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ENERGY AND ECONOMIC EFFICIENCY ANALYSIS OF RICE AND COTTON PRODUCTION IN CHINA

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ABSTRACT

Energy is a key factor in boosting crop yield for rapidly growing world population. Plan to conserve energy for future generations without threatening the food supply, requires a comprehensive analysis of energy inputs and outputs as a result. A study was conducted in 2002-03 to ascertain the effects of different parameters of energy inputs on biomass production of rice and cotton in Liuyuankou Irrigation System, Henan province of China. The contribution of direct energy, including human, pumping and tractor, was 30% and 14% of the total energy required to grow rice and cotton crops respectively. Pumping energy alone was 13% and 1% of the total energy required for growing rice and cotton crops respectively. Fertilizer was another major component of indirect energy inputs for both of these crops accounting for 76% and 63% for cotton and rice, respectively. The comparison of Chinese farms with Turkish and Indian farms showed that the fertilizer applied on Chinese farms was significantly higher than Turkish and Indian farms. Moreover, fertilizer application in Turkey boosted the yield significantly. The fertilizer application on Indian farms was too low to impact on yield. However, it improved energy efficiency. The overall energy efficiency, energy productivity, water productivity and combined energy and water productivity were lower for cotton crop. The net return was higher for cotton because of its higher price in the market.

Key Words: Rice, Cotton, Energy, Economic, China

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INTRODUCTION

Chinese agriculture is heavily dependent on energy inputs mainly from fossil fuels. Agriculture can be treated as an energy conversion process such as the conversion of solar energy through the photosynthetic process to produce food for human and feed for livestocks. Ancient agriculture was less energy intensive and included spreading seeds on the land and accepting any yield as a result. However, today's agriculture is very energy intensive and aims at targeted outputs (Stout, 1990). The cost of energy has been increasing faster than other inputs over the past decades (Energy Information Administration 2007). The agricultural production system is characterised by the intensive use of inorganic fertilizers, pesticides and irrigation. These inputs are heavily dependent on fossil fuels. The global dynamics of fossil fuel costs have significantly affected the input costs of crop production and will be one of the major factors affecting profitability in future (Weinheimer and Johnson, 2008).

Planning to conserve energy and water for feeding the growing world population requires a comprehensive analysis of energy-water usage in agriculture. Energy auditing is one of the common and reliable approaches to examine energy use efficiency and its impact on the fossil fuel reserves. Moreover, energy auditing provides enough information to understand the dynamics of energy input and its influence on biomass production.

China, one of the developing countries with a population of 1.25 billion, strongly needs energy for its economic development, rational utilization of natural resources and protection of environment. A study was undertaken on rice and cotton, two of the important summer crops in China. Rice is the staple food of more than half of the world's population. Similarly cotton plays a major role in the economy of many Asian countries including China. The output-input relationship of bio-energy of these two important crops has rarely been analyzed in China. In other parts of the world, researchers mostly limited their research to estimate the energy or water requirements only (Thakur and Makan, 1997; Mandal *et al.*, 2002; Canakci *et al*., 2005; Hatirli *et al.*, 2005). Very little efforts have been made to explore the relationship of energy–water nexus and the yield. Therefore, the information on energy-water input and its impact on biomass production can be useful for farmers, researchers and planners for making informed decisions when choosing different alternatives. This paper also analyzes the economics of rice and cotton crops in China. Cob Douglas energy production functions (Hatirli *et al*., 2005) were developed and applied to determine different factors affecting crop yields.

Study Area and Sample Size

Study Area

The study was conducted at Liuyuankou Irrigation System (LIS) in Kaifeng County, Henen Province, in North West China (Fig. 1). It is part of the Hui Ji River system (Huai He River basin). Surface and ground water are two of the key sources of irrigation water in LIS (Loeve *et al*., 2002). The river bed is above the ground surface making it is easier to divert water from river to crop fields. However, due to higher seepage losses from sandy canals overlying the permeable aquifers, surface water is not available for the entire study area. In the low land, crops are generally irrigated with groundwater. Seepage from irrigated field in upper part of the system is an important source of recharge to lower basin with groundwater level varying from 3 to 30 meter. In addition, without enough lateral recharge from the Yellow river to lowland groundwater, the groundwater table has been falling in groundwater-dependent areas. This has increased the cost of groundwater extraction on and some cases resulted in withdrawal of water beyond its sustainable limits (Khan *et al*., 2007).

Total Area and Land Use

Out of total command area of LIS of 40,724 hectares, 30,900 hectares are the cultivated area. With cropping intensity of about 1.43, total cropped area reported in 2000-01 was approximately 44,124 hectares. Rice, cotton, maize and soybean are major summer crops of the area. Crops on northern part are mainly irrigated with water from the Yellow River. However, due to unavailability of surface water on southern part, the main sources of irrigation are bore water and seepage from irrigation canals. In addition, some areas are irrigated by the combination of surface and groundwater sources.

MATERIALS AND METHODS

Sample Size and Data Collection

After an extensive survey and consultation with the Department of Agriculture and Irrigation, 35 rice and 14 cotton farms were randomly selected to represent the study area. The data collected included the number of family members engaged in farming operations, the number of permanently hired labourers and the number of plots and their sizes. For each crop-plot, information was collected on water and energy inputs from various sources including human labour, electric motors or diesel engines and tractors used on farms for growing these crops.

Energy Analysis

Energy Coefficient for Various Sources of Energy

Each agricultural input has its own energy values and energy is invested to produce individual component. These individual energy inputs may be in the form of food/feed, machinery and fuel etc. Energy coefficients were obtained from Thakur and Makan (1997) taking into account all forms of energy in the production system.

Analysis of energy coefficients (of rice and cotton) were based on energy equivalents available in the literature (Mandal *et al.,* 2002; Canakci *et al*., 2005; Hatirli *et al.,* 2005). The energy values used in this study are the dietary energy values of agricultural outputs obtained from fossil energy spent to grow these crops (Bonny, 1993).

The energy inputs can also be classified into direct - indirect, renewable- non-renewable and commercial-non-commercial energy forms (Thakur and Makan, 1997, Mandal *et al*., 2002). The direct energy consists of human power, tractor and electric motor. While the total energy is the combination of direct energy and indirect energy from seed of high yielding varieties, fertilizers and chemicals used in crop production processes. The renewable energy component consists of human labour, farm yard manure (FYM), and irrigation water, while non-renewable energy consists of diesel, electricity, fertilizers and chemicals.

Energy inputs are also classified as commercial and non-commercial on the basis of their comparative economic values. Commercial energy is generally purchased on cash terms, and no component of it is produced on the farm. It includes electricity, diesel, fertilizers, chemicals, machinery and the seed. Non-commercial energy includes human labour, animals, farm yard manure 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 or sold (Thakur and Makan, 1997). In addition, Cob Douglas energy production functions were applied to determine different factors affecting crop yields.

Energy Conversion

For this study, 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 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 is equal to actual electricity consumed (read from energy meter) during operation over electricity consumed at rated power (Khan and Singh, 1996)

$$E_c = F_c * T_c * Load \;\; factor \qquad (1)$$

Where E_c = Energy output of the machine (kWh)
F_c = Energy consumption of the machine on energy meter (kWh/hr)
T_c = Time consumed in operation (hr)

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

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 spent, caloric value of the fuel and load factor. The Load factor is the ratio of actual fuel consumed and fuel consumed at rated power (Khan and Singh, 1996).

$$E_c = F_c * T_c * C_v * Load\ factor \qquad (3)$$

Where E_c = Energy output of the Machine (kWh)
F_c = Fuel consumption of the Machine (l/hr)
T_c = Time consumed in operation (hr)
C_v = Caloric value of the fuel (kWh/l)

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

Seed, Fertilizer, Agro-Chemicals and Farm Yard Manure

The materials such as seed, chemical fertilizers, FYM and other agro-chemicals used in crop production were transformed into energy equivalent by multiplying the quantity of the material used in the plots with the energy value of each material (Khan and Singh, 1996).

Energy Efficiency, Specific Energy, Energy and Water Productivity

In this study, energy efficiency, specific energy, energy productivity, water productivity and combined water and energy productivity for rice and cotton production were calculated using the following equations.

$$Energy\ Efficiency = \frac{Total\ energy\ output\ (kWh)}{Energy\ input\ (kWh)} \qquad (5)$$

$$Specific\ energy = \frac{Amount\ of\ energy\ applied\ (kWh)}{Grain\ yield\ (kg)} \qquad (7)$$

$$Energy\ \ productivity = \frac{Grain\ yield\ (kg)}{Energy\ input\ (kWh)} \qquad (6)$$

$$Water\ \ productivity = \frac{Grain\ yield\ (kg)}{Amount\ of\ water\ applied\ (m^3)} \qquad (8)$$

$$Combined\ water-energy\ productivity = \frac{Grain\ yield\ (kg)}{Amount\ of\ water\ applied\ (m^3)\ and\ energy\ input\ (kWh)} \quad (9)$$

Crop Profitability

The net economic returns by growing rice and cotton crops were calculated to estimate the economic efficiency of each cropping system. The net economic returns of both of these crops were calculated as gross returns minus the costs associated with variable inputs including irrigation, seed, fertilizers, chemicals, and labour etc. The cost of family labour was considered equal to the cost of permanently hired labour. Casually hired labour was employed during the peak periods for specific operations like transplanting, of rice or picking of cotton. Payment to casually hired labour was made either in kind or cash or both. Whatever the mode of payment, the entire cost of this labour component was estimated and allocated to each farm.

Price Estimates and Model Assumption

Prices highly influenced investment calculation. Most often market prices are directly chosen after harvest, but they tend to be either too high or too low, and thus do not reflect the average price received by the farmers. For more periodic analysis, the calculations are normally based on empirical prices and yield information for comparison. This sort of information is normally unavailable; the average farm gate prices can be a reasonable substitute. The mean values of all stochastic variables such as yield, price, etc. were used for data analysis. The distribution of prices and yields were assumed to be stationary. The price estimates for various inputs and outputs are as follows:

i. Human labour: the prevailing market rate of 8 hours work was 30 to 40 Yuan (1US$ = 8.2 Yuan in 2005).
ii. The hourly rates for running electric motors or diesel engines to operate irrigation pumps depend on the electricity or fuel (diesel, oil etc) consumed. The electricity charges to run electric motors for operating irrigation pumps were 0.81 Yuan/kWh and the cost of diesel was 2.80 Yuan/litre in 2005.
iii. The commonly used tractor power in the area ranged from 11 kWh to 18kWh.
iv. The hiring charges of tractors varied from operation to operation and the implements used for any particular operation. For example, the charges for rotary plough, seeders and reapers were 375, 150 and 450 Yuan/ha, respectively.
v. Seed rates were 64 kg/ha and 49 kg/ha for rice and cotton respectively in the study area. The price of seed varied from 2.40 to 5.00 Yuan per kg for rice and 28 to 30 Yuan per kg for cotton in the study area.
vi. Fifteen types of fertilizers and agro-chemicals were applied by these farmers. The costs of fertilizers and agro-chemicals varied depending on the type of fertilizers and agro-chemicals used in the district.
vii. Gross value of output included the value of crops and the by-products (rice straw). The values of the crops were 2,500 Yuan per ton and 10,000 Yuan per ton for rice and cotton respectively based on an average market price (farm gate price). The quantity of rice straw was estimated from the yield data. On an average, for every ton of rice grain yield there was approximately 1.25 tons of straw. The market value of rice straw was 100 Yuan/ton.

Empirical Productivity Functions

The Cobb-Douglas model is used extensively for examining the relationship between energy inputs and production or yield (Hatirli *et al.,* 2005, Selim *et al.,* 2006, Singh *et al.,* 1998). Several structural forms of Cobb-Douglas production function are used for assessing the relationship between energy inputs and crop yield. Among all, linear-logarithmic model showed better estimates in terms of statistical significance and expected signs of parameters. The Cobb-Douglas model can be expressed mathematically as follows:

$$\ln Y_i = \alpha + \sum_{j=1}^{n} \beta_j \ln(X_{ij}) + E_i \quad i = 1, 2, ..n \quad (10)$$

Where Y_i denote the yield level of the i^{th} farmer, X_{ij} is the vector of inputs used in the production process, α is a constant, β_j represents the coefficients of inputs which are estimated from the mode and E_i is the error term for farm.

Equation 10 is further expanded in accordance with the assumption that the yield (energy output) is a function of energy inputs including human labour hours (Lbr), tractor hours (Tr), amount of fertilizers (Fert), amount of agro-chemicals (Chem.), seed energy, and irrigation energy (Irri). Equation 10 can therefore be rewritten in the following empirical form;

$$\ln Y_i = \alpha + \beta_1 \ln(Lbr\,hr) + \beta_2 \ln(Tr) + \beta_3 \ln(Fert) + \beta_4 \ln(Chem) + \beta_5 \ln(Seed) + \beta_6 \ln(Irri) + E \qquad (11)$$

The data describing above equation were processed in a Microsoft Excel spreadsheet.

RESULTS AND DISCUSSION

Direct Energy Inputs

The physical energy inputs for cotton and rice crops contain human, pumping and tractor energy. These energy inputs are given for different operations required to grow rice and cotton crops in Tables I and II. When comparing the energy inputs, the total energy input of human labour was higher on cotton farms (298.21 kWh/ha) as compared to rice farms (145.02 kWh/ha). The land preparation and sowing operations required less, human energy on rice farms than cotton farms. These operations were mainly performed by the farmers themselves with very limited use of tractors.

Table I. ***Per hectare direct energy inputs for various agricultural operations for the production of cotton (based on data of 14 farms)***

Operations		Direct energy inputs, kWh/ha			
		Human	Pumping	Tractor	Total
Land preparation and sowing		298.21	-	230.56	528.78
Irrigation	Canal	1.82	-	-	1.82
	Pump	41.83	91.40	-	133.23
Irrigation related activities		289.72	-	-	289.72
Fertilizer application		71.60	-	-	71.60
Chemical application		52.79	-	-	52.79
Harvesting threshing and cleaning, etc.		283.96	-	-	283.96
Total direct energy		1039.92	91.4	230.56	1361.89

Majority of the cotton farms were irrigated with canal water. Although human energy required for application of irrigation water was small but the other operation such as canal maintenance was heavily labour dependent. Cotton picking was another operation heavily reliant on human labour. On rice farms, seedbed preparation, pulling, bundling and transplanting of nursery were labour intensive operations (Table II).

Table II. ***Direct energy inputs for various agricultural operations for the production of rice in China (based on data of 35 farms)***

Operations		Direct energy inputs, kWh/ha			
		Human	Pumping	Tractor	Total
Land preparation and sowing		145.02	-	623.56	768.58
Pulling and bundling		126.83	-	-	126.83
Transplanting		108.69	-	-	108.69
Irrigation	Canal	65.29	-	-	65.29
	Pump	54.59	1300.62	-	1355.21
Hand weeding		54.58	-	-	54.58
Fertilizer application		19.54	-	-	19.54
Chemical application		73.59	-	-	73.59
Harvesting threshing and cleaning, etc.		333.59	-	-	333.59
Total direct energy input		981.72	1300.62	623.56	2905.89

The human energy consumptions for growing cotton crop in Turkey and India were 316 kWh/ha and 635 kWh/ha respectively. The human energy requirements in both of these countries are comparatively lower than China (1040 kWh/ha) (Table III). Smaller land holding in China may be one of the reasons for higher human labour requirements. Most of the farmers were dependent on their small land holding. They preferred to work themselves rather than doing it by machinery. The fuel and tractor energy requirements were comparatively lower in China (231 kWh/ha) mainly because of smaller tractor size (11.19 – 17.90 kWh) and minimal usage of tractors for growing crops. The machinery energy consumption for growing cotton crops in Turkey and India were 1865 kWh/ha and 830 kWh/ha respectively (Table III).

Table III. ***Comparative energy inputs (kWh/ha) of cotton production systems in China, India and Turkey***

Energy sources	China*	India	Turkey
Human	1040	635	316
Irrigation pumps	91	1509	1418
Fuel for Machines	231	830	1865
Seed	325	44	433
Fertilizers	7215	1742	4916
Chemicals	633	396	350
Others	0	233	394
Total input	9534	5389	9692
Yield (kg/ha)	1994	1553.5	3105
Energy efficiency (kWh/kWh)	1.51	7.00	4.80
Specific energy (kWh/kg)	4.78	3.47	3.12
Energy productivity (kg/kWh)	0.21	0.29	0.32

* The present study
** Singh *et al.,* 1998
*** Canakci *et al.,* 2005

The pumping energy requirement for rice was comparatively higher than cotton, primarily due to higher irrigation water requirements for growing a rice crop (Table I). Pumping energy requirements in China are higher than Australian paddy fields (Croke, 1979). In the Murrumbidgee Irrigation Area (MIA) of Australia, the irrigation energy is 1250 kWh/ha for paddy rice as compared to China (1420 kWh/ha). In Australia, irrigation water flow is mainly because of gravity from canal system. Therefore, the water use energy was calculated by estimating the energy consumed in the construction of head works, water storage and channels for conveyance of water. These energy requirements were 300MJ per 1000 m^3 of irrigation water in MIA. The irrigation water requirement for growing a rice crop in Australia is much higher (15000 m^3/ha) than China (3417 m^3/ha).

The irrigation energy requirements for growing a cotton crop in Turkey and India were 1418 kWh/ha and 1509 kWh/ha respectively (Table III). The irrigation energy requirements for growing cotton crops in China are much smaller (91 kWh/ha) than Turkey and India mainly because of the use of canal irrigation water which requires mainly human energy. However, the authors did not mention the amount of water applied in Turkey or India.

Total Energy Inputs

The trend of total energy input per hectare was similar to the direct energy input (Table IV). Total enery inputs (Direct and Indirect energy inputs, including seed, fertilizers and chemicals) used during the growing season for rice crop was higher (9774 kWh/ha) than cotton crop (9534 kWh/ha). The higher energy requirements for both of these crops were mainly because of higher doses of chemical fertilizers applied (76% for cotton and 63% for rice), which is a non-renewable commercial form of energy.

The use of urea, a high energy consuming material has been increasing over time globally (Stout, 1990). The increase in fossil energy usage in agriculture can create some serious environmental problems such as global warming through CO_2 emissions and degrading water quality (Hatirli *et. al.,* 2005). Moreover, the increasing use of non-renewable energy such as chemical fertilizers to boost crop yield is not sustainable in longer term.

A very small portion of total energy inputs (11%) for growing cotton crop in China was from renewable sources (Table IV). The commercial energy (non-renewable sources) accounted for almost 90% of the total energy inputs to grow cotton in China. Similar trend of renewable energy inputs was observed for rice crop as well (Table IV).

Table IV. ***Total energy inputs (kWh/ha) for cotton and rice production in the study area***

Heads	Cotton	Rice
Human labour	1040	982
Pumping energy	91	1301
Tractor energy	231	624
Total physical energy	1362	2906
Seed	325	432
Fertilizers	7215	6118
Chemicals	633	318
Renewable energy	1040	982
Non-renewable energy	8494	8792
Commercial energy	8598	8890
Non-commercial energy	936	884
Total energy inputs	9534	9774

Crop Productivity

The average yield of rice crop across the study area was 6.6 tons/ha (Table V). It is quite low as compared to Australian farms, 7.5 tons/ha (Croke, 1979). In the MIA of Australia, agriculture is heavily mechanised with a single crop system in majority of the area contributed to higher yields.

Total cotton yield in China was much lower (1994 kg/ha) than Turkey (>3000 kg/ha) (Table III). The main reasons could be high energy input in land preparation and better weed control in Turkey. The fuel energy for land preparation was 1865 kWh/ha in Turkey as compared to 231 kWh/ha in China where land is prepared mainly by the human labour (Table III).

Temporal agricultural operations are very important and one should not be misled by the average values of energy usage on annual, monthly or weekly basis. Sowing or planting dates involve yield penalties when not carried out on time. Seedbed preparation must be done within a proper range of soil moisture. Irrigation, intercultural operations, weed control, fertilizers applications and all other production practices should be done on time. The farmers should be prepared to organise the necessary resources before hand to avoid serious yield penalties for not doing the jobs on time. Consumption of fertilizer energy in Turkey was lower (4916 kWh/ha) than China (7215 kWh/ha) (Table III). Higher doses of fertilizers may be responsible for lower yields in China. Stout (1990) stated that the first 15-30 kg/ha of Nitrogen fertilizer increases the yield by up to 10–15 kg/ha of grain per kg of Nitrogen used. The yield response declines slowly with any additional increase in its application. Chang *et al.* (2003) reported that wastage of energy is common in China.

Energy Efficiency

Energy efficiency was higher for rice crop (2.75) as compared to cotton crop (1.51) (Table V). The overall energy input-output ratio for cotton crop in China was lower than Turkey (4.8) (Table III). However, the total energy inputs in China were higher than India (5389 kWh/ha). The application of fertilizer higher than recommended rates in China may be contributing to lower yields. In India, a combination of animal power and human labour were used for land preparation. The energy inputs of fertilizer and farm yard manure were 1742 kWh/ha in India. The cotton yield (1553 kg/ha) in India was lower than China mainly because of suboptimal fertilizer application. The Indian agriculture is comparatively low energy intensive and plays important role in increasing energy efficiency to 7.00 (Table III).

Specific Energy

Specific energy shows the amount of energy spent to produce a unit of marketable product (kWh/kg). It was much higher (4.78 kWh/kg) for cotton than rice (1.49 kWh/kg) (Table V). Results of this study indicated that cotton farms used three times more energy to produce one kg of the marketable product in China. The specific energy requirements in China were higher than Turkey (3.12 kWh/kg) and India (3.47 kWh/kg) (Table III).

Energy Productivity

Energy productivity is the term used to estimate the yield of marketable product received on per unit of energy consumed (kg/kWh). Energy productivity was higher on rice farms (0.67) as compared to cotton farms (0.21) (Table V). The energy productivity was higher in Turkey (0.32 kg/kWh) and India (0.29 kg/kWh) than China (Table III). In another study, Yilmaz *et al.* (2005) reported energy productivity in Turkey as 0.216

kg/kWh which is close to that observed in present study in China (0.210 kg/kWh). This shows that energy productivity varies from region to region.

Water Productivity

Water productivity was 0.80 kg/m^3 and 1.92 kg/m^3 for cotton and rice farms respectively in China (Table V). Water productivity observed on cotton farms in Turkey is 0.46 kg/m^3 (Yilmaz *et al.,* 2005). The water productivity observed on Australian rice farms in MIA is 0.50 kg/m^3 (Croke, 1979).

Energy-Water Productivity

The data was analyzed to see the combined effects of energy and water productivity. The energy and water productivity of rice was higher (0.197g/m^3-kWh) than cotton (0.083g/m^3-kWh). It shows that rice crop is more efficient in terms of both energy and water use (Table V).

Table V. ***Analysis of energy inputs and outputs, energy and water use efficiencies for cotton and rice crops in the study area***

Variables	Cotton	Rice
Total energy input , kWh/ha	9534	9774
Water use , m^3/ha	2505	3417
Total energy output, kWh/ha	14394	26830
Yield , kg/ha	1994	6576
Energy efficiency, kWh/kWh	1.51	2.75
Specific energy, kWh/kg	4.78	1.49
Energy productivity, kg/kWh	0.21	0.67
Water productivity, kg/m^3	0.80	1.92
Energy-water productivity, g/m^3-kWh	0.083	0.197

Crop Profitability

Crop profitability is one of the indicators for a farmer to decide about which crop to grow and the energy inputs for growing that specific crop. Table VI shows the cost of production, gross return, net return and benefit-cost ratios of two crops grown in the study. The benefit-cost ratio was higher for growing cotton (2.07) than rice (1.68). The cotton crop was also higher in value than rice crop and cotton growers paid less for irrigation. The human labour chargers were higher for cotton crop and the hired labour accounted for 9 to 11 percent of the total labour requirements. About 90% of the labour requirements were met by the farmers' families and were not paid in cash. Practically, the family labour on cotton farms with canal irrigation system received the maximum return per hour due to higher market rates of the crop output.

On an average each cotton grower earned 19,936 Yuan/ha as compared to rice growers receiving 17, 262 Yuan/ha. The higher costs of pump irrigation (1211 on rice farms compared to 607 Yuan/ha on cotton farms) contributed to lower return for rice growers. Total irrigation cost of 1755 Yuan /ha comprised of pump and canal irrigation on rice farms as compared Yuan 620/ha on cotton farms (Table VI).

Table VI. ***Cost of production (Yuan/ha) of the two crops in the study area***

Cost variables		Cotton	Rice
Land preparation, seed & sowing		2240	1028
Interculture/Transplant etc.		872	2640
Irrigation	Farms with canal irrigation	13	544
	Farms with pump irrigation	607	1211
Irrigation related activities and hand weeding		2146	455
Fertilizer & fertilizer application		1008	804
Chemical & chemical application		625	819
Harvesting, threshing and cleaning		2103	2780
Cost of production		9613	10282
Gross return		19936	17262
Net return		10323	6981
Benefit:cost ratio		2.07	1.68

Table VII. ***Results of econometric estimation of energy inputs for the two crops with different sources of irrigation***

Variables	Rice		Cotton	
	Coefficient	P-Value	Coefficient	P-Value
Constant	4.11^{***}	0.000	2.380^{***}	0.000
Seed	0.41^{***}	0.002	0.408^{*}	0.070
Tractor	0.42^{**}	0.039	0.214	0.120
Diesel	0.40^{***}	0.002	0.230^{*}	0.085
Fertilisers	0.35^{***}	0.000	0.459^{*}	0.090
Chemicals	0.04	0.506	0.109^{***}	0.007
Labour	-0.07	0.526	0.473	0.743
Irrigation source[a]	0.40^{*}	0.090	-0.12	0.280
F value	49.46^{***}	0.000	23.260^{***}	0.000
R^2	0.96		0.83	
Adjusted R^2	0.92		0.780	
Number of observations	35		14	

***, ** and * indicate the significance at 1, 5, and 10 percent probability levels, respectively.
Dummy variable for irrigation source: 0 for gravity irrigation and 1 for pumping groundwater

Regression Analysis

Cobb-Douglas energy production functions were employed to determine the significance of energy inputs to energy output. The energy inputs variables shown in equation 11 included in this analysis are labour hours, tractor hours, fertilizers quantities, chemicals, seed, and irrigation water. The results of regression models are presented in Table VII. According to these results, the role of all energy variables was significant which is obvious from the values of F (in all cases value of $P < 0.01$). The value of R^2 was 0.83 and 0.96 for cotton and rice crops respectively. 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 inputs and crop yield. Since the logarithmic form of Cobb-Douglas model was used in the estimation, the coefficient of variability in log form also represented elasticity.

The regression results on rice farms showed that seed energy, tractor use, diesel energy and fertilizer energy were the important inputs and significantly affected the yield measured in term of output energies. The chemicals used and labour inputs have no significant effects on rice yield. The coefficient of seed energy (0.41) was found significant at $P <0.01$, which implies that a 10% increase in seed energy will result in 4.1% increase in rice yield (out put energy). The dummy coefficient of irrigation sources (0.40) was also found significant at $P <0.1$, which indicates that changing from gravity irrigation system to pump irrigation system will increase the rice output energy by 0.4%.

The regression results on cotton farms were similar to that of rice farms. The coefficient of seed, diesel, fertilizer and chemical energy showed significant influence on cotton yield. The coefficient of seed energy (0.408), diesel (0.230), fertilizer (0.459) were significant at $P <0.10$; whereas, the chemical energy (0.109) was found significant at $P <0.01$. The significant coefficient of chemical energy implies that given 10% increase in chemical energy will result in 1.09% increase in cotton yield (output energy). The dummy coefficient of source of irrigation (-0.12) was not significant. Therefore, changing from surface to pump irrigation will not have any major impact on cotton output energies. It will rather decrease cotton yield marginally by 0.12%.

CONCLUSION

The study was conducted to ascertain the effects of different energy parameters on cotton and rice yields. The results indicated that fertilizer was the major energy inputs in China. However, this energy input did not boost the yield accordingly. In certain cases, the over application of fertilizer has negative effects on crop yield. In Turkey, the yield was comparatively higher even at fertilizer inputs lower than Chinese farms. In India, both the yield and energy inputs were much lower than China. Therefore, even with low yield, the energy efficiency was higher in India. These results indicated that fertiliser application in China could be reduced without compromising on the yield. However, Indian farms have the potential to increase the yield by increasing the fertiliser inputs which will boost energy efficiency. In China both the cotton and rice farms were heavily dependent on human labour mainly because of the smaller size of the farms. However, lesser use of tractor energy may have contributed to low productivity. The energy productivity was lower on cotton farms as compared to rice farms. However, the profitability was higher than rice farms mainly due to higher cost of cotton. Regression analysis showed that seed, diesel and fertilizer energies have significant effects on crop yields. Land preparation and weed management may play a dominant role in boosting the yield.

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