ANALYSIS OF ENERGY INPUTS AND OUTPUTS IN PAKISTAN AGRICULTURE – PART II

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ABSTRACT

This study investigated the pattern of energy consumption and its relationship with crop production in Pakistan from 1981-82 to 2005-06. Output was a function of physical, seed and fertilizer energies in this study. Whereas physical energy included human labour, animal power, electricity, petroleum and tractor manufacturing and repair energy. The total physical energy increased from 7 GJ/ha in 1981-82 to 10 GJ/ha in 2005-06. The total energy (physical +seed + fertilizer) also increased from 14 GJ/ha in 1981-82 to 23 GJ/ha in 2005-06. Although, energy efficiency ratio fluctuated with overall marginal decrease during this period, these results revealed that fertilizer and seed energy in general and nitrogenous fertilizer energy in particular contributed significantly to output.

INTRODUCTION

In most of the developing countries such as Pakistan, agriculture is transforming from conventional (low energy input) to mechanized (high energy input) agricultural production systems. These methods include assured irrigation, use of chemical fertilizer and plant protection chemicals, high yielding varieties, and higher use of farm machinery and related equipment.

Since evaluation of Maxi-Pak (the first non-traditional high yielding wheat variety cultivated in Pakistan), the country experienced a very rapid technological change in its agriculture. Efforts were made to bring the cropped area under assured irrigation. As a result, the irrigated area increased from 9.25 million hectare in 1950-51 to 19.02 in 2005-06 (Agricultural Statistics of Pakistan, 2005-06; Economic Survey of Pakistan, 2005-06). Fertilizer application also increased with assured irrigation from 14 thousand nutrient tonnes per hectare in 1954-55 to 2,508 thousand nutrient tonnes per hectare in 2003-04. Most of the irrigated area came under high yielding varieties of crops which responded well to irrigation and fertilizer. Farming system changed from conventional to partially or fully mechanized system. This change in production system brought a visible change in energy use pattern as result.

Agricultural mechanization primarily depends on fossil fuel, which is a key part of chemical fertilizer, and petroleum products. Unfortunately, the fossil fuel is scarce commodity of the country. However, their availability and usage are important factors in improving the productivity of an agricultural system. Therefore, its conservation and replacement need to be in a very systematic fashion. Any change in production methods intended to achieve this goal without compromising on output or imposing any significant economic burden on the farmers. This can be achieved when a comprehensive picture of energy demand and consumption in agriculture is available to policy makers.

Although a few studies of energy use pattern in Pakistan has been carried out but these were mostly for a specific area or a specific crop (Khan, 1994; Khan and Singh, 1996; Khan and Singh, 1997). However, studies mostly in developed countries have been conducted (Croke, 1979; Bonny, 1993; Hatirli *et al*., 2005; Canakci *et al*., 2005) which cannot be used as such for estimating the future energy demand of Pakistan because of different economic and ecological regions.

In another study (Analysis of Energy Input and Output in Pakistan Agriculture), investigation was mainly focussed on the energy use at the aggregate level in Pakistan agriculture. This study determined determining energy use of 13 crops in Pakistan over a 25 years period from 1981 to 2006. The current study is the extension of previous study in terms of modelling energy usage for different energy sources.

The main objective of this study is to examine the energy use pattern for 13 major food commodities for the same period. Furthermore, this study aims to explore the relationship between energy inputs and outputs using various functional forms. This energy model will be useful for researchers and policy makers for using various energy resources efficiently and effectively with minimum impact on our environment.

MATERIAL AND METHODS

The data used in the study is based on annual data for the period 1981-82 to 2005-06, primarily obtained from

Agricultural Statistics of Pakistan (1990-91, 1998-99, 2005-06) and Economic Survey of Pakistan (1995-96, 2002-03). However, the other sources like Pakistan Energy Yearbook (2003) and FAO Statistical Database (2006) were also consulted for data collection. Methodology adopted in Part I of this was strictly followed for calculation of energy equivalent, energy inputs and outputs of all energy sources.

It is well a known fact that crop yield is a function of various energy inputs. It is not possible to consider all the variables for developing this model. Therefore, only those energy inputs were used in this model that can be controlled by the farmers and have signification effect on crop yield.

The Cobb-Douglas model has been used by many authors to establish the relationship between energy inputs and crop production or yield (Singh *et al.*, 1998; Singh *et al.*, 2002; Yilmaz *et al.*, 2005). To analyse the relationship between energy inputs and yield, linear-logarithmic model of Cobb-Douglas production function showed better estimates in terms of statistical significance. The Cobb-Douglas model is generally expressed as:

$$Y = \int (x)\exp(u) \qquad (1)$$

This model can also be expressed in the following terms.

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

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.

Equation 2 is further expanded further after assuming that the yield is the function of various energy inputs including human labour (Lbr), animal power (Ani) chemical fertilizers (Fert), seed, electricity (Elec), diesel (Diesel), tractor manufacturing and repair (Tra). Equation 2 can be written in the following empirical form after using the above stated parameters;

$\ln y_i = \alpha + \beta_1 \ln(Lbr) + \beta_2 \ln(Ani) + \beta_3 Ln(Fert) + \beta_4 \ln(Seed) + \beta_5 \ln(Elec) + \beta_6 \ln(Diesel) + \beta_7 \ln(Tra) + e$ (3)

Microsoft Excel spreadsheet was used to process the data.

RESULTS AND DISCUSSION

Table 1 shows annual energy consumption in agriculture for the period 1981-82 to 2005-06. The total physical energy used in agriculture increased gradually from 107 × 10^{15} J in 1981-82 to 185 × 10^{15} J in 2005-06.

This total physical energy consumption was approximately 42% higher in 2005-06 than that in1981-82.

There has also been a continuous increase in human labour usage in agriculture. However, the usage of animal power in agriculture has been declining throughout the study period. The animal power has been replaced with tractors and other machinery. It was observed that the number of tractors manufactured/assembled have gradually increased. It was noted that the energy associated with usage, repair and maintenance of tractors has increased during this period.

Table 1 Average annual physical energy input in Pakistan agriculture

Year	Human (10^{15} J)	Animal (10^{15} J)	Tractor* (10^{15} J)	Electricity (10^{15} J)	Petroleum (10^{15} J)	Total Physical (10^{15} J)
1981-82	43.860	28.61	0.013	28.262	7.00	107.736
1982-83	44.881	28.96	0.015	30.529	9.08	113.466
1983-84	44.881	29.32	0.018	31.889	9.76	115.861
1984-85	44.881	29.68	0.019	33.380	12.33	120.287
1985-86	48.108	22.59	0.017	34.597	13.66	118.968
1986-87	46.527	22.35	0.015	41.409	13.53	123.834
1987-88	48.832	22.12	0.014	52.671	18.61	142.241
1988-89	50.347	21.89	0.017	52.241	16.54	141.031
1989-90	51.927	21.66	0.013	59.972	16.16	149.730
1990-91	46.132	21.43	0.009	67.047	14.94	149.557
1991-92	48.602	21.21	0.007	69.755	15.85	155.429
1992-93	49.227	20.99	0.011	67.226	16.17	153.625
1993-94	53.080	20.77	0.010	68.860	17.33	160.054
1994-95	49.853	20.55	0.011	74.574	15.13	160.119
1995-96	51.038	15.79	0.015	79.883	14.08	160.809
1996-97	51.104	16.09	0.008	84.536	15.14	166.883
1997-98	57.492	16.40	0.010	82.758	13.79	170.452
1998-99	58.776	16.42	0.020	67.047	14.03	156.296
1999-2000	59.501	16.23	0.025	54.186	16.50	146.445
2000-01	60.818	16.54	0.022	58.803	14.35	150.536
2001-02	54.924	16.86	0.016	66.892	12.71	151.407
2002-03	56.076	17.19	0.018	71.771	11.08	156.137
2003-04	59.863	17.53	0.024	79.561	10.33	167.308
2004-05	61.246	17.86	0.033	83.379	8.00	170.523
2005-06	62.366	17.78	0.033	94.832	10.24	185.257

*Repair and maintenance energy

Electricity consumption in agriculture increased from 28 × 10^{15} J in 1981-82 to 95 × 10^{15} J in 2005-06. However, the consumption of petroleum product remained fluctuating during this period. Its consumption was primarily related with price and to some extent with its availability in remote areas of the country. Human energy changed from 41% to 34%, animal energy from 27% to 9.6%, tractor energy 0.01 to 0.02%, electricity consumption from 26% to 51% and petroleum product from 6% to 5.53% of the total physical energy consumption from 1981-82 to 2005-06. The changing consumption pattern of the physical energy use can be attributed to an increase in technology level of the country (Fig 1).

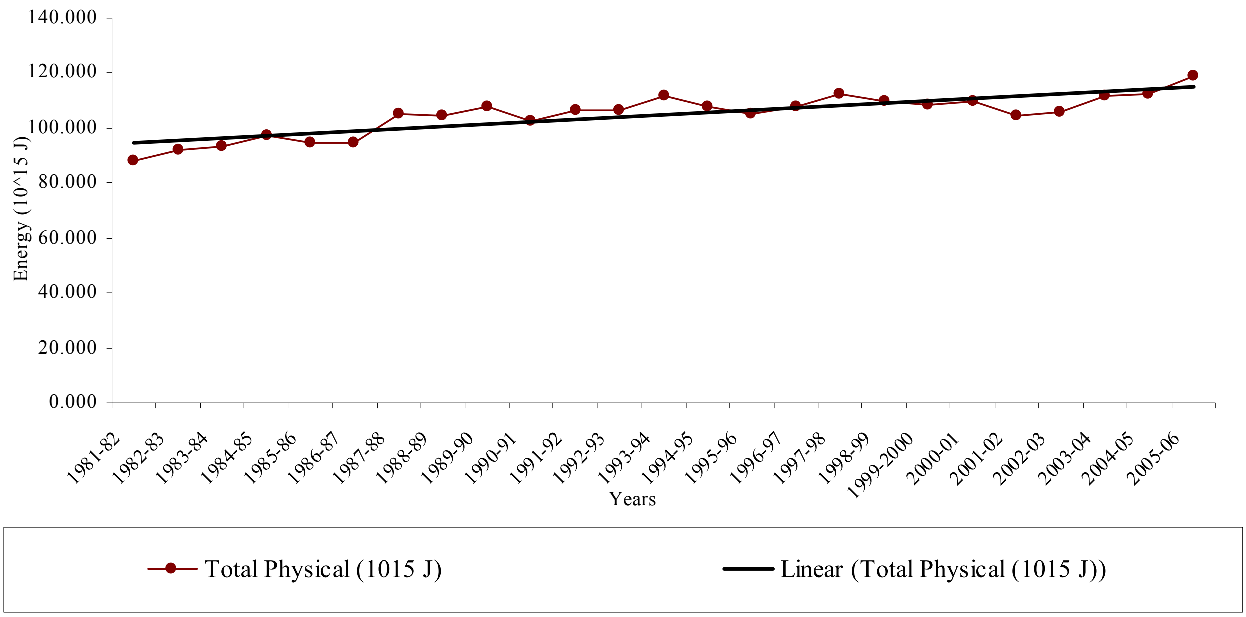

Fig 1 Per year Actual and Trend of Total Physical Energy Consumption

The financial conditions of Pakistani farmers played a crucial role while deciding about the energy inputs. Therefore, majority of the farmers depended on low cost traditional methods of cultivation, which less energy intensive. The cropped and irrigated areas increased continuously during this period (Agricultural Statistics of Pakistan, 1990-91, 1998-99, 2005-06; Economic Survey of Pakistan, 2002-03, 2005-06). Continuous increase in cropped area, required more human and animal energies on the farm. The increasing energy demand was mainly met by increased number of tractors with less reliance on animal energy. Therefore, agricultural mechanization in the country has been increasing during this period. This trend showed that agriculture has been transforming from conventional (less energy intensive) to mechanized in which tractor and other agricultural machinery become major parts of farming operations.

With the increase in cropping areas and mechanization, the energy consumption associated fertilizers increased from 53 × 10^{15} J in 1981-82 to 187 × 10^{15} J in 2005-06 (Table 2). The fertilizer consumption increased by 3.5 folds. Nitrogenous fertilizer was 94 to 96% of the total fertilizer consumption and its consumption increased from 831 tones in 1981-82 to 2927 tonnes in 2005-06. There was significant increase (3.78 folds) in phosphorus consumption during the same period. However, the Potash consumption fluctuated during this period. The result of this study showed that fertilizer consumption will keep on increasing in the future (Fig 2).

Energy inputs and outputs were also calculated on per hectare basis (Table 3). The cropped area increased from 15.65 million hectare in 1981-82 to 18.18 million hectare in 2005-06. Fig. 3 illustrates physical seed, fertilizers and total energy consumptions. Total energy consumption almost doubled from 13.60 in 1981-82 GJ/ha to 23.40 in 2005-6 GJ/ha. This increase was primarily due to increasing fertilizer energy input. The seed rate did not change during this period. Therefore, seed energy consumption per hectare remained almost constant as a result. Electricity was the main component of physical energy input and increased significantly between 1981-82 and 2005-06.

During this 25 years period, the total output energy increased by 27% from 49 GJ/ha in 1981-82 to 87 GJ/ha in 2005-06. However, the output/input ratio fluctuated slightly from the average value (Fig.4). This indicates that the high energy inputs do necessarily achieve the same level of outputs. There are other factors which should be considered while increasing energy inputs. It is important to use these resources efficiently and effectively. For example, the fertilizer application techniques and its application timings are as important as the fertilizer itself.

Table 2. Annual average fertilizer energy input in Pakistan agriculture

Year	N (000 tonnes)	Energy (10^{12} J)	P_2O_5 (000 tones)	Energy (10^{12} J)	K_2O (000 tonnes)	Energy (10^{12} J)	Total energy (10^{15} J)
1981-82	830.55	50331.33	225.19	2499.61	21.74	145.66	52.98
1982-83	952.66	57731.20	265.26	2944.39	25.65	171.86	60.85
1983-84	914.30	55406.58	259.80	2883.78	28.48	190.82	58.48
1984-85	934.85	56651.91	293.91	3262.40	24.68	165.36	60.08
1985-86	1128.14	68365.28	349.78	3882.56	33.21	222.51	72.47
1986-87	1332.50	80749.50	408.87	4538.46	42.51	284.82	85.57
1987-88	1281.65	77667.99	393.45	4367.30	45.12	302.30	82.34
1988-89	1324.83	80284.70	390.61	4335.77	24.53	164.35	84.78
1989-90	1467.87	88952.92	382.45	4245.20	40.07	268.47	93.47
1990-91	1471.64	89181.38	388.50	4312.35	32.76	219.49	93.71
1991-92	1462.62	88634.77	398.01	4417.91	23.30	156.11	93.21
1992-93	1635.36	99102.82	488.20	5419.02	24.06	161.20	104.68
1993-94	1659.35	100556.61	464.26	5153.29	23.17	155.24	105.87
1994-95	1738.10	105328.86	428.41	4755.35	16.55	110.89	110.20
1995-96	1990.85	120645.51	494.45	5488.40	29.67	198.79	126.33
1996-97	1985.08	120295.85	419.47	4656.12	8.43	56.48	125.01
1997-98	2075.10	125751.06	550.92	6115.21	20.03	134.20	132.00
1998-99	2096.98	127076.99	465.00	5161.50	21.28	142.58	132.38
1999-00	2217.77	134396.86	597.16	6628.48	18.50	123.95	141.15
2000-01	2264.49	137228.09	676.73	7511.70	22.75	152.43	144.89
2001-02	2285.30	138489.18	624.54	6932.39	18.75	125.63	145.55
2002-03	2349.10	142355.46	650.17	7216.89	20.49	137.28	149.71
2003-04	2526.73	153119.84	673.46	7475.41	21.79	145.99	160.74
2004-05	2796.42	169463.05	685.11	7604.72	32.51	217.82	177.29
2005-06	2926.62	177353.17	850.53	9440.88	27.04	181.17	186.98

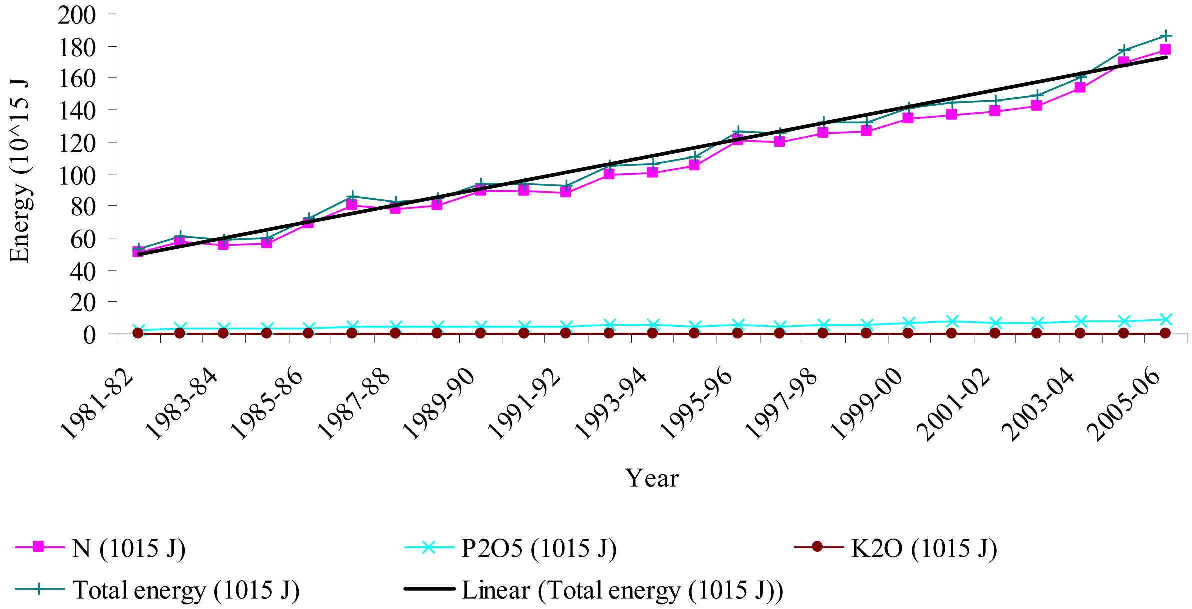

Fig 2 Annual Total Fertilizer Energy Consumption

The Econometric Results for Energy Use

One of the major objectives of this study was to explore the relationship between total energy output and input. For this purpose Cobb-Douglas energy production functions were employed to determine the significance of energy inputs to energy output. The energy inputs variables shown in equation 3 were used for analysis. These variables including labour hours, animal, fertilizer, seed, electricity, petroleum and manufacturing and repair energy of tractor were all used for data analysis. The results of regression models are shown in Table 4. These results showed that the energy variables played very significant role in output/input ratio which is obvious from the values of F and R^2. The higher value of R^2 such as 0.97 implies that 97% of the variation in the yield was explained by the variable used in this 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

Table 3 Per hectare annual average energy input and output in Pakistan agriculture (GJ/ha)

Year	Cropped area	Human	Animal	Tractor*	Electricity	Petro leum	Fertilizer	Seed	Total	Total	Total Output	Output/ Input
	(Mha)	Energy	Energy			Energy			Input	output	Energy/ ha	Ratio
1981-82	15.65	2.80	1.83	0.001	1.81	0.45	3.38	3.33	13.60	766.68	48.99	3.60
1982-83	15.78	2.84	1.83	0.001	1.93	0.58	3.86	3.24	14.28	771.96	48.92	3.42
1983-84	15.70	2.86	1.87	0.001	2.03	0.62	3.72	3.21	14.31	736.29	46.89	3.28
1984-85	15.85	2.83	1.87	0.001	2.11	0.78	3.79	3.19	14.57	748.04	47.20	3.24
1985-86	15.80	3.04	1.43	0.001	2.19	0.86	4.59	2.91	15.02	767.79	48.58	3.23
1986-87	16.40	2.84	1.36	0.001	2.52	0.83	5.22	2.80	15.56	772.81	47.12	3.03
1987-88	15.44	3.16	1.43	0.001	3.41	1.20	5.33	3.12	17.66	779.00	50.45	2.86
1988-89	16.61	3.03	1.32	0.001	3.14	1.00	5.10	3.04	16.63	865.08	52.07	3.13
1989-90	16.79	3.09	1.29	0.001	3.57	0.96	5.57	2.97	17.45	852.60	50.77	2.91
1990-91	16.97	2.72	1.26	0.001	3.95	0.88	5.52	3.01	17.35	865.36	50.99	2.94
1991-92	16.81	2.89	1.26	0.0004	4.15	0.94	5.55	3.07	17.86	921.71	54.84	3.07
1992-93	17.34	2.84	1.21	0.001	3.88	0.93	6.04	2.99	17.88	919.84	53.04	2.97
1993-94	17.13	3.10	1.21	0.001	4.02	1.01	6.18	3.18	18.71	964.84	56.33	3.01
1994-95	17.45	2.86	1.18	0.001	4.27	0.87	6.31	3.24	18.73	1032.83	59.19	3.16
1995-96	18.00	2.84	0.88	0.001	4.44	0.78	7.02	3.07	19.03	1038.30	57.69	3.03
1996-97	17.83	2.87	0.90	0.0005	4.74	0.85	7.01	3.09	19.46	1010.98	56.70	2.91
1997-98	18.23	3.15	0.90	0.001	4.54	0.76	7.24	3.24	19.83	1162.63	63.79	3.22
1998-99	18.21	3.23	0.90	0.001	3.68	0.77	7.27	3.44	19.30	1165.89	64.03	3.32
1999-00	18.13	3.28	0.90	0.001	2.99	0.91	7.78	3.16	19.02	1200.76	66.22	3.48
2000-01	17.57	3.46	0.94	0.001	3.35	0.82	8.25	3.11	19.93	1107.18	63.02	3.16
2001-02	17.56	3.13	0.96	0.001	3.81	0.72	8.29	3.20	20.11	1093.68	62.30	3.10
2002-03	17.26	3.25	1.00	0.001	4.16	0.64	8.67	3.47	21.19	1173.14	67.96	3.21
2003-04	18.07	3.31	0.97	0.001	4.40	0.57	8.90	3.29	21.45	1209.83	66.96	3.12
2004-05	18.22	3.36	0.98	0.002	4.58	0.44	9.73	3.05	22.14	1257.59	69.03	3.12
2005-06	18.18	3.43	0.98	0.002	5.22	0.56	10.28	2.92	23.40	1222.38	67.24	2.87

**Tractor manufacturing and repair energy*

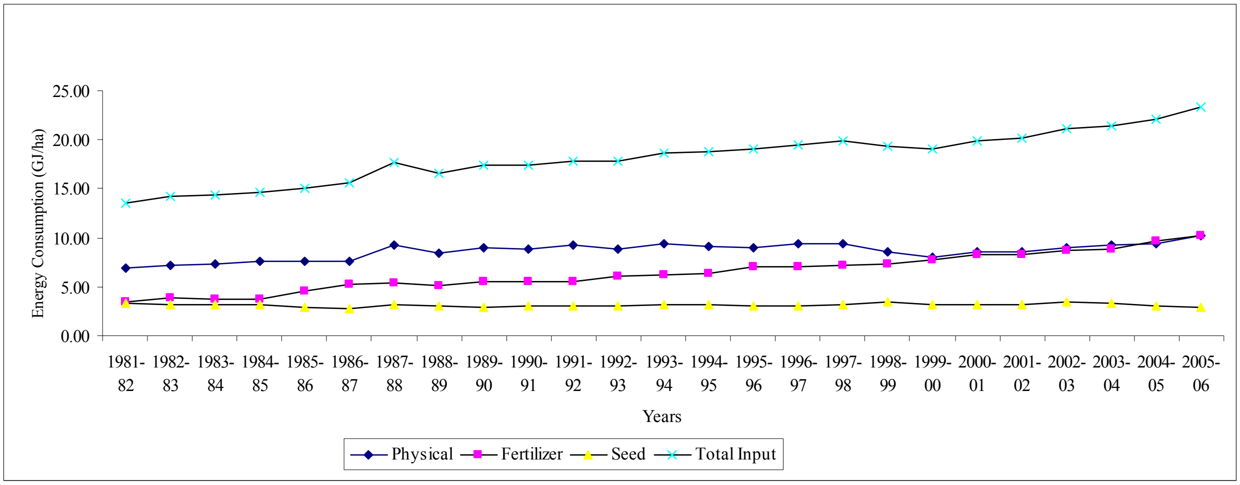

Fig 3. Annual average energy inputs per hectare in Pakistan agriculture (GJ/ha)

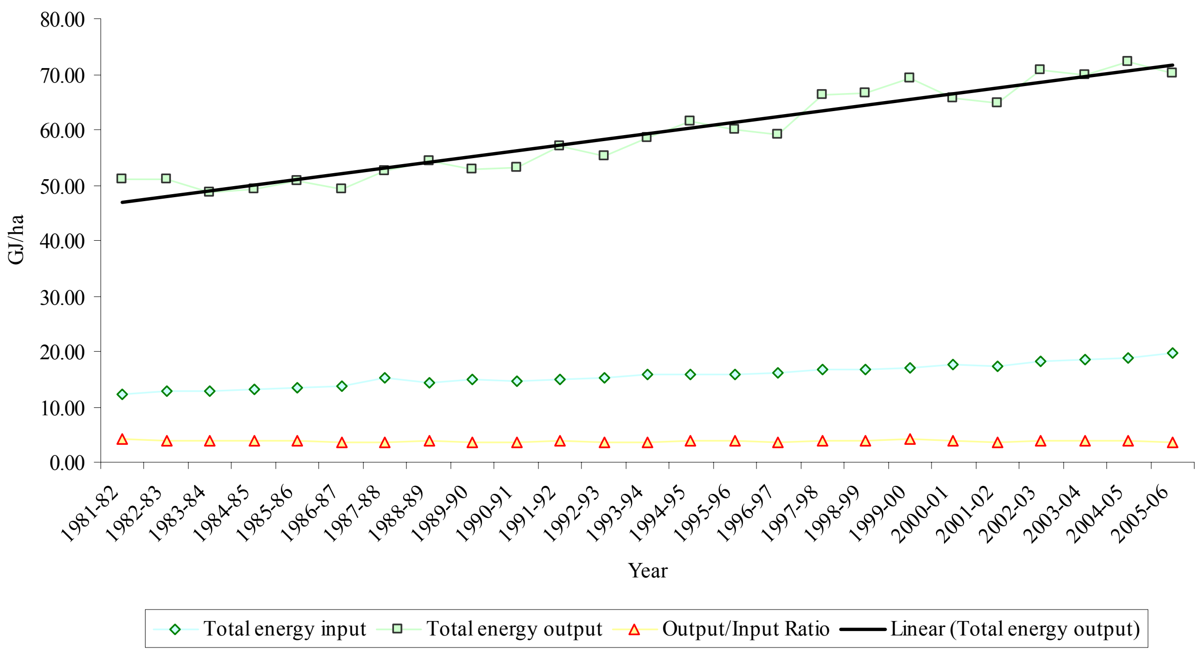

Fig 4 Annual total energy inputs and outputs per hectare in Pakistan agriculture.

model was used in the estimation, the coefficient of variability in log form also represented elasticity. The elasticity of seed energy was 0.62, implying that given 1% change in seed energy will result in 62% increase in yield. The other important input found was fertilizer energy with elasticity of 0.26. The results show that change in yield over last 25 years was mainly due to growing of high yielding variates of seed and increase in fertilizers application.

Table 4 Statistical analysis of all energy input Vs output

Regression Statistics	
Multiple R	0.98
R Square	0.97
Adjusted R Square	0.95
Standard Error	0.03
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	7	0.41	0.06	72.52	0.00
Residual	17	0.01	0.00		
Total	24	0.42			

	Coefficients	*Standard Error*	*P-value*
Intercept	2.47	0.36	0.00
Human	0.28	0.18	0.13
Animal	-0.10	0.08	0.19
Fertilizer	0.26	0.11	0.03
Seed	0.62	0.13	0.00
Electricity	0.00	0.06	0.96
Petroleum	-0.07	0.03	0.03
Tractor	-0.01	0.03	0.77

Regression Statistics	
Multiple R	0.977
R Square	0.955
Adjusted R Square	0.949
Standard Error	0.030
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.404	0.135	148.944	0.000
Residual	21	0.019	0.001		
Total	24	0.423			

	Coefficients	*Standard Error*	*P-value*
Intercept	2.684	0.233	0.000
Physical	-0.138	0.098	0.171
Fertilizer	0.426	0.032	0.000
Seed	0.763	0.121	0.000

Regression Statistics	
Multiple R	0.967
R Square	0.935
Adjusted R Square	0.925
Standard Error	0.050
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	0.758	0.253	99.975	0.000
Residual	21	0.053	0.003		
Total	24	0.812			

	Coefficients	*Standard Error*	*P-value*
Intercept	1.747	0.558	0.005
N	0.538	0.124	0.000
P_2O_5	-0.084	0.130	0.524
K_2O	-0.070	0.036	0.065

Regression Statistics	
Multiple R	0.959
R Square	0.920
Adjusted R Square	0.898
Standard Error	0.042
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	0.389	0.078	43.477	0.000
Residual	19	0.034	0.002		
Total	24	0.423			

	Coefficients	*Standard Error*	*P-value*
Intercept	3.084	0.467	0.000
Human	0.676	0.217	0.006
Animal	-0.273	0.067	0.001
Electricity	0.075	0.053	0.173
Petroleum	-0.154	0.041	0.001
Tractor	-0.016	0.039	0.694

The effect of other energy inputs variables on yield was not significant. Among all the chemical fertilizers, nitrogenous fertilizer has significant effect on yield.

CONCLUSION

The results of this showed that total energy input increased from 14 GJ/ha in 1981-82 to 23 GJ/ha in 2005-06. The fertilizer application played an important role in the total energy input increases over 25 years period. Other energy inputs such as human and electricity also increased during this period. However, animal energy consumption declined as a result of increased mechanization level in Pakistan agriculture. The animal power was substituted by the introduction of mechanical energy such as agricultural machinery mainly tractor. The seed energy consumption per hectare remained almost constant throughout the study period. The increased energy input 49 GJ/ha in 1981-92 to 67 GJ/ha in 2005-06, resulted in an increase in output energy. The energy output/input ratio fluctuated over this period. Therefore, the increase in energy output was not proportional to the corresponding increase in energy inputs. Econometric estimation results showed that fertilizer and seed energy had a positive impact on output. Physical energy input did not show any significant effect on total output.

In conclusion, energy use in the Pakistan agriculture has significantly increased over the last 25 years. This trend will continue in the future. The policy makers are required to prepare energy use policies which are environment friendly energy and guarantee a sustainable growth of agriculture sector.

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