Assessing the impact of watershed development on energy efficiency in groundnut production using DEA approach in the semi-arid tropics of southern India

Suresh Kumar[1,]*, A. Raizada[1], H. Biswas[1] and P. K. Mishra[2]

[1]ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Bellary 583 104, India
[2]ICAR-Indian Institute of Soil and Water Conservation, Dehradun 248 195, India

The present study is aimed at assessing the impact of watershed development on the energy efficiency in groundnut cultivation. Overall technical, pure technical and scale efficiency increased by 11, 3 and 12% over the pre-watershed scores due to watershed development. Estimated potential for saving input energy was 3608, 3223 and 2907 MJ ha^{-1} for marginal, small and large farmers respectively, in groundnut production while maintaining status quo for energy output. Farm size, age of farmer, number of livestock owned and implementation of watershed activities were identified as key determinants for higher overall energy efficiency.

Keywords: Data envelopment analysis, energy efficiency, groundnut, soil and water conservation.

ENERGY, economics and the environment are mutually dependent[1], and there is a close relationship between agriculture and energy[2]. Agriculture has become an increasingly energy-intensive sector in the last half a century, with much of it attributable to necessary inputs. For example, chemical fertilizers and pesticides require much greater energy to manufacture than to apply on-farm[3]. With rapid depletion of non-renewable energy sources, rapid population growth and environmental degradation energy use in agriculture has become an issue of concern[4], as evident by deteriorating water and land resources and their contribution to global warming through increased emission of greenhouse gases[5,6]. Therefore, energy-efficient crop production is vital for reducing environmental hazards, preventing destruction of natural resources and ensuring agricultural sustainability[7]. In India, various studies have been conducted to determine energy efficiency in crop production. Nassiri and Singh[8] observed that small farmers in Punjab realized high energy ratio and low specific energy requirement compared to large farmers growing paddy. Mandal *et al.*[9] suggested that on the economic front, based on net return, soybean–wheat system is marginally better than other systems, but soybean–chickpea system is more suitable in central India due to its low requirement for non-renewable resources and higher energy use efficiency. Similarly, Singh *et al.*[10] showed that zero and minimum tillage saved more energy than conventional tillage under rainfed soybean-based cropping systems. Based on output–input ratio, Singh *et al.*[11,12] suggested that cultivation of green gram (6.8) is more remunerative compared to pearl millet (4.8) and wheat (3.2). They also observed that cotton consumed the highest energy, followed by wheat, mustard, maize and cluster bean; however in all crops the consumption of non-renewable energy (73.2%) was higher than renewable energy.

Existing literature mostly substantiates the scope for improvement in energy efficiency in various crops, but none of these deals with the impact of watershed implementation on energy efficiency of crops grown in watershed areas treated with soil and water conservation measures. Watershed is a land-based programme, which is mainly focused on water, with its main objective being to enhance agricultural productivity through increased *in situ* moisture conservation and protective irrigation for socio-economic development of rural people[13]. Many studies have reported the economical viability of watershed programmes but, to the best of our knowledge, no study has highlighted the impact of watershed programme on energy efficiency. Keeping this in view, we examined the impact of watershed interventions on the energy use efficiency in groundnut cultivation, which is an important oilseed crop in India, primarily being grown under rainfed conditions during *kharif* season. It is cultivated in about 6 m ha, which is about one-fifth of the total area under oilseeds in the country. However, three-fourths of cultivated area falls in the semi-arid tropics characterized by low and erratic rainfall, and poor soil. In Karnataka, groundnut is cultivated in about 0.85 m ha, with around 71% under rainfed conditions[14]. In the watershed taken for study, groundnut accounts for 65% of the total gross cropped area. Therefore the crop was considered for the present study, wherein we estimated the impact of watershed development on energy efficiency using data envelopment analysis (DEA) in groundnut production cultivated under rainfed conditions in a semi-arid watershed of South India.

The study was carried out in Netranahalli watershed in the drought-prone Chitradurga district of Karnataka. The watershed was treated under Integrated Watershed Development Programme scheme, sponsored by the Ministry of Rural Development, Government of India. Annual mean rainfall of the area is 526 mm, and during the last 18 years (1994–2011) deficit rainfall occurred in about 50% and severe drought in 30% of the period[15]. A number of soil and water conservation measures (SWCM), viz. field bund, ponds, check dams and drainage line treatment measures were taken up in the watershed for soil moisture conservation and controlling run-off and soil loss.

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

Table 1. Energy equivalents for different inputs and outputs

Particular	Unit	Equivalent energy (MJ)
Human labour		
Man	Man-hour	1.96 (ref. 16)
Woman	Woman-hour	1.57 (ref. 16)
Bullocks (body weight 352–450 kg)	Pair-hour	10.10 (ref. 15)
Chemical fertilizer		
Nitrogen	kg	60.60 (ref. 16)
Phosphate (P_2O_5)	kg	11.1 (ref. 15)
Potash (K_2O)	kg	6.7 (ref. 16)
Farmyard manure (FYM)	kg	0.30 (ref. 16)
Machinery	hours	62.70 (ref. 15)
Seed	kg (dry mass)	25.0 (ref. 17)
Output		
Groundnut	kg (dry mass)	25.0 (ref. 17)

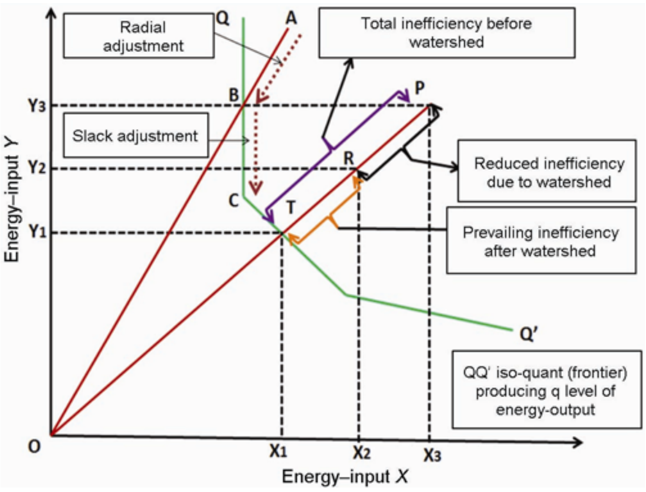

Figure 1. Framework for assessing the impact of watershed on energy efficiency.

Data were collected from groundnut cultivating farmers through face-to-face interviews. Identified outliers and extreme observations were discarded, and finally 137 farm data were used for the study comprising 57 farmers (22, 18 and 15 marginal (<1 ha), small (1–2 ha) and large (>2 ha) farmers respectively) during 2008 (pre-watershed), and 80 farmers (29, 22 and 29 marginal, small and large farmers respectively) during 2013 (post-watershed). Data on inputs (labour, bullock-labour, farm machinery use, seed, fertilizer and farmyard manure (FYM)) and outputs were collected and converted into energy equivalents using energy conversion coefficients[16–18] (Table 1). Besides physical data, farmer-specific information on socio-economic and demographic features was collected.

Figure 1 presents the conceptual framework for working out the technical efficiency. Suppose a farmer is operating at *P* before watershed development, and producing *q* amount of output energy (defined by the frontier QQ') by consuming OX_3 and OY_3 amounts of inputs *X* and *Y* respectively. However, the same level of output can be produced by consuming OX_1 and OY_1 levels of input, if the farmer produces efficiently and operates on any point, say *T*, on the frontier.

Therefore, at point *P*, TE_{pre} (technical efficiency before watershed implementation) with a value Z_1 is defined by eq. (1):

$$TE_{\text{pre}} = \frac{OP}{OT} = Z_1. \qquad (1)$$

In the post-watershed implementation scenario, the same farmer starts operating at point *R*, producing the same level of output (*q*) by consuming OX_2 and OY_2 quantities of inputs *X* and *Y*, respectively. At this point *R*, TE_{post} (technical efficiency post-watershed implementation) can be computed by eq. (2) with a value Z_2.

$$TE_{\text{post}} = \frac{OR}{OT} = Z_2. \qquad (2)$$

Therefore, watershed implementation enabled the farmers to produce the same level of output with lesser amounts of the inputs, consequently increasing efficiency or decreasing inefficiency by $\Delta Z = (Z_2 - Z_1)$.

However, even after implementation of watershed, production inefficiency still exists (indicated by distance between *R* and *T*), and the farmer can further reduce inputs consumption to the tune of X_1X_2 (difference between OX_2 and OX_1) and Y_1Y_2 (difference between OY_2 and OY_1), which in turn could save the input energy for producing the same output level *q*.

DEA is a non-parametric technique of frontier estimation that determines both the relative efficiency of a number of decision-making units and targets for their improvement[19]. It was introduced by Charnes *et al.*[20] in 1978, developing on Farrell's[21] idea of estimating technical efficiency relating to production frontier. Data envelopment analysis allows decision makers to simultaneously consider multiple inputs and outputs, where efficiency of each decision-making unit is compared to that of an ideal operating unit rather than to the average performance. Decision makers can then differentiate between efficient and inefficient decision-making units and address the sources and amount of inefficiency for each of the inefficient ones[22]. In this study, input-oriented DEA was used as it is more reasonable to assume that farmers minimize the use of inputs[23].

Technical efficiency can be calculated by the ratio of sum of weighted outputs to sum of weighted inputs[24]

$$\text{Max } h_k = \frac{\sum_{r=1}^{s} u_{rk} y_{rk}}{\sum_{i=1}^{m} v_{ik} x_{ik}}, \tag{3}$$

subjected to

$$\frac{\sum_{r=1}^{s} u_{rk} y_{rj}}{\sum_{i=1}^{m} v_{ik} x_{ij}} \leq 1; \; j = 1,\ldots,n,$$

$$u_{rk}, v_{ik} \geq 0; \; r = 1,\ldots,s; \; i = 1,\ldots,m,$$

where k is the decision-making unit (groundnut cultivating farmer) being evaluated in the set of $j = 1, 2, \ldots, n$. n the total number of groundnut cultivating famers; h_k the measure of efficiency of the kth groundnut producing farmer in the set of n farmers; y_{rk} the amount of output r produced by the farmer k during the period of observation; y_{rj} the amount of output r produced by the groundnut cultivating farmer j during the observation period; x_{ik} the amount of resource input i used by the groundnut cultivating farmer k; x_{ij} the amount of resource i used by farmer j during the period of observation; u_{rk} the weight assigned to output r computed in the DEA model; v_{ik} the weight assigned to resource input i computed DEA model; m the number of inputs used by farmers, i.e. six in our case, and s is the number of outputs produced by the farmers, i.e. one in our case. The model represented by eq. (4) is known as the CCR model (after Charnes, Cooper and Rhodes). It provides Farrell's input-oriented technical efficiency under the assumption of constant returns to scale. Technical efficiency measure corresponding to constant return to scale assumption represents overall technical efficiency (OTE), which measures inefficiencies due to the input/output configuration as well as the size of operations.

$$\text{Min}_{\theta,\lambda} \theta_i^{\text{CCR}}, \tag{4}$$

subjected to

$$Y\lambda \geq Y_i,$$

$$X\lambda \leq \theta_i^{\text{CCR}} X_i,$$

$$\lambda \geq 0,$$

where θ_i^{CCR} provides the overall technical efficiency score for the ith groundnut cultivating farmer, Y_i and X_i are the output and input vectors of the ith farmer respectively; Y and X represent the amount of output and input matrices for all the n groundnut cultivating farmers; N represents the unit vector, and λ is an $N \times 1$ vector of constants. A groundnut cultivating farmer is considered technically efficient and will lie on the efficiency frontier, if and only if the optimal value of θ_i^{CCR} is equal to one. Any value less than one indicates a relatively inefficient farmer operating below the frontier. However, estimating technical efficiency using constant returns to scale is only suitable when all decision-making units are operating at an optimal scale[25], which in reality is not possible due to factors like financial constraints, imperfect competition, etc. The above model with an additional convexity constraint $N'\lambda = 1$ is known as the BCC model (after Banker, Charnes and Cooper; 1984), which works under the assumption of variable returns to scale. The program DEAP Version 2.1 was used to estimate the efficiency scores. Further, overall technical efficiency scores can be decomposed into pure technical efficiency and scale efficiency (SE). Scale efficiency is a ratio of overall technical efficiency to pure technical efficiency[26]. (If SE = 1, then a farmer is scale-efficient and SE < 1 indicates the presence of scale inefficiency.)

Consider that a farmer is operating at A after the watershed implementation (Figure 1). If he wants to operate at the projected point on the frontier (B), he has to cut down the levels of inputs uses (X and Y) to the point B (iso-quant, the maximum level of output energy which can be produced with given technology). Thus, reduced amount of inputs is called 'radical adjustment' or a reduction in the inputs in proportion to overall inefficiency.

Amount of input ith reduced in the radical adjustment = $(1 - \theta^{\text{CCR}})X_i$.

Further, observed level of energy output can be produced if the farmer operates at point C. Since the movement of the farmer from point B to C is on the frontier (iso-quant), the output energy (q) will remain the same; only the quantity of one of the two inputs, i.e. Y input will reduce. Therefore, there is an opportunity to reduce amount of input Y to the tune of BC while maintaining the same level of X. This type of reduction is known as 'slack adjustment'. The summation of slack and radical adjustment of energy inputs is called the 'total adjustment', representing the total amounts of ith input which should be reduced by a farmer so as to reach his optimal production efficiency. The practical minimum input level is called the target input level for a farmer. Thus, total adjustment needs to be adjusted so as to reach a 'target'

Table 2. Average energy input and output in groundnut production in the pre- and post-watershed scenario (MJ ha^{-1})

Category	Output energy	Human labour	Bullock labour	Farm machinery	Fertilizer	Seed	FYM	Total input energy
Pre-watershed								
Marginal	11,427 (8248)	852 (182)	542 (123)	287 (189)	897 (430)	2097 (289)	535 (295)	5210
Small	12,846 (6260)	972 (167)	874 (199)	285 (176)	951 (191)	2484 (421)	612 (173)	6178
Large	11,336 (5740)	1051 (157)	820 (144)	167 (67)	960 (137)	2243 (288)	541 (144)	5782
Overall	11,762 (6664)	967 (185)	747 (208)	236 (155)	938 (271)	2261 (355)	558 (209)	5707
Post-watershed								
Marginal	18,454 (10,879)	1054 (158)	744 (179)	406 (244)	1392 (528)	2176 (237)	545 (241)	6317
Small	17,639 (8443)	984 (148)	855 (207)	308 (217)	1128 (326)	2270 (336)	670 (151)	6215
Large	15,225 (5191)	976 (194)	826 (201)	214 (92)	1065 (226)	2137 (414)	523 (184)	5741
Overall	16,988 (8257)	1000 (170)	814 (200)	301 (204)	1178 (385)	2196 (345)	582 (200)	6071

Figures in parenthesis are the values of standard deviation.

energy input for the ith input while keeping the output unchanged. For the ith energy input, the total adjustment is nothing but a energy-reduction-target or potential energy saving (Z_i), defined as radical adjustment for ith input + slack adjustment for ith input.

The Tobit model was applied to predict the association of energy efficiency with farmer-specific characteristics[27]. This method was used because of the censored nature of the efficiency scores ranging between 0 and 1. The present study used second-stage regression analysis to model farmer-specific characteristics for explaining efficiency in groundnut production. The Tobit model is expressed as follows:

$$y_k^* = \alpha_0 + \sum_{i=1}^{3} \alpha_i x_{ik} + \sum_{r=1}^{2} \beta_r D_{rk} + \varepsilon_k, \quad (5)$$

where y_k^* is the latent independent variable for the Kth groundnut-cultivating farmer; x_{ik} ($x_{1k}x_{2k}$ and x_{3k}) a vector of independent continuous variables which are assumed to influence efficiency; D_{rk} (D_{1k} and D_{2k}) the binary variable which is also expected to have an impact on the efficiency, α (α_0, α_1, α_2 and α_3) and β (β_1 and β_2) are vectors of unknown parameters associated with independent continuous and binary variables and ε_k is an error term independently identically distributed with zero mean and constant variance IID ~ $N(0, \sigma^2)$.

The latent variable y_k^* can be linked with the observed variable y_k by

$$y_k = y_k^* \text{ if } y_k^* > 0, \text{ and}$$

$$y_k = 0, \text{ otherwise.} \quad (6)$$

The vectors of independent variables x (x_1, x_2 and x_3 are age, family labour and livestock respectively) and D (D_1 and D_2 are own either bullock or tractor and watershed respectively) were used in the model.

Table 2 provides the average values of input energy consumption and output energy production during pre- and post-watershed scenarios. The average output and input energy values in case of pre-watershed scenario were 11762 and 5707 MJ ha^{-1} respectively, whereas after watershed implementation, production of output as well as utilization of input energy increased by 5226 and 364 MJ ha^{-1} respectively. Among different farm categories, maximum output energy (12,486 MJ ha^{-1}) was produced by small farmers in pre-watershed condition and by marginal farmers during post-watershed scenario (18,454 MJ ha^{-1}). Seeds constituted the major share of energy inputs, contributing around 40% and 36% during pre- and post-watershed scenarios respectively. Up to the time of sowing, around 80% of total input energy is consumed in the form of seed, human labour, farm machinery, fertilizer and FYM. In rainfed areas, even one standard deviation decline in mean annual rainfall often leads to complete crop failure[28], and resultant wastage of input energy. Thus, around 80% of total input energy is left to the peril of uncertain rainfall during the rest of the crop growth period. High standard deviation values (Table 2) in both the scenarios indicate wide variations in the quantum of energy inputs used and the output of groundnut. This also indicates disparities among the farmers in input management, implying that energy efficiency can be improved by optimum use of different inputs.

Table 3. Overall, pure and scale efficiency during pre- and post-watershed scenario (%)

	Pre-watershed			Post-watershed		
	OTE	PTE	SE	OTE	PTE	SE
Marginal	51*	72	71	63*	78	81
Small	51	74	68**	61	76	80**
Large	55**	78	67***	68**	81	82***
Overall	53**	75	69**	64**	78	81**

OTE, PTE and SE stand for overall technical efficiency, pure technical efficiency and scale efficiency respectively. ***, ** and * indicate that difference between the average values of efficiencies between pre- and post-watershed scenarios are significant at 2%, 5% and 10% level of significance respectively.

Average values of overall technical efficiency (which reflect the ability of using suitable configuration and level of input uses on efficient scale of farm size), pure technical efficiency (which indicate the ability of managerial skill of farmers) and scale efficiency (which indicates optimum size of a farm) were 53%, 75% and 69%, respectively (Table 3). These low overall technical efficiency scores across the farm categories may be attributed to the adverse conditions (rainfed conditions, varying soil depth, poor fertility and poor soil moisture retention) during the crop period. The value of overall technical efficiency (53%) implies that, on an average, up to 47% of total input energy can be minimized while maintaining status quo with respect to the existing output energy level. This inefficiency (47%) is the combined effect of inappropriate configuration, combination and level of inputs used at scale-inefficient size of operations. Pure technical efficiency reflects the managerial performance and skills of farmers to organize inputs for groundnut production devoid of scale effect. This was estimated as 75%, indicating that 25% output energy can be increased while operating at the observed scale of operation and with the same combination and level of inputs, by merely adopting best management practices and improving the managerial skills of farmers. Overall scale efficiency was 69%, signifying that around 31% of output energy level can be increased with the same level and combination of inputs usage, just by applying them or operating at an optimal scale (scale-efficient area) for groundnut cultivation, thereby ensuring optimum utilization of energy inputs. Lower efficiency for smallholder farmers may be due to higher risk associated with crop failure or poor yield, low investments for enhancing soil fertility, less use of improved crop varieties and other yield enhancing inputs.

In the post-watershed period, overall technical efficiency, pure technical efficiency and scale efficiency increased to the tune of 11%, 3% and 12% compared to pre-watershed scores respectively, which is significant at 5% threshold for overall and scale efficiency (Table 5). Mann–Whitney test results showed that there was a statistically significant difference between the overall technical efficiency and scale efficiency for large farmers at 5% and 2% level of significance respectively, in pre- and post-watershed scenarios. For small and marginal farmers the difference between the mean value of pre- and post-watershed scenarios for scale efficiency and overall technical efficiency was significant at 5% and 10% level of significance respectively. These differences in efficiency can be attributed to increased output, however, with higher uses of inputs under conditions of sustained soil moisture availability during the crop growing period. The lower standard deviation values during post-watershed period suggest a reduction in the output instability. The maximum increment in pure technical efficiency occurred in the case of marginal (6%), followed by large (3%) and small (2%) farmers, whereas maximum increase in scale efficiency was observed for large (15%) followed by small (12) and marginal (10%) farmers.

Energy efficiency can be enhanced by three ways: first, by simultaneously changing the ‘quantum and combination of input uses’ and ‘scale of operation’; second, by merely optimizing the ‘quantum and combination of input uses’ keeping scale of operation the same, and third, only by operating on the ‘optimal scale of operation’ and keeping the uses and combination of inputs as earlier. On an average, energy efficiency can be enhanced by 36%, following the first approach using appropriate package of practices with their timely execution at optimum scale of operation (area under groundnut cultivation). Interestingly, at same scale of operation and merely by improving the managerial skill of farmers, the energy efficiency (input energy saving) can be increased up to 22%. Earlier studies in different parts of the world have also pointed out that there is ample scope for improving energy efficiency in different crops by following recommended practices[29,30–33].

Table 4 gives the total potential for saving input energies in post-watershed scenario. Overall, there is need to cut down input use (as a part of radical adjustment) to the tune of 400 (human labour), 326 (bullock labour), 120 (farm machinery), 471 (fertilizers), 878 (seeds) and 233 (FYM) MJ ha^{-1}; which means that a total of 2843, 2610 and 1952 MJ ha^{-1} input energy can be saved by marginal, small and large farmers, respectively. Even after reaching the frontier, there still exists an opportunity to reduce human labour, bullock labour, farm machinery use, fertilizers, seeds and FYM to the extent of 128, 110, 19, 221,

Table 4. Total potential for energy saving (MJ ha^{-1})

Category	Overall technical inefficiency (%)	Human labour	Bullock labour	Farm machinery	Fertilizer	Seed	FYM	Total
Extent of radical adjustment								
Marginal	45	474	335	183	626	979	245	2843
Small	42	413	359	129	474	953	281	2610
Large	34	332	281	73	362	727	178	1952
Overall	40	400	326	120	471	878	233	2428
Extent of slack adjustment								
Marginal	–	164	48	37	232	250	34	765
Small	–	72	102	26	178	206	29	613
Large	–	161	159	1	257	358	19	955
Overall	–	128	110	19	221	274	27	779
Total potential energy saving								
Marginal	–	638	383	220	858	1229	279	3608
Small	–	485	461	155	652	1159	310	3223
Large	–	493	440	743	619	1085	197	2907
Overall	–	528	436	139	692	1152	260	3207

Table 5. Estimates of parameters determining technical efficiency in the Tobit model

Parameter	Description of variable	Estimate	*t*-value
Intercept		1.420[a]	0.158
Age (X_1)	Number of years	–0.037[a]	0.005
Own either bullock or tractor (D_1)	$D_1 = 1$, if a farmer has either his own bullock or tractor; otherwise it is 0	0.010	0.014
Family labour (X_2)	Number of working person in a family	0.001	0.002
Watershed (D_2)	$D_2 = 1$ for post–watershed; otherwise it is 0	0.058[a]	0.016
Livestock (X_3)	Total number of livestock	0.048[a]	0.002
Sigma		0.047[a]	0.003
log likelihood (full model)		225.19	
log likelihood (reduced model)		–3.47	

LR statistics = 228.66; this is significant at 1% of significance level.
[a]Indicates that coefficients are significant at 1% level of significance.

274 and 27 MJ ha^{-1} respectively, as slack adjustment. Overall, a total of 2428 and 779 MJ ha^{-1} input energy can be saved as radical and slack adjustments respectively, resulting in a total saving of 3207 MJ ha^{-1} without compromising the output energy levels.

Age of farmer had a negative relationship with overall technical efficiency, implying that young farmers were more efficient than older ones; the same was observed by Mondal *et al.*[34], and Abdulai and Eberlin[35]. Younger farmers generally have formal education, and therefore may understand and adopt new practices, which in turn improves their efficiency (Table 5). Although it was expected that ownership of bullock or tractor and higher number of family labour may ensure timely completion of different agronomic practices leading to relatively high energy efficiency, the effect was not significant. Variables like 'implementation of watershed' and 'number of livestock owned' had statistically significant impact on the energy efficiency. Implementation of watershed activities ensured better retention of soil moisture which is critical in rainfed areas receiving low rainfall and where crops experience long dry spells.

The DEA model has been used in the present study to assess the impact of soil and water conservation measures on energy efficiency. Among the different farm categories analysed, larger farmers are relatively more efficient than small and marginal farmers. Watershed implementation enhances the value of overall technical efficiency, pure technical efficiency and scale efficiency by 11%, 3% and 12% respectively, over the pre-watershed scenario. However, even after the watershed implementation, there is room for saving input energy to the tune of 3207 MJ ha^{-1} in groundnut production without compromising on output energy levels. Results pertaining to determinants of efficiency show that 'implementation of watershed activities', 'age of the farmers' and 'ownership of livestock' have a positive bearing on the overall energy efficiency. In terms of policy implications, especially in the face of predicted climate change in rainfed areas, the results suggest that there is a need to promote watershed development activities for environmentally sustainable agriculture.

1. Pimentel, D. *et al.*, Achieving a secure energy future: environmental and economic issues. *Ecol. Econ*., 1994, **9**(3), 201–219.
2. Tabatabaeefar, A., Emamzadeh, H., Varnamkhasti, M. G., Rahimizadeh, R. and Karimi, M., Comparison of energy of tillage systems in wheat production. *Energy*, 2009, **34**(1), 41–45.
3. Dyer, J. A. and Desjardins, R. L., Carbon dioxide emissions associated with the manufacturing of tractors and farm machinery in Canada. *Biosyst. Eng.*, 2006, **93**(1), 107–118.
4. Rahman, S. and Rahman, M. S., Energy productivity and efficiency of maize accounting for the choice of growing season and environmental factors: an empirical analysis from Bangladesh. *Energy*, 2013, **49**(1), 329–336.
5. Lal, R., Carbon emission from farm operations. *Environ. Int.*, 2004, **30**(7), 981–990.
6. Ozkan, B., Fert, C. and Karadeniz, C. F., Energy and cost analysis for greenhouse and open-field grape production. *Energy*, 2007, **32**(8), 1500–1504.
7. Mulwa, R., Emrouznejad, A. and Muhammad, L., Economic efficiency of smallholder maize producers in western Kenya: a DEA meta-frontier analysis. *Int. J. Oper. Res*., 2009, **4**(3), 250–267.
8. Nassiri, S. M. and Singh, S., Study on energy use efficiency for paddy crop using data envelopment analysis (DEA) technique. *Appl. Energy*, 2009, **86**(7), 1320–1325.
9. Mandal, K. G., Saha, K. P., Hati, K. M., Singh, V. V., Misra, A. K., Ghosh, P. K. and Bandyopadhyay, K. K., Cropping systems of central India: an energy and economic analysis. *J. Sustain. Agric*., 2005, **25**(3), 117–140.
10. Singh, K. P., Prakash, V., Srinivas, K. and Srivastva, A. K., Effect of tillage management on energy-use efficiency and economics of soybean (*Glycine max*) based cropping systems under the rainfed conditions in North-West Himalayan Region. *Soil Tillage Res.*, 2008, **100**(1), 78–82.
11. 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**(16), 2275–2286.
12. Singh, H., Singh, A. K., Kushwaha, H. L. and Singh, A., Energy consumption pattern of wheat production in India. *Energy*, 2007, **32**(10), 1848–1854.
13. Joshi, P. K., Jha, A. K., Wani, S. P., Joshi, L. and Shiyani, R. L., Meta-analysis to assess impact of watershed program and people's participation. Research Report 8, International Water Management Institute (IWMI), Colombo, Sri Lanka, 2005.
14. MoA, Agricultural Statistics at a Glance 2012, Directorate of Economics and Statistics, Ministry of Agriculture, Government of India. 2012.
15. Mondal, B., Loganandhan, N. and Raizada, A., Meteorological drought and coping strategies by small and marginal farmers in semi-arid Karnataka. *Indian J. Soil Conserv*., 2014, **42**(1), 54–61.
16. Devasenapathy, P., Senthilkumar, G. and Shanmugam, P. M., Energy management in crop production. *Indian J. Agron.*, 2009, **54**(1), 80–89.
17. Ghosh, P. K., Mohanty, M., Bandyopadhyay, K. K., Painuli, D. K. and Misra, A. K., Growth, competition, yield advantage and economics in soybean/pigeonpea intercropping system in semi-arid tropics of India: I. Effect of sub soiling. *Field Crops Res.*, 2006, **96**(1), 80–89.
18. Kitani, O., Jungbluth, T., Peart, R. M. and Ramdani, A., *CIGR Handbook of Agricultural Engineering, Vol. V: Energy and Biomass Engineering*, American Society of Agricultural Engineers, 1999.
19. Malana, N. M. and Malano, H. M., Benchmarking productive efficiency of selected wheat areas in Pakistan and India using data envelopment analysis. *Irrig. Drain*., 2006, **55**(4), 383–394.
20. Charnes, A., Cooper, W. W. and Rhodes, E., Measuring the efficiency of decision making units. *Eur. J. Oper. Res*., 1978, **2**(6), 429–444.
21. Farrell, M. J., The measurement of productive efficiency. *J. R. Stat. Soc., Series A*, 1957, **120**, 253–290.
22. Angulo-Meza, L. and Lins, M. P. E., Review of methods for increasing discrimination in data envelopment analysis. *Ann. Oper. Res.*, 2002, **116**(1–4), 225–242.
23. Thanh Nguyen, T., Hoang, V. N. and Seo, B., Cost and environmental efficiency of rice farms in South Korea. *Agric. Econ*., 2012, **43**(4), 369–378.
24. Heidari, M. D., Omid, M. and Mohammadi, A., Measuring productive efficiency of horticultural greenhouses in Iran: a data envelopment analysis approach. *Expert Syst. Appl*., 2012, **39**(1), 1040–1045.
25. Coelli, T. J., Rao, D. S. P., O'Donnell, C. J. and Battese, G. E., An Introduction to Efficiency and Productivity Analysis, Springer, 2005.
26. Sarıca, K. and Or, I., Efficiency assessment of Turkish power plants using data envelopment analysis. *Energy*, 2007, **32**(8), 1484–1499.
27. Thanassoulis, E., *Introduction to the Theory and Application of Data Envelopment Analysis*, Kluwer, Dordrecht, 2001.
28. Rockström, J. and Falkenmark, M., Semiarid crop production from a hydrological perspective: gap between potential and actual yields. *Crit. Rev. Plant Sci*., 2000, **19**(4), 319–346.
29. Chauhan, N. S., Mohapatra, P. K. and Pandey, K. P., Improving energy productivity in paddy production through benchmarking – an application of data envelopment analysis. *Energy Convers. Manage*., 2006, **47**(9), 1063–1085.
30. Singh, G., Singh, S. and Singh, J., Optimization of energy inputs for wheat crop in Punjab. *Energy Convers. Manage.*, 2004, **45**(3), 453–465.
31. Sidhu, H. S., Singh, S., Singh, T. and Ahuja, S. S., Optimization of energy usage in different crop production system. *Agric. Eng.*, 2004, **85**, 2071–1050.
32. Khoshnevisan, B., Rafiee, S., Omid, M. and Mousazadeh, H., Reduction of CO_2 emission by improving energy use efficiency of greenhouse cucumber production using DEA approach. *Energy*, 2013, **55**, 676–682.
33. Rahman, S. and Hasan, M. K., Energy productivity and efficiency of wheat farming in Bangladesh. *Energy*, 2014, **66**, 107–114.
34. Mondal, B., Singh, A. and Jha, G. K., Impact of watershed development programmes on farm-specific technical efficiency: a Study in Bundelkhand Region of Madhya Pradesh. *Agric. Econ. Res. Rev.*, 2012, **25**(2), 299–308.
35. Abdulai, A. and Eberlin, R., Technical efficiency during economic reform in Nicaragua: evidence from farm household survey data. *Econ. Syst*., 2001, **25(**2), 113–125.

ACKNOWLEDGEMENTS. We thank Technology Development, Extension and Training (TDET), Ministry of Rural Development, Government of India for financial support and our technical staff K. Channabasappa, K. K. Reddy, W. Muralidhar, P. Mohan Kumar, K. S. Rao and B. N. Sheshadari for help. We also thank the anonymous reviewers for their valuable suggestions that helped improve the manuscript.

Received 26 September 2014; revised accepted 8 July 2015

doi: 10.18520/v109/i10/1831-1837