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The bulk of mechanical energy is used in the execution of tillage, irrigation and threshing operation.

4. Acquisition of mechanical sources of farm power on the tractor farms helps in timely accomplishment of farm operations and realisation of higher cropping intensity which helps in the attainment of greater returns per unit of area and energy costs.

AN ECONOMIC ANALYSIS OF ENERGY REQUIREMENTS IN PUNJAB AGRICULTURE

A. J. Singh and S. S. Miglani*

Energy forms one of the most crucial inputs in agriculture, whatever be the source from which it is supplied—man, animal or machine. Energy requirements in agriculture vary according to the type of farming area, the size of farm and the level of technology. However, empirical studies in this direction are conspicuous by their absence. Besides, there is lack of knowledge regarding the productivity of different types of energy and the rates of substitution between them. This study was, therefore, undertaken in Ferozepur district of Punjab with the following objectives: (*a*) to examine the energy requirements from various sources for different categories of farms; (*b*) to analyse the marginal value productivities between different types of energies; and (*c*) to estimate the marginal rates of substitution between selected sources of energy as a guide to cost minimization.

METHODOLOGY

The study was located in Ferozepur district of the Punjab and multi-stage stratified random sampling design was adopted with villages as the primary and operational holdings as the ultimate units of study.[1] Based on the soil-climate-crop complex, Ferozepur district was stratified into three zones, *viz.*, maize-wheat, paddy-wheat and American cotton-wheat zones. The cultivated area in these zones worked out to be in the proportion of 3:5:7 respectively. The sample villages were, therefore, selected from these zones in this proportion. Thus three villages from maize-wheat, five from paddy-wheat and seven from American cotton-wheat zone were selected randomly with probability proportional to the cultivated area in each zone. As such a total of 15 villages was selected for this study.

The cultivated area in the selected villages was pooled and transformed to show the size ranges of operational holdings in five size-groups, *viz.*, below

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1. A. S. Kahlon, Surjit Singh and S. K. Mehta: Studies in the Economics of Farm Management in Ferozepur (Punjab) 1967-68, Directorate of Economics and Statistics, Ministry of Food and Agriculture, Government of India, New Delhi, 1967-68.

6 hectares, 6-9 hectares, 9-14 hectares, 14-24 hectares and 24 hectares and above. The holdings in each selected village were stratified according to these size-groups and two of them were randomly selected from each group. This provided a sample of 10 holdings from each village and a total of 150 holdings from the sample villages. As the number of farmers in the largest size-group was small, this group was combined with 14-24 hectares size-group.

Six sample farmers left the operational area of the study. So, this analysis pertains to the remaining 144 observations. Thel data for this study were collected with the help of schedules specifically prepared for this project through the survey method.

RESULTS AND DISCUSSION

I

Energy Use Per Hectare from Different Sources according to Agro-climatic Zones

Table I indicates the energy requirements per hectare from human, bullock and mechanical sources for the three types of farming regions in the study area. It would be seen that energy per hectare was the highest in zone I (902.74 h.p. hours) followed by zone III (633.28 h.p. hours). The share of mechanical energy was found to vary from 87 per cent in zone I to 79.77 per cent in zone III. The share of human energy varied from 5.70 per cent in zone III to 7.45 per cent in zone II. Out of the mechanical sources, maximum share was contributed by tractor energy followed by stationary machinery energy.

TABLE I—ENERGY USE PER HECTARE FROM DIFFERENT SOURCES IN THE STUDY AREA, FEROZEPUR DISTRICT, PUNJAB : 1973-74

(horse power hours)

Source of energy	Zones			Size-group				Pooled
	I	II	III	I	II	III	IV	
1. Irrigational energy	7·05 (0·78)	6·69 (1·09)	1·73 (0·27)	5·94 (1·31)	5·37 (1·05)	4·48 (0·63)	3·76 (0·48)	4·41 (0·65)
2. Human energy	54·44 (6·03)	45·64 (7·45)	36·10 (5·70)	62·47 (13·76)	51·17 (10·09)	42·06 (10·30)	36·73 (4·68)	42·76 (6·33)
3. Bullock energy	62·95 (6·97)	83·63 (13·66)	92·03 (14·53)	107·75 (37·62)	137·18 (27·08)	73·25 (10·30)	51·27 (6·53)	82·28 (12·19)
4. Tractor energy	616·28 (68·27)	368·75 (60·22)	391·31 (61·79)	100·16 (22·06)	224·06 (44·20)	471·21 (66·28)	533·44 (67·90)	425·31 (62·99)
5. Stationary machinery energy	162·02 (17·95)	107·63 (17·58)	112·11 (17·71)	114·59 (25·25)	89·14 (17·58)	120·17 (16·90)	160·41 (20·41)	120·43 (17·84)
6. Total	902·74 (100·00)	612·34 (100·00)	633·28 (100·00)	453·91 (100·00)	506·92 (100·00)	711·17 (100·00)	785·61 (100·00)	675·19 (100·00)

Energy Requirements from Different Sources according to Size

Table I also indicates the energy requirements per hectare in horse power hours from various sources for different size categories of farms. It would be seen that, as expected, human energy use declined from a maximum of 62.47 h.p. hours for size I to a minimum of 36.73 h.p. hours for size IV. Similarly, bullock energy use varied from a maximum of 170.75 h.p. hours for size I to a minimum of 51.27 h.p. hours for size IV. However, mechanical energy use, generally speaking, increased with the size of farm. Energy use for irrigation purposes was found to be the highest on the smallest size category and the lowest on the largest size category of farms.

Energy Requirements for Different Agricultural Operations through Various Sources at Different Levels of Technology

Table II is devoted to a detailed analysis of the supply of energy through various sources for different agricultural operations for different levels of technology. It would be seen that human energy requirement declined from 59.72 h.p. hours on the bullock plus tube-well operated farms to 47.55 h.p. hours per cropped hectare on the tractor plus tube-well operated farms. Bullock energy requirement declined from 115.62 h.p. hours to 6 h.p. hours per cropped hectare and mechanical energy requirement increased from 610.73 h.p. hours to 1,144.10 h.p. hours per hectare in the tractor plus tube-well situation over the bullock plus tube-well situation.

In the canal irrigated areas, it was observed that human energy requirements declined from 169.26 h.p. hours on the bullock operated to 119.54 h.p. on the tractor operated farms per cropped hectare and the bullock energy requirements decreased from 56.93 h.p. hours to 15.52 h.p. hours; whereas the mechanical energy requirements increased from 54.45 h.p. hours to 282.02 h.p. hours per cropped hectare.

It would also be seen that the major operations performed through human labour were harvesting, threshing, irrigation and inter-culture. Bullock energy was mainly used for preparatory tillage, sowing, inter-culture, threshing and transportation, whereas mechanical energy was mainly utilized for irrigation, preparatory tillage and threshing purposes.

II

In order to determine the relative contribution of different sources of energy input to output, the data were subjected to production function analysis. For this purpose, gross value of output in rupees was considered as a function of farm size in hectares (X_1), irrigation energy in h.p. hours (X_2), bullock energy in h.p. hours (X_3), expenditure on seeds, fertilizers and insecticides (X_4), human energy in h.p. hours (X_5), tractor energy in h.p. hours (X_6) and stationary machinery use in h.p. hours (X_7). Linear and Cobb-Douglas types of production functions were tried. However, Cobb-Douglas

TABLE II—ENERGY REQUIREMENTS PER CROPPED HECTARE FOR DIFFERENT AGRICULTURAL OPERATIONS FOR BULLOCK AND TRACTOR OPERATED FARMS IN THE STUDY AREA, FEROZEPUR DISTRICT, PUNJAB : 1973-74

Sr. No.	Operations	Bullock operated + tube-well irrigated			Tractor operated + tube-well irrigated			Bullock operated + canal irrigated			Tractor operated + canal irrigated		
		H.E.	B.E.	M.E.	H.E.	B.E.	M.E.	H.E.	B.E.	M.E.	H.E.	B.E.	M.E.
1.	Preparatory tillage ..	9·61 (16·03)	86·57 (74·87)	54·34 (8·89)	2·30 (4·83)	0·81 (13·58)	378·70 (33·10)	3·81 (2·25)	37·78 (66·35)	12·03 (22·01)	0·70 (0·59)	5·51 (35·50)	146·50 (51·95)
2.	Sowing	6·20 (10·34)	14·13 (12·21)	4·63 (0·65)	4·30 (9·03)	2·86 (47·73)	46·19 (4·03)	1·36 (0·80)	6·82 (11·98)	—	0·95 (0·79)	4·14 (26·68)	23·58 (8·35)
3.	Fertilization and manuring	2·49 (4·16)	5·70 (4·93)	4·84 (0·69)	1·53 (3·22)	0·12 (2·05)	47·20 (4·18)	1·20 (0·71)	3·08 (5·41)	3·22 (5·91)	0·83 (0·69)	0·10 (0·64)	41·27 (14·63)
4.	Irrigation	9·08 (15·16)	—	466·91 (76·40)	9·16 (19·27)	—	489·63 (42·79)	18·76 (11·00)	—	8·86 (16·27)	14·61 (12·22)	—	9·55 (3·39)
5.	Inter-culture	6·52 (10·88)	1·73 (1·49)	—	9·81 (20·62)	1·53 (25·51)	0·49 (0·04)	33·69 (19·90)	4·70 (8·26)	0·74 (1·35)	0·30 (0·25)	4·22 (27·19)	4·39 (1·56)
6.	Plant protection	0·17 (0·28)	—	—	0·10 (0·20)	—	—	2·88 (1·69)	—	2·86 (5·25)	4·62 (3·85)	—	4·62 (1·64)
7.	Harvesting	17·68 (29·51)	—	—	13·41 (28·20)	—	—	75·18 (44·42)	—	—	69·82 (58·43)	—	—
8.	Threshing	7·04 (11·74)	2·07 (1·79)	80·92 (13·14)	6·82 (14·33)	0·20 (3·29)	124·56 (10·88)	28·10 (16·60)	2·83 (4·97)	26·74 (49·13)	24·82 (20·76)	1·31 (8·44)	29·34 (10·44)
9.	Transportation	1·11 (1·85)	5·41 (4.67)	—	0·12 (0.25)	0·47 (22·29)	57·11 (4·99)	4·30 (2·63)	1·72 (3·03)	—	2·89 (2·42)	0·24 (1·55)	22·67 (8·04)
	Total	59·92 (100·00)	115·62 (100·00)	610·73 (100·00)	47·55 (100·00)	6·00 (100.00)	1,144·10 (100·00)	169·26 (100·00)	56·93 (100·00)	54·45 (100·00)	119·54 (100·00)	15·52 (100·00)	282·02 (100·00)

Note:—Figures in parentheses are percentages. H.E. = Human energy. B.E. = Bullock energy. M.E. = Mechanical energy.

TABLE III—PRODUCTION FUNCTION ANALYSIS ON SAMPLE FARMS ZONEWISE, SIZEWISE AND AGGREGATE BASIS, FEROZEPUR DISTRICT, PUNJAB : 1973-74

Sr. No.	Type of data	Intercept	X_1	X_2	X_3	X_4	X_5	X_6	X_7	R^2
1.	Size-group I									
	Cobb-Douglas ..	Log 5·5262	0·2351 (1·132)	—0·0416 (—1·065)	—0·0373 (—0·753)	0·1888** (1·977)	0·5100** (2·772)	0·0051 (0·303)	0·0076 (0·266)	0·8756***
2.	Size-group II									
	Cobb-Douglas ..	Log 5·3299	0·0545 (0·2504)	0·224 (1·0219)	—0·0112 (—0·3413)	0·2302*** (3·2121)	0·5030*** (4·4020)	0·0194** (2·2115)	—0·0182 (—1·2457)	0·7337***
3.	Size-group III									
	Cobb-Douglas ..	Log 4·8645	0·5358* (1·8711)	0·0138 (0·4180)	0·0308 (1·0591)	0·2105 (1·2882)	0·3779 (1·4936)	0·0197 (0·7720)	0·0086 (0·2144)	0·6802***
4.	Size-group IV									
	Cobb-Douglas ..	Log 3·8654	0·3864 (2·0584)	—0·0590 (—1·7080)	0·0105 (0·2703)	0·3359** (2·3154)	0·5200** (2·5751)	0·0249 (1·4509)	—0·0440 (—0·607)	0·8111**
5.	Pooled data ..	Log 5·3342	0·3847*** (6·936)	—0·0079 (—0·597)	—0·0027 (—0·172)	0·2313*** (5·208)	0·3990*** (5·379)	0·0176** (2·667)	—0·1007 (—0·673)	0·9158***
6.	Zone I ..	Log 4·3670	0·3785** (2·64)	—0·0443 (1·002)	0·0443 (1·002)	0·2931* (1·897)	0·5078** (2·024)	0·0492** (2·997)	—0·1208 (—2·280)	0·9513***
7.	Zone II ..	Log 5·4018	0·3810*** (5·0205)	—0·0240 (—0·922)	—0·0043 (—0·203)	0·1989*** (3·174)	0·4535*** (3·583)	0·0170 (1·654)	—0·0137 (—0·632)	0·9526***
6.	Zone III ..	Log 5·3566	0·3697*** (3·229)	0·0083 (0·333)	—0·0891 (—1·931)	0·2245*** (3·660)	0·4699 (0·700)	0·0080 (0·019)	0·0003 (0·935)	0·9350***

Figures in parentheses are the t values.
*** Significant at 1 per cent level.
** Significant at 5 per cent level.
* Significant at 10 per cent level.

gave better results as indicated by the higher R^2 values in almost all the cases. So for further analysis, we made use of the empirical estimates of different coefficients as given by this function.

The problem of multicollinearity was tested by the Klein method. According to this method, multicollinearity is not necessarily a problem unless it is high relative to the overall degree of multiple correlation among all variables simultaneously.[2] Since the value of multiple correlation (R_y) was higher than r_{ij} (zero order correlation between the independent variables) in all the cases, multicollinearity was not found to present any serious problem in this analysis.

It would be seen from Table III that output(Y) was significantly affected by farm size (X_1), expenditure on seeds, fertilizers and insecticides (X_4), human energy in h.p. hours (X_5), and tractor energy in h.p. hours (X_6).

The result of the zonewise analysis of the production functions also indicated that farm size (X_1), seed-fertilizer-insecticides (X_4), human labour (X_5) were the major variables, significantly affecting output (Y). In the size-wise analysis, seed-fertilizer-pesticide expenditure (X_4), and human labour (X_5) were the crucial variables explaining changes in output. The other variables were found to be non-significant, except for size-group IV in which farm size was also found to be significant.

Marginal Value Productivities

An analysis of marginal value productivities zonewise indicated that these productivities were, generally speaking, higher in zone II. The inter-size comparison revealed that the marginal value productivity of land was highest in size-group III (9-14 hectares) and the marginal value productivity of human energy and seed-fertilizers, etc., was highest in the largest size-group (14 hectares and above) (see Table IV).

TABLE IV—MARGINAL VALUE PRODUCTIVITIES OF INPUT FACTORS AT THEIR GEOMETRIC MEAN LEVELS FOR DIFFERENT ZONES AND SIZE-GROUPS IN THE STUDY AREA, FEROZEPUR DISTRICT, PUNJAB : 1973-74

Sr. No.	Resources	Zone I	Zone II	Zone III	Pooled	Below 6 hectares	6-9 hectares	9-14 hectares	14 hectares and above
1.	Land	1536·02	1578·03	1226·91	1522·22	1028·24	201·47	2103·18	1547·56
2.	Seeds, fertilizers and insecticides ..	2·89	1·89	2·24	2·25	1·96	2·34	2·16	3·12
3.	Irrigation	—	—	—	—	—	15·43	12·08	—
4.	Bullock energy ..	2·85	—	—	—	—	—	1·64	0·82
5.	Human energy ..	37·85	41·16	47·73	36·92	35·71	36·35	35·25	56·69
6.	Tractor energy ..	0·32	0·19	0·07	0·16	0·22	1·40	0·16	0·18
7.	Stationary machinery energy	—	—	0·01	—	0·29	—	0·28	—

2. Lawrence R. Klein: An Introduction to Econometrics, Prentice-Hall of India (Pvt.) Ltd., New Delhi, 1969, p. 101.

The explanatory variables were ranked for their contribution to the total output at their geometric mean levels at the existing input prices. For this purpose, land rent was assumed to be Rs. 7.50 per hectare, the price of bullock h.p. hour was taken as Re. 1.44 and the cost of one h.p. hour of tractor and farm machinery was assumed to be Re.0.42 and the cost of one h.p. hour of human energy was assessed at Rs. 14.[3] The factor cost of seed-fertilizers-insecticides which was expressed in rupee terms was considered as rupee one. The ranks thus worked out for the selected variables are shown in Table V. It would be seen from the table that human energy ranked first in size-groups I and IV and zones II and III. Seeds, fertilizer and insecticides ranked first in zone I and second in zone III and in size-groups I and IV respectively. Irrigation energy occupied first rank in size-groups II and III. Land ranked second in size-group III and zone II and occupied third place in size-groups I and IV and zones I and III respectively. In the overall analysis, human energy ranked first followed by seed-fertilizer-insecticides, land and tractor energy.

TABLE V—RANKS OF INDEPENDENT VARIABLES IN RELATION TO TOTAL OUTPUT AT THEIR GEOMETRIC MEAN LEVELS AT EXISTING FACTOR PRICES: FEROZEPUR DISTRICT, PUNJAB : 1973-74

Sr. No.	Resources	Below 6 hectares	6-9 hectares	9-14 hectares	14 hectares and above	Zone I	Zone II	Zone III	Pooled
1.	Land	3	5	2	3	3	2	3	3
2.	Seeds, fertilizers and insecticides ..	2	4	4	2	1	3	2	2
3.	Irrigation energy ..	—	1	1	—	—	—	—	—
4.	Bullock energy ..	—	—	5	4	4	—	—	—
5.	Human energy ..	1	3	3	1	2	1	1	1
6.	Tractor energy ..	5	2	7	5	5	4	4	4
7.	Stationary machinery energy	4	—	6	—	—	—	—	—

III

Marginal Rates of Substitution between Different Types of Energy

The marginal rates of substitution between different forms of energy were worked out at their geometric mean levels and are shown in Table VI. It would be seen that the marginal rate of substitution of tractor energy for human energy (both in h.p. hours) was found to be 0.0044 which means that one h.p. hour of tractor energy would replace 0.0044 h.p. hour of human

3. C. P. Singh, *et. al* : Energy Requirement in Intensive Agricultural Production Programme (I.C.A.R. Co-ordinated Project), Department of Farm Power and Machinery, Punjab Agricultural University, Ludhiana, Punjab, 1975, pp. 29-30.

energy in the overall analysis. Similarly, the marginal rate of substitution of farm machinery energy for bullock energy was estimated at 1.6390 in the aggregate analysis. This implies that one h.p. hour of machinery energy would substitute for 1.6390 h.p. hour of bullock energy.

TABLE VI—MARGINAL RATES OF SUBSTITUTION BETWEEN DIFFERENT SOURCES OF ENERGY AT THEIR GEOMETRIC MEAN LEVELS, FEROZEPUR DISTRICT, PUNJAB : 1973-74

	Zone I	Zone II	Zone III
Marginal rates of substitution of tractor energy for human energy ..	0·0085	0·0046	0·0015
Marginal rates of substitution of farm machine energy for bullock energy	3·1172	2·2177	0·3255

	Size I	Size II	Size III	Size IV	Pooled	Price ratio
Marginal rates of substitution of tractor energy for human energy ..	0·0062	0·0088	0·0046	0·0032	0·0044	$\frac{(PTE)}{(PHE)} = 0\cdot0300$
Marginal rates of substitution of farm machine energy for bullock energy	1·7053	1·1475	1·5153	1·5588	1·6390	$\frac{(PFME)}{(PBE)} = 0\cdot2916$

The marginal rates of substitution of different types of energy were compared with their respective price ratios for examining the rationality of the extent of their use. It was found that the marginal rate of substitution of tractor energy for bullock energy was greater than the price ratio which indicated that it would be economical to substitute tractor power for bullock on the given isoquant at the existing level of prices. On the other hand, the marginal rate of substitution of tractor energy for human energy was found to be less than the price ratio which indicated the need to extend the use of human labour. However, the farmers have been resorting to increasing mechanization of agriculture due to their eagerness to ensure better timeliness and more effective performance of certain agricultural operations. They have also been found to be going in for the purchase of machinery due to their preference for more leisure and sometimes only to enhance their prestige in the society.

CONCLUSION

From the foregoing analysis, it can be concluded that energy use per hectare varied significantly as between different types of soil-crop-climate complexes, as between levels of technology and also according to size categories of farms. Further, the production function analysis of the data of this study indicated that output was significantly affected by farm size, seed-fertilizer-insecticides and tractor hours in the overall analysis. The analysis also revealed that the marginal productivity of land was the highest followed by human labour, seed-fertilizer-insecticides and tractor energy, whereas the marginal value productivity of bullock energy was found to be negative but non-significant. The ranking of the explanatory variables for their contribution to output indicated that human energy ranked first followed by seed-fertilizer-insecticides, land and tractor energy in order. The comparison of marginal rates of substitution of tractor energy for bullock energy with price ratio indicated the need for substituting tractor power for bullock power. This type of substitution is already taking place. On the other hand, the comparison of marginal rate of substitution of machine energy for human energy with the corresponding price ratio pointed to the need for substituting human energy for mechanical energy on purely economic considerations. However, a number of other considerations were responsible for increasing substitution of machine power for human power. These were the desire of the farmers to perform the important agricultural operations more effectively and on time, their preference for greater convenience and leisure and lastly, their urge to enhance their social prestige.

ENERGY CONSUMPTION AND AGRICULTURAL DEVELOPMENT IN PUNJAB AND HARYANA

R. N. Senapati*

The use of energy in agriculture has received a great deal of emphasis in recent years with increasing modernization and mechanization of traditional agriculture in developing countries like India. The objectives of this paper are : (*a*) to present some estimates of the consumption of energy in its various forms in the agricultural sector in the States of Punjab and Haryana for the years 1961-62, 1966-67 and 1972-73; (*b*) to analyse the changes in the pattern of energy consumption during the above period; (*c*) to study the relationship between changes in energy consumption and changes in cropping intensity, yield and production in these two States for the above years; and (*d*) to investigate into the social cost of such energy consumption in relation to the value of the total output for the same years.

Energy as input into agriculture can be applied in the form of draft power, irrigation and fertilizers. In the category of draft power we have included the number of bullocks, the number of tractors operating in those years. As regards irrigation, we have considered the number of oil engines and the

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