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Energy and economic efficiency of wheat production using different irrigation supply methods

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Abstract

Energy inputs are being used increasingly in Pakistan to boost agricultural production and are resulting in a transition from traditional to more energy-oriented agricultural production systems. In assessing the form of this transition and the trend that is likely to continue in the near future, it is imperative to know the present use of energy in agricultural production in order to formulate rational policy. The objective of the research was to provide an energy and economic efficiency analysis of wheat production in the Balochistan province of Pakistan using gravity and lift irrigation with diesel and electric energy. The applied inputs evaluated were farms irrigated with canal water, farms irrigated with electric motor driven pumps and the farms using diesel engine to pump the irrigation water. The sources of energy inputs included the human labour, FYM, chemical fertilizer, electrical or diesel pumps used for irrigation and tractor. The results indicate that irrigation using an electric motor and diesel engine is inefficient in term of energy consumption and economic returns at the farm level compared with canal irrigation. Consequently, the benefit cost ratios of the diesel and electric engine lift irrigation were also relatively small when compared with the canal irrigation.

Key words: Wheat, energy use efficiency, commercial and non-commercial energy, renewable and non-renewable energy

Introduction

Farmers in developed countries produce almost four times more food for each hour of work than farmers in under developed countries. The contributing factors in this achievement are effective use of energy inputs: particularly improved irrigation systems, judicious use of fertilizers and pesticides and efficient use of farm machinery. For example, with total energy use of 7205 MJ ha^{-1}, Croke (1979) obtained the grain yield of 5 t ha^{-1} in irrigated agriculture with 425 mm of rainfall at Northern Victoria (Australia). This was almost 3 times the yields obtained in Pakistan in 1991-92 in irrigated areas with traditional production methods using 6282 to 8889 MJ ha^{-1} (Khan and Singh, 1996). However, with increased availability of water and higher use of commercial energy, Pakistan could manage to get the average yield of 2.6 tons per hectare in 2004-05 (Economic Survey of Pakistan, 2005-06).

In achieving the goal of higher agricultural production, irrigation played a dominant role, as it provided 90% of the total wheat production demand of Pakistan and almost 100% of cotton, sugarcane, rice, fruit and vegetables. The irrigated area has increased from 9 million hectares in 1947 to above 18 million hectares in 2004-05. That is a major factor in increasing total agriculture productivity. Expending irrigation water supply allowed an increase in cropping intensity of 60% in 1947 to above 120% in 2003 and lead to a 4-fold increase in production compared to 1947 level (Economic Survey of Pakistan, 2005-06; Agricultural Statistics of Pakistan, 2005-06). In 1953-54, total irrigated area by all sources was 9.65 million hectares, of which only 0.2 million hectares of the total irrigated area was under tubewell irrigation system. However, in 2004-05, this ground water dependent irrigated area increased to 3.48 million hectares i.e. 18.53% of the total irrigated area. This is in excess of canal and tube well irrigated area, which did not exist in 1953-54 but in 2004-05, it comprised 7.50 million hectares. The cost of the pumped water from water courses to grow wheat is over two times the cost of wheat grown using the canal water. Therefore, profitability of wheat production using the pumped water is a serious concern. Moreover, non-renewable energy used by these pump operators is a scarce commodity of Pakistan, so its utilization requires higher consideration.

The agriculture sector in the province of Balochistan (in Pakistan) receives very little attention in general planning. The area is rich in physical resources that can be efficiently utilized through integrated planning. The development of a sound irrigation and improved agricultural mechanization system in the area under an integrated project would go a long way toward improving the economic condition of the society, and play a vital role in the overall development of this province. Much could be achieved if a systems approach is adopted for planning water and agriculture management. Most important is the assessment of alternative forms of energy which can reduce production costs and result in overall increase in agricultural

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productivity. This approach involves a comprehensive assessment of the local situation, available energy sources, skills, and needs.

In this study, the economic and energy use efficiency for the production of wheat production is investigated based on input data from farm surveys in Balochistan. Different economic parameters (net return and benefit-cost ratio) and energy parameters (net energy yield, energy use efficiency with different water application sources) are calculated and compared with respect to their suitability to allow a proper assessment of alternative options. In addition, Cob Douglas energy production functions were applied to determine different factors affecting yields.

Thus, this study was conducted to find out relationship between energy input and energy output, under three modes of irrigations, for wheat production in Qilla Abdullah District in Balochistan Province. Furthermore, this study sought to develop and estimate an energy production model for the crop production. The modelling exercise was aimed at exploring the relationship between energy inputs and yield providing energy input elasticities on yield. The study was also intended to find out the gross margin and net return of farms using three different irrigation sources in wheat production.

Materials and Methods

Study area

The study was conducted at Messazai and Pir Alizai villages of Qilla Abdullah District of Balochistan Province, Pakistan (Figure 1). The population of Qilla Abdullah district was estimated to be over 400,000 in the year 2005. The area is bounded by the lower edge of Sulaiman range (an extension of the Himalayas) extending over a major portion of the north-west part of the area. Quetta (capital of Balochistan) lies on east side of the study area. Northern part joins similar arid areas of Pashin. This area has an arid with sub-tropical continental climate. The mean annual rainfall ranges from 150 to 200 mm. The rainfall pattern is erratic and uncertain. About 60% of the rainfall occurs in Monsoon season (July and August) usually in the form of intense showers causing floods. July is the hottest month with a mean maximum temperature of 30 °C. January is the coldest month with a mean minimum temperature of 5 °C. The source of water is three underground channels called Kareze in local dialect and a seasonal watercourse with planned flows of almost 200 to 700 cubic meters per hours (2 to 7 cusecs). Public as well as private tube wells are also installed in the area. The Government of Pakistan charges electricity on subsidized rate of Rupees (Rs) 2.30 per kilowatt hours.

After travelling extensively in the District and consulting authorities in the departments of Agriculture, Irrigation and Revenue, 37 farms in the mentioned area were randomly selected to represent the district. The data were collected from each of the farmers and the information included: the number of family members engaged in farming operations, the number of permanent hired labourers, the number of plots and their size.

For each crop-plot, information was collected about the energy inputs from various sources including human labour, electric motors or diesel engines and tractors used to perform the agricultural operations.

Energy analysis

The inputs and outputs used in wheat production were converted to energy units to carry out the output-input analysis. The conversion was based on ratios available in the literature (Mandal *et al*., 2002; Yilmaz *et al*., 2005; Hatirli *et al*., 2006; Selim *et al*., 2006). These energy equivalents of input used in wheat production is given in Table 1. The inputs of energy were classified into direct and indirect, renewable and non-renewable and commercial and non-commercial energy form (Hatirli *et al*., 2006; Thakur and Makam, 1997).

The direct energy consists of human power, tractor and electric motor, while indirect energy includes seed, fertilizer (Chemical and Farm Yard Manure - FYM) used in production process. Similarly, renewable energy consists of human labour, FYM and canal water, while non-renewable consists of diesel, electricity and chemical fertilizer.

In addition, the energy inputs were also classified as commercial and non-commercial energy inputs on the basis of comparative economic values. Commercial energy generally purchased on cash terms, and no component of it is produced on the farm. It includes electricity, diesel, fertilizer and other agro-chemicals, machinery and the seed of high yielding varieties (HYV). Non-Commercial energy is generally available to farmers and includes human labour, animals, FYM and home grown seeds. Generally farmers do not pay cash for it. However, in monetary terms every form of energy has its cash value and may be purchased as well as sold in the village itself.

The following procedures of energy conversion were adopted:

Human labour

The human power (man-hours) was converted into energy inputs by multiplying the number of man hours and estimated power rating (0.54 kW h) of human labour (Khan and Singh, 1996).

Electric motors

The output of electric motor was calculated by the product of rated power of the electric motor, time consumed in operation and load factor. The load factor was equal to actual electricity consumed (read from energy meter) during operation over electricity consumed at rated power.

$$E_C = F_C * T_C * \text{Load factor} \quad (1)$$

Where E_c = Energy output of the machine (kWh)

F_c = Energy consumption of the machine on energy meter (kWh hr^{-1})

T_c = Time consumed in operation (hr)

$$\text{Load factor} = \frac{\text{Actual electricity consumed}}{\text{Electricity consumed at rated power}} \quad (2)$$

Diesel engines and tractors

The output of tractor and diesel engine was calculated by the product of fuel consumed by tractor or diesel engine, time consumed in operation, caloric value of the fuel and load factor. The Load factor was equal to actual fuel consumption over fuel consumed at rated power. In Pakistan, the caloric value of the fuel has been calculated by Enercon (1990).

$$E_C = F_C * T_C * C_V * \text{Loadfactor} \quad (3)$$

Where E_c = Energy output of the Machine (kW h)

F_c = Fuel consumption of the Machine (l hr^{-1})

T_c = Time consumed in operation (hr)

C_v = Caloric value of the fuel (kW h l^{-1})

$$\text{Load factor} = \frac{\text{Actual fuel consumed}}{\text{Fuel consumed at rated power}} \quad (4)$$

Seed, fertilizer, chemicals and farm yard manure

The seeds, chemical fertilizers, FYM and other chemicals used in crop production were transformed to energy equivalent by multiplying the quantity of the material used in the plots with the energy value of each material given in Table (1) to find out its energy value for the crop (Khan and Singh, 1996).

In this study, output-input ratio of energy, specific energy and energy productivity for wheat production were also calculated using the following equations suggested by Hatirli *et al*. (2006).

$$1.\ \text{Energy Ratio} = \frac{\text{Total Energy Output(kWh)}}{\text{Total Energy Input(kWh)}} \quad (5)$$

$$2.\ \text{Specific Energy} = \frac{\text{Total Energy Input(kWh)}}{\text{Ouput of Grain yield (kg)}} \quad (6)$$

$$3.\ \text{Energy productivity} = \frac{\text{Grain Yield (kg)}}{\text{Energy Input (kWh)}} \quad (7)$$

A total energy input is the sum of all individual energy inputs in accordance with their energy values and quantity used to grow crop. These inputs include human energy, tractor energy, energy through fertilizer, chemicals, seed, farm yard manure and irrigation (with canal or pumped (either with electric motor or diesel engine)). Similarly, a total energy output includes the energy obtained from grain and its by-product i.e. straw.

Economic analysis

Net economic returns from wheat production were calculated to estimate the economic efficiency of wheat production under different water supply systems. The net economic return of wheat crop was calculated as gross returns minus the cost of all variable inputs, which include the cost of irrigation, seed, fertilizer, chemical and labour etc. However, we did not include the cost of family labour while calculating the net returns from the crops.

Price estimates and model assumption

Prices highly influence investment calculation. Most often market prices are directly chosen after harvest, but they tend to be either very high or too low, and thus do not reflect the average price received by the farmers. In case of more periodic analysis, the best bases for calculation consist of empirical prices and yield information to allow comparison. Since this type of data often rarely available thus, average farm gate prices will be reasonable substitute. In the analysis, all stochastic variables such as yield, price, etc. represented in the model were used by their mean values. The distribution of prices and yields was assumed to be stationary. The price estimates and assumptions for various input and output are as follows:

- Regarding charges on human labour, it was observed that three types of labour were used by the farmers for all agricultural operations of various crops. These were family labour, permanently hired labour and casually hired labour. The prevailing market rate of 8 hours work in normal times was Rs. 100.00 in the village.
- The hourly rates for the use of diesel engines to power irrigation pumps depends upon the electricity or fuel (diesel) consumed. The charges for the use of electricity to run electric motors to power irrigation pumps were Rs. 2.26 per kWh and the rate of diesel was Rs 15 per litre.
- The hiring charges of tractors (average size of 37 kW) varied from operation to operation. In the case of ploughing, these charges were Rs. 150 per hour and for threshing it was Rs. 250 per hour.
- A common seed rate of wheat was 100 kg ha^{-1} in the district. Though the price of one kg of wheat seed varied

from Rs 10.50 to 12.00, however, an average value of Rs. 11.00 was commonly observed in the study area and so is used to compute the cost of seed.

- The costs of fertilizers applied were almost similar through out the district. Two types of chemical fertilizers were commonly used on the farms; Nitrogenous fertilizer (Urea) and Di Ammonium Phosphate (DAP).
- Gross value of output includes the value of crops (wheat) and by-products (wheat straw). Value of the wheat crop was computed using an average market price (farm gate price) of Rs. 7000 per ton which the farmers received during 2003-04.
- The quantity of straw was calculated from the grain yield. For every ton of grain there was 1.25 ton of straw. An average price of 1.25 tons of straw obtained from a ton of wheat grain was Rs. 1250.

Empirical model

The Cobb-Douglas model has been used by many researchers to examine the relationship between energy inputs and production or yield (Yilmaz *et al*., 2005; Singh *et al*., 1998; Singh *et al*., 2002). To analyse the relationship between energy inputs and yield, several structural forms of Cobb-Douglas production function was tried. Among all, linear-logarithmic model showed better estimates in terms of statistical significance and expected signs of parameters. The Cobb-Douglas model is expressed as:

$$Y = \int(x)\exp(u) \quad (8)$$

The model can further be expressed in the following terms.

$$\ln Y_i = \alpha + \sum_{j=1}^{n} \beta_j \ln(X_{ij}) + e_i \quad i = 1, 2, \ldots n \quad (9)$$

where Y_i denote the yield level of the ith farmer, X_{ij} is the vector of inputs used in the production process, α is the constant term, β_j represents the coefficients of inputs which are estimated from the mode and e_i is the error term.

Equation 9 is further expanded in accordance with the assumption that the yield is the function of energy inputs including human labour hours (Lbr), tractor hours (Tr), chemical fertilizers (Fert), farm yard manure (FYM), seed, and irrigation (Irri). Equation 9 can be written in the following empirical form;

$$\ln Y_i = \alpha + \beta_1 \ln(\text{Lbrhr}) + \beta_2 \ln(\text{Tr}) + \beta_3 \ln(\text{Fert}) + \beta_4 \ln(\text{FYM}) + \beta_5 \ln(\text{Seed}) + \beta_6 \ln(\text{Irri}) + e \quad (10)$$

The data were processed in a Microsoft Excel spreadsheet.

Results and Discussion

Energy efficiency

The energy consumption for wheat crop under canal irrigation is given in Table 2. Energy sources are calculated as direct-indirect, renewable-non-renewable and commercial non-commercial forms. It is clear from the table that among all energy inputs used for growing wheat, the energy share of nitrogenous fertilizer (urea) remained the maximum (61.41%). It was followed by seed of high yielding varieties (HYV).

Urea is high energy consuming material and its use has been increasing with time (Economic Survey of Pakistan, 2005-06). Stout (1990) reported that the first 15-30 kg ha^{-1} of nitrogen fertilizer brings an increased yield of 10-15 kg ha^{-1} of grain per kg of nitrogen, after which the response slowly declines. Moreover, use of non-renewable energy use like chemical fertilizer to boost the yield is non-sustainable for healthy long term agriculture.

The other factor which showed a significant effect on yield was diesel energy, which was used to move tractors. Table 2 also showed that the dominant roll of indirect, non-renewable and commercial energy over direct, renewable and non-commercial energy. This is also mostly due to high energy consumption through chemical fertilizer and diesel energy, which falls under the category of direct, non-renewable and commercial energy.

Overall energy input-output ratio i.e. Energy Use Efficiency (EUE) remained 6.28. It is high compared to farms at Dera Ismail Khan (D.I. Khan), Pakistan, (Khan and Singh, 2006), where it was only 3.6. The main reason was low energy output with low energy input in the mentioned study of D.I. Khan. Among all energy inputs, the highest energy consumption was through fertilizer (74.9%), however, this energy input through fertilizer was 2100 kWh per hectare, whereas in this study the input through fertilizer was 2793 kWh per hectare. In the D.I. Khan, the total energy inputs remained only 2805 kWh, whereas in this study total energy input was 4206 kWh per hectare.

Comparing the energy consumption by all energy inputs in case of irrigation with electric motor driven pumps (Table 3), it was observed that on these farms maximum energy consumption was through electric motor (45%). Because of high electricity consumption due to high depth of water in the area, electric motor consumed more than 3000 kWh, which was almost 45% of the total energy consumption among all energy inputs.

Table 1. Energy equivalent of inputs and output in agricultural production in Pakistan

Input (Unit)	Units	Energy Equivalent			
Human power	Man-hrs	1.96	MJ	0.54	kWh
Diesel (includes cost of lubricants)	litter	56.31	MJ	15.64	kWh
Machinery					
(a) Electric Motor	hr	64.80	MJ	18.00	kWh
(b) Farm Machinery	hr	62.70	MJ	17.42	kWh
Chemical fertilizers					
(a) Nitrogen	kg	60.60	MJ	16.83	kWh
(b) Di-ammonium Phosphate (DAP)	kg	11.10	MJ	3.08	kWh
(c) Potash	kg	6.70	MJ	1.86	kWh
Farm Yard Manure (FYM) (Dry matters)	kg	0.25	MJ	0.07	kWh
Electricity	kWh	3.60	MJ	1.00	kWh
Seed & Output (wheat)	kg	14.70	MJ	4.08	kWh
Straw (wheat)	kg	12.50	MJ	3.47	kWh

Table 2. Energy inputs and output and output-input ratio in wheat production with canal irrigation (per ha)

Input (unit)	Quantity used	Total energy equivalent (kWh)	%	Cost of energy input (Rs.)	%
Fertilizer (kg)	417.06	2793.89	66.43	2041.32	30.21
Urea (kg)	153.47	2582.96	61.41	1074.31	15.90
DAP (kg)	63.95	196.96	4.68	767.37	11.36
FYM (kg)	199.64	13.97	0.33	199.64	2.95
Machinery (h)	9.52	165.79	3.94	1665.50	24.65
Human (hr)	269.41	269.41	6.41	779.53	11.54
Diesel (l)	38.07	446.54	10.62	574.77	8.51
Seed (kg)	126.52	516.21	12.27	1391.74	20.59
Irrigation (man-hours)	26.07	14.19	0.34	304.97	4.51
Total Input (kWh ha^{-1})		4206.03	100.00	6757.83	100.00
Yield (grain) (kg ha^{-1})	3136.22	12795.78	48.47	23521.66	92.31
Yield (Straw) (kg ha^{-1})	3920.28	13603.36	51.53	1960.14	7.69
Total Output		26399.14	100.00	25481.80	100.00
Direct Energy		895.93	21.30		
Indirect Energy		3310.10	78.70		
Renewable Energy		297.57	7.07		
Non-Renewable Energy		3908.46	92.93		
Commercial Energy		3908.46	92.93		
No-Commercial Energy		297.57	7.07		
Energy Use Efficiency (kWhkW h^{-1})		6.28			
Specific Energy (kWh kg^{-1})		8.42			
Energy Productivity (kg kW h^{-1})		0.75			
Cost of Production (Rs. ha^{-1})				6757.83	
Gross Return (Rs. ha^{-1})				25481.80	
Net Return (Rs. ha^{-1})				18723.97	
Benefit : Cost Ratio				3.77	

The data also shows that due to high use of electric motor, the EUE decreased to 3.46, which is low compared to EUE of the plots with canal irrigation system where it was 6.28. In canal irrigated plots, total energy input was 4206 kWh per hectare, but in this case, it increased to 7622 kWh per hectare. As high energy input could not increase the output with same ratio, the EUE decreased on plots that had high energy inputs. The EUE is still high compared to a similar study conducted by Khan and Singh (1996). In their study, the energy in irrigation included the energy by electric motor as well as energy by diesel pump. However, the main difference was, as explained before, low energy output from low energy input.

Mandal *et al.* (2002) observed 60% energy consumption through fertilizer and FYM in India on farms with electric motor driven pumps. In their study, the energy consumption compared to this study is quite low. This is because the motors used in India are only 3 hp and used only for 3 irrigations. In this study, on an average 5 irrigations were applied with 10 hp motor, as the area in Balochistan is mostly arid to semi-arid. Thakur and Makan (1997) observed 56% of the total energy was through motor driven pump. This supports the study of Balochistan, which indicates that if the energy consumption is through electric motor then that dominates the other energies consumptions.

In case of farms where the source of irrigation was diesel engine driven pump (Table 4), farms used higher energy compared to the farms of other two categories and the major factor was high energy consumption through diesel engine used for pumping motor (68%). The diesel used for tractor operation was calculated separately and on these farms its share remained only 3%. Diesel engines are comparatively less energy efficient compared to electric motors driven pumps, yet the number is increasing in Pakistan with every passing year (Qurashi *et al*., 2003). The common reasons for preferring diesel pump include low installation cost of diesel pump, continuous access (no power cut off), and suitability for fragmented land (mobility of diesel engine) (Qurashi *et al*., 2003). EUE is the lowest (1.99) in this system of irrigation compared to other two systems of irrigation for wheat production in Balochistan. The main reason is high use of diesel energy for pumping. The higher input with lower output decreased the EUE.

Direct-Indirect, Renewable-Non-renewable, commercial and Non-commercial energy was also calculated for this systems of irrigations. Like the plots with electric motors, the roll of direct energy, non-renewable energy and commercial energy remained dominant over the indirect, renewable, commercial energy. The results show that the share of direct energy input was only 21% in canal irrigated farms where as it was 57% in electric motor driven pump system of irrigation. In the diesel engine driven pump system, it was 75%, compared to indirect energy where it was only 25%. Direct energy consists of human labour, tractor energy and the diesel. Use of diesel boosted the energy values on these farms.

Similarly non-renewable energy consumption was also quite high in all the three categories of farms compared to use of renewable energy. The same trend was observed in commercial energy inputs. Agriculture in this area depends mostly on commercial energy input. This dependency will increase with the change of irrigation system from canal to

Table 3. Energy inputs and output and output-input ratio in wheat production with electric motor driven pump irrigation system (per ha)

Input (unit)	Quantity used	Total energy equivalent (kWh)	%	Cost of energy (Rs.)	%
Fertilizer (kg)	417.06	2793.89	36.65	2041.32	13.84
Urea (kg)	153.47	2582.96	33.89	1074.31	7.28
DAP (kg)	63.95	196.96	2.58	767.37	5.20
FYM (kg)	199.64	13.97	0.18	199.64	1.35
Machinery (h)	9.52	165.79	2.18	1665.50	11.29
Human (hr)	269.41	269.41	3.53	779.53	5.28
Diesel (l)	38.07	446.54	5.86	574.77	3.90
Seed (kg)	126.52	516.21	6.77	1391.74	9.43
Irrigation (man-hours)	26.07	14.19	0.19	304.97	2.07
Electric Motor (kWh)	3416.43	3416.43	44.82	7994.03	54.19
Total Input (kWh ha^{-1})		7622.46	100.00	14751.87	100.00
Yield (grain) (kg ha^{-1})	3136.22	12795.78	48.47	23521.66	92.31
Yield (Straw) (kg ha^{-1})	3920.28	13603.36	51.53	1960.14	7.69
Total Output		26399.14	100.00	25481.80	100.00
Direct Energy		4312.37	56.57		
Indirect Energy		3310.10	43.43		
Renewable Energy		297.57	3.90		
Non-Renewable Energy		7324.89	96.10		
Commercial Energy		7324.89	96.10		
Non-Commercial Energy		297.57	3.90		
Energy Use Efficiency (kWhkW h^{-1})		3.46			
Specific Energy (kWh kg^{-1})		8.42			
Energy Productivity (kgkW h^{-1})		0.41			
Cost of Production (Rs. ha^{-1})				14751.87	
Gross Return (Rs. ha^{-1})				25481.80	
Net Return (Rs. ha^{-1})				10729.93	
Benefit : Cost Ratio				1.73	

electric motor driven pump and further to diesel engine powered pumps and consequently the province will depend only on the availability of petroleum products to run these pumps.

Economic efficiency

Economic efficiency is the indicator for a farmer to decide what to grow and how to grow. The total cost of production, gross return, net return and benefit-cost ratios of the three mentioned categories of farms (Table 2-4) shows that the benefit-cost ratio is at maximum on the farms with canal irrigation system (3.77). These farmers spent less on irrigation. Due to this reason, their total cost of production remained less than Rs. 7000 per hectare. On the other hand, the farms with electric motors and diesel engines had to pay heavy amount on irrigation i.e. Rs. 8000 and Rs. 9000 per hectare, respectively. However, even with high costs of irrigation, the benefit-cost ratios of the two categories of farms were high i.e. 1.73 and 1.62.

Table 4. Energy inputs and output and output-input ratio in wheat production with diesel engine driven pump irrigation system (per ha)

Input (unit)	Quantity used	Total energy equivalent (kWh)	%	Cost of energy (Rs.)	%
Fertilizer (kg)	417.06	2793.89	21.02	2041.32	12.95
Urea (kg)	153.47	2582.96	19.43	1074.31	6.81
DAP (kg)	63.95	196.96	1.48	767.37	4.87
FYM (kg)	199.64	13.97	0.11	199.64	1.27
Machinery (h)	9.52	165.79	1.25	1665.50	10.57
Human (hr)	269.41	269.41	2.03	779.53	4.94
Diesel (l)	38.07	446.54	3.36	574.77	3.65
Seed (kg)	126.52	516.21	3.88	1391.74	8.83
Irrigation (man-hours)	26.07	14.19	0.11	304.97	1.93
Diesel Engine (l)	580.09	9086.84	68.36	9006.35	57.13
Total Input (kWh ha^{-1})		13292.87	100.00	15764.19	100.00
Yield (grain) (kg ha^{-1})	3136.22	12795.78	48.47	23521.66	92.31
Yield (Straw) (kg ha^{-1})	3920.28	13603.36	51.53	1960.14	7.69
Total Output		26399.14	100.00	25481.80	100.00
Direct Energy		9982.77	75.10		
Indirect Energy		3310.10	24.90		
Renewable Energy		297.57	2.24		
Non-Renewable Energy		12995.29	97.76		
Commercial Energy		12995.29	97.76		
Non-Commercial Energy		297.57	2.24		
Energy Use Efficiency (kWhkW h^{-1})		1.99			
Specific Energy (kWh kg^{-1})		8.42			
Energy Productivity (kgkW h^{-1})		0.24			
Cost of Production (Rs. ha^{-1})				15764.19	
Gross Return (Rs. ha^{-1})				25481.80	
Gross Margin (Rs. ha^{-1})				9717.61	
Benefit : Cost Ratio				1.62	

Table 5. Results of econometric estimation with different sources of irrigation

Variables	Canal Irrigation			Irrigation with Electric Motor			Irrigation with Diesel Engine		
	Coeff.	E	P-value	Coeff.	SE	P-value	Coeff.	SE	P-value
Intercept	4.079**	0.495	0.000	2.169**	0.346	0.000	1.732**	0.465	0.001
Tractor	0.005	0.046	0.913	0.034	0.040	0.405	0.034	0.040	0.403
Seed energy	0.424**	0.107	0.000	0.121	0.152	0.435	0.120	0.152	0.435
Urea	0.163**	0.056	0.007	0.289**	0.051	0.000	0.289**	0.051	0.000
DAP	0.0002	0.005	0.966	0.002	0.004	0.607	0.002	0.004	0.606
Man-hrs	0.158*	0.080	0.057	0.096	0.077	0.220	0.096	0.077	0.220
FYM	0.010**	0.003	0.003	0.011**	0.003	0.000	0.012**	0.003	0.000
Irrigation	0.242*	0.120	0.053	0.448**	0.136	0.003	0.448**	0.135	0.003
F value	375.61**			454.57**			454.50**		
R^2	0.989			0.991			0.991		
Adjusted R^2	0.986			0.989			0.989		
Number of observations	37			37			37		

Regression analysis

Regression results for equation 3 for various sources of irrigation, (Table 5) shows that F values of all the three models were found significant at $P < 0.01$, which indicate that models were overall significant. The adjusted R^2 values for all the three sources of irrigation were 0.98. The values of adjusted R^2 such as 0.98 imply that 98% of the variation in the yield was explained by the variables included in the model. The coefficients estimated in the model were in accordance with the *a priori* expected signs.

The elasticity is particularly useful for determining the relationship between energy input and yield. Since the logarithmic form of Cobb-Douglas model was used in the estimation, the coefficient of variability in log form also represents elasticity. On the plots where the source of irrigation was via canal, high yielding seed varieties were found to be the most important variable that influenced the yield among all the variables included in the model. The elasticity for seed energy is 0.42, implying that given 1% change in seed energy will result 0.42% increase in yield. However, this source of energy did not show the same impact when the modes of irrigation changed. The role of seed energy remained non-significant in the other two modes of irrigation systems.

The second important input found was energy consumption in irrigation with elasticity of 0.24 in canal irrigation system; this variable remained important for the other two modes of irrigation systems. Energy input by nitrogenous fertilizer (urea) also had a significant effect on the yield of wheat; its impact remained significant in all the three modes of irrigations. Human energy played an important role in canal irrigated plots only. Phosphate fertilizers could not show their significant importance on yield. This indicates that the area is self sufficient in phosphoric matter.

Conclusions

The study conducted to ascertain the effects of energy inputs on yield indicates that irrigation with electric motor and diesel engine as compared with canal irrigation are quite inefficient in term of energy consumption and economic

Figure 1. Study area, Qilla Abdullah, Balochistan, Pakistan

returns at the farm level. The energy efficiency of the canal irrigated wheat is twice that of the lift irrigated wheat using electric and diesel motors.

Regression analysis shows that the role of seed energy is non-significant in the diesel and electric lift irrigation systems. The energy consumption in irrigation with elasticity of 0.24 in canal irrigation system; this variable also remained important for the other two modes of irrigation systems. Energy input by nitrogenous fertilizer (urea) also had a significant effect on the yield of wheat; its impact remained significant in all the three modes of irrigations.

Irrigation with electric motor or diesel engine driven pump increase the cost of irrigation by around 200% from that of canal irrigation system. A two-fold increase in cost of production of a farm certainly justifies the capital investment required for the improvement of hill torrent (Rod-Kohi) irrigation system in the area.

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