-duration cultivar JG11 and short-duration cultivar BGD103 are more suitable for the black soil region of South India with higher gross and net returns and high B : C ratio of 2.30 and 2.26 respectively. Cultivation of improved chickpea cultivars[45] and wheat varieties[46] has been shown to increase income and reduce poverty.

Early flowering, pod formation and physiological maturity with higher grain and stover yield, dry matter and WUE of medium-duration cultivar JG11 and short-duration cultivar BGD103 indicate their suitability for cultivation in the SAT region. Thus BGD103 could be cultivated during normal to above-normal rainfall years and JG11 during normal to drought years in winter season on residual soil moisture in Vertisols of SAT in South India for higher energy efficiency and economics.

---

1. Dorward, A., Rethinking agricultural input subsidy programmes in a changing world. School of Oriental and African Studies, University of London, UK, 2009, p. 48.
2. Grossman, N. and Dyland, C., Agriculture policy in India: the role of input subsidies. In USITC Executive Briefings on Trade, 2011; http://usitc.gov/publications/332/executive_briefings/EBOT_IndiaAgSubsidies.pdf
3. Wiggins, S. and Brooks, J., The use of input subsidies in developing countries. In Global Forum on Agriculture Policies for Agricultural Development, Poverty Reduction and Food Security, OECD, Paris, 29 and 30 November 2010; http://www.oecd.org/tad/agricultural-policies/46340359.pdf
4. Spiertz, J. H. J., Nitrogen, sustainable agriculture and food security – a review. *Agron. Sustain. Dev.*, 2010, **30**, 43–55.
5. Patil, S. L., Winter sorghum (*Sorghum bicolor*) productivity as influenced by tillage practices and nitrogen management in Vertisols of SAT, India. *Soil Till. Res.*, 2013, **126**, 183–192.
6. Shamabadi, Z., Evaluation the effect of reduced tillage on irrigated wheat yield and energy efficiency. *Int. J. Agric. Crop Sci.*, 2012, **4**(20), 1508–1511.
7. Tabatabaeefar, A., Emamzadeh, H., Ghasemi Varnamkhasti, M., Rahimizadeh, R. and Karimi, M., Comparison of energy of tillage systems in wheat production. *Energy*, 2009, **34**, 41–45.
8. Khaledian, M. R., Mailhol, J. C. and Ruelle, P., Impacts of direct seeding into mulch on the CO_2 mitigation. *Agron. Res.*, 2012, **10**(1–2), 303–310.
9. Mitchell, J. *et al.*, No-tillage and high-residue practices reduce soil water evaporation. *Calif. Agric.*, 2012, **66**(2), 55–61; DOI: 10.3733/ca.v066n02p55.
10. Tripathi, J., Evaluation and promotion of resource conservation technologies in low land rice–wheat ecosystem. *Agron. J. Nepal*, 2010, **1**, 28–39.
11. Gan, Y. T., Zentner, R. P., Campbell, C. A., Biederbeck, V. O., Selles, F. and Lemke, R., Conserving soil and water with sustainable cropping systems: research in the semiarid Canadian prairies. In 12th ISCO Conference, Beijing, 2002; http://www.pulsecanada.com
12. Cutforth, H. W. *et al.*, Comparing rooting characteristics and soil water withdrawal patterns of wheat with alternative oilseed and pulse crops grown in the semiarid Canadian prairie. *Can. J. Soil Sci.*, 2013, **93**, 147–160.

13. Gowda, C. L. L., Srinivasan, S., Gaur, P. M. and Saxena, K. B., Enhancing the productivity and production of pulses in India. In *Climate Change and Sustainable Food Security 2013* (eds Shetty, P. K., Ayyappan, S. and Swaminathan, M. S.), National Institute of Advanced Studies, Bangalore and Indian Council of Agricultural Research, New Delhi, ISBN: 978-81-87663-76-8.
14. IIPR, Vision 2030. Indian Institute of Pulses Research, Kanpur, 2011, p. 42.
15. Pimentel, D., Herdendorf, M., Eisenfeld, S., Olander, L., Carroquino, M. and Corson, C., Achieving a secure energy future: environmental and economic issues. *Ecol. Econ*., 1994, **9**(3), 201–219.
16. Singh, H., Mishra, D. and Nahar, N. M., Energy use pattern in production agriculture of a typical village in arid zone, India – part I. *Energy Convers. Manage*., 2002, **43**, 2275–2286.
17. Singh, S. A., Singh, S. U., Pannu, C. J. S. and Singh, J., Energy input and yield relations for wheat in different agro-climatic zones of the Punjab. *Appl. Energy*, 1999, **63**, 287–298.
18. Karimi, M., Beheshti Tabar, I. and Khubbakht, G. M., Energy production in Iran's agronomy. *Am.–Eurasian J. Agric. Environ. Sci*., 2008, **4**(2), 172–177.
19. Alam, M. S., Alam, M. R. and Islam, K. K., Energy flow in agriculture, Bangladesh. *Am. J. Environ. Sci*., 2005, **1**(3), 13–20.
20. Esengun, K., Gunduz, O. and Erdal, G., Input–output energy analysis in dry apricot production of Turkey. *Energy Convers. Manage*., 2007, **48**, 592–598.
21. Yilmaz, L., Akcaoz, H. and Ozkan, B., An analysis of energy use and input costs for cotton production in Turkey. *Renew. Energy*, 2005, **30**, 145–155.
22. Hatirli, S. A., Ozkan, B. and Fert, C., Energy inputs and crop yield relationship in greenhouse tomato production. *Renew Energy*, 2008, **31**, 427–438.
23. Erdal, G., Esengun, K., Erdal, H. and Gunduz, O., Energy use and economical analysis of sugar beet production in Tokat province of Turkey. *Energy*, 2007, **32**, 35–41.
24. Ozkan, B., Fert, C. and Karadeniz, C. F., Energy and cost analysis for greenhouse and open-field grape production. *Energy*, 2007, **32**, 500–504.
25. Demircan, V., Ekinci, K., Keener, H. M., Akbolat, D. and Ekinci, C., Energy and economic analysis of sweet cherry production in Turkey. a case study from Isparta province. *Energy Convers. Manage*., 2006, **47**, 1761–1769.
26. Canakci, M., Topakci, M., Akinci, I. and Ozmerzi, A., Energy use pattern of some field crops and vegetable production. Case study for Antalya region, Turkey. *Energy Convers. Manage*., 2005, **46**, 655–666.
27. Sartori, L., Basso, B., Bertocco, M. and Oliviero, G., Energy use and economic evaluation of a three year crop rotation for conservation and organic farming in NE Italy. *Biosyst. Eng*., 2005, **91**(2), 245–256.
28. Mandal, K. G., Saha, K. P., Ghosh, P. K. and Hati, K. M., Bioenergy and Economic analysis of Soybean-based crop production system in central India. *Biomass Bioenergy*, 2002, **23**, 337–345.
29. Rathke, G. W. and Diepenbrock, W., Energy balance of winter oilseed rape (*Brassica napus* L.) cropping as related to nitrogen supply and preceding crop. *Eur. J. Agron*., 2006, **24**, 35-44.
30. Mohammadi, A. and Omid, M., Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. *Appl. Energy*, 2010, **87**, 191–196.
31. Black, C. A., *Methods of Analysis, Part II. Chemical and Microbial Properties*, American Society of Agronomy Incorporation, Madison Wisconsin, USA, 1965, no. 9, p. 1569.
32. Piper, C. S., *Soil and Plant Analysis*, Academic Press, New York, USA, 1966, pp. 47–77.
33. Subbaiah, B. V. and Asija, G. L., A rapid procedure for the estimation of available nitrogen in soils. *Curr Sci*., 1956, **25**, 259–260.
34. Jackson, U. L., *Soil Chemical Analysis*, Prentice-Hall of India Private Ltd, New Delhi, 1967, p. 498.
35. Muhr, G. R., Datta, N. P., Shankaranbramoney, H., Lely, V. P. and Donahaue, R. L., *Soil Testing in India*, USAID, New Delhi, 1965, pp. 39–41.
36. Patil, S. L. and Sheelavantar, M. N., Soil water conservation and yield of winter sorghum (*Sorghum bicolar* L. Moench) as influenced by tillage, organic materials and nitrogen fertilizer in semi-arid tropical India. *Soil Till. Res*., 2006, **89**, 246–257.
37. Krishnamurthy, K., Bommegouda, A., Venugopal, N., Jagannath, M. K., Ragunath, C. and Rajashekhar, B. G., Investigations on the varietal differences on the growth components of maize and sorghum. *Mysore J. Agric. Sci*., 1973, **7**, 377–384.
38. Yousefi, M. and Damghani, A. M., Evaluation of energy flow and indicators of chickpea under rainfed condition in Iran. *Int. J. Farm. Allied Sci*., 2012, **1**(2), 57–61.
39. Zarini, R. L., Ghasempour, A. and Mostafavi, S. M., A comparative study on energy use of greenhouse and open-field cucumber production systems in Iran. *Int. J. Agric. Crop Sci*., 2013, **5**(13), 1437–1441.
40. Gomez, K. A. and Gomez, A. A., *Statistical Procedures for Agricultural Research*, John Wiley, New York, 1984, 2nd edn, p. 657.
41. Salami, P. and Ahmadi, H., Energy inputs and outputs in a chickpea production system in Kurdistan, Iran. *Afr. Crop Sci. J*., 2010, **18**(2), 51–57.
42. Koocheki, A., Ghorbani, R., Mondani, F. and Alizade, Y., Pulses production systems in term of energy use efficiency and economical analysis in Iran. *Int. J. Energy Econ. Policy*, 2011, **1**(4), 95–106.
43. Asakereh, A., Keyhani, A., Safaienejad, H. A. M. and Garavand, A. T., Energy consumption pattern and economic efficiency of dry farming chickpea in Koohdashtcounty, Iran. Role of agricultural engineering in advent of changing global landscape (eds Salokhe, V. M. and Soni, P.), In Proceedings of the 10th International Agricultural Engineering Conference, Bangkok, Thailand, 7–10 December 2009.
44. Shah, N. A., Aujla, K. M., Abbas, M. and Mahmood, K., The economics of chickpea production in the Thal desert of Pakistan. *Pak. J. Life Soc. Sci*., 2007, **5**(1–2), 6–10.
45. Ibrahim, M., Alastair, O., Franklin, S. and Solomon, A., Potential economic and poverty impact of improved chickpea technologies in Ethiopia. In Triennial Conference, International Association of Agricultural Economists (IAAE), Foz do Iguacu, Brazil, 18–24 August 2012; http://oar.icrisat.org/6121/1/IAAE_18-24_2012_Triennial_conf_Brazil.pdf
46. Alene, A. D., Menkir, A., Ajala, S. O., Badu-Apraku, B., Olanrewaju, A. S., Manyong, V. M. and Ndiaye, A., The economic and poverty impacts of maize research in West and Central Africa. *Agric. Econ*., 2009, **40**, 535–550.
47. Thyagaraj, C. R., Enhancing energy use efficiency through conservation agriculture. In ICAR sponsored training course on 'Conservation Agriculture Strategies for Resource Conservation and Mitigation of Climate Change', CRIDA Hyderabad, 24–30 September 2012, pp. 229–240.

Received 9 April 2014; revised accepted 26 June 2014