Ind. Jn. of Agri. Econ.
Vol. 53, No. 3, July-Sept. 1998

Energy Management for Sustainability of Hill Agriculture: A Case of Himachal Pradesh

A.S. Saini, K.D. Sharma, K.P. Pant and D.R. Thakur*

I

INTRODUCTION

With the advancement in technology and overall agricultural development, the use of energy resources has increased manifold. Traditional or low energy farming is being substituted by modern/ energy intensive farming wherever feasible in order to meet the growing demand for agricultural products, particularly food. There is, therefore, the need for exploring alternative energy efficient systems for agricultural production so as to make agriculture energy efficient and sustainable. This paper seeks (i) to examine the existing energy input-output pattern of important cropping systems of the study area; (ii) to estimate the energy requirements of important cropping systems at improved level of technology; and (iii) to maximise the net returns and net energy through optimal allocation of inputs on different categories of farms.

Study Area, Data and Energy Conversion

The study was conducted in Kangra valley of Himachal Pradesh — a model state for hills of India from the viewpoint of energy conservation and overall development. For the selection of sample, three-stage random sampling technique, using stratification at the final stage, was employed for the selection of blocks (stage I), villages (stage II) and farmers (stage III). Using the size of operational holding as stratification variable, the farm households were categorised into two groups, viz., small and large, with operational holdings upto 2 hectares and more than 2 hectares respectively.

For this study, two blocks (Nagrota Bhagwan and Nurpur) were selected randomly from Kangra valley of Himachal Pradesh.[1] From each selected block a sample of one per cent (8 villages) of total villages was chosen randomly. From each village, a sample of 10 per cent of the farmers was selected randomly, thus making a total sample size of 80 farmers (59 small and 21 large). The primary data were collected on a specifically designed and pretested schedule through personal contact method for the agricultural year.[2]

The physical inputs and outputs of crops and livestock production activities were converted into energy terms by using energy conversion factors (Annexure 1). Various energy economists have reported conversion factors of different farm inputs and outputs and the same were made use of in the

* Department of Agricultural Economics, Himachal Pradesh Krishi Vishvavidyalaya, Palampur 176 062, District Kangra (H.P.)

Sourcewise energy[4] use in various cropping systems/enterprises was worked out for small and large farms separately. The important sources of direct energy are seed. farmyard manure, pesticides, chemical fertilisers, human labour and bullock labour. And indirect energy sources accounted for in the study are implements and machineries.

Further, operationwise energy was also worked out by accounting for all operations like land preparation, manuring and fertilisation, sowing, irrigation, inter-culture, plant protection, harvesting and threshing, transportation and marketing. Energy output in terms of main and by-products of crops and livestock enterprises was also estimated.

II

ENERGY OPTIMISING MODEL

A mathematical model to optimise net energy returns of crops in central Missouri state, U.S.A. was attempted for the first time by Ozkan and Frisby in 1980. A mathematical model to optimise net energy returns of crops in central Missouri state, USA was attempted for the first time by Ozkan and Frisby in 1980. Then Adhaoo (1981) used a log-linear form of production function to study the impact of different energy sources, and for generating optimal plans on different sizes of farms, linear programming model was employed by foreign scholars (see Bell and Willcock 1982 Bender *et al.*, 1984; Gopala Krishana *et al.* 1985).

In India, energy optimisation in major crops was attempted for the first time by Sirohi *et al.* (1981) through production function approach. Later on Singh and Subbarayan (1986) employed linear programming model to optimise the allocation of energy inputs in Uttar Pradesh. It is clear that till now no study relating to energy management in agriculture of hill regions has been undertaken, despite the fact that these areas of the country need such studies in the context of energy conservation and sustainability of agriculture.

The maximisation of net energy was arrived at by optimising energy inputs with the help of linear programming technique. For this purpose, separate programmes were designed for the maximisation of net energy in each category, both at the existing and recommended level of technology. Altogether, the following four optimum farm plans (two each of energy efficient and returns efficient) were developed for each category of farm:

P_1 = Net energy maximising plan under existing level of technology.
P_2 = Net energy maximising plan under improved technology.
P_3 = Net returns maximising plan under existing level of technology, and
P_4 = Net returns maximising plan under improved technology.

The systematic energy optimising/management model employed in this study is as follows:

$$\text{Maximise } Z = -\sum_{j=1}^{16} E_{cj}X_{cj} - \sum_{j=17}^{19} E_{dj}X_{dj} - \sum_{j=20}^{39} E_{hj}X_{hj}$$

$$- \sum_{j=40}^{46} E_{pj} X_{pj} - \sum_{j=47}^{49} E_{bj} X_{bj} + \sum_{j=50}^{62} E_{sj} X_{sj}$$

Subject to the following constraints,

$$\sum_{j=1}^{5} X_{cj} \leq A_{ui}$$ .... unirrigated land (i = 1; j = 1, 2, ..., 5)

$$\sum_{j=6}^{16} X_{cj} \leq A_{ri}$$ .... irrigated land (i = 2; j = 6, ..., 16)

$$\sum_{j=1}^{16} a_{hij} X_{cj} + \sum_{j=17}^{19} a_{hij} X_{dj} - X_{hi} \leq H_i$$ .... human labour (i = 3, 4, ..., 14 (June to July) and (j = 1, 2, ..., 19)

$$\sum_{j=1}^{16} a_{hij} X_{cj} - X_{hi} \leq B_i$$ .... bullock labour (i = 15, 16, ..., 20 May, June, July, October, November, December)

$$\sum_{j=1}^{16} a_{hij} X_{cj} - X_{hi} \leq 0$$ .... tractor power (i = 21, 22; *kharif, rabi*)

$$\sum_{j=1}^{16} a_{pij} X_{cj} - X_{pi} = 0$$ .... nitrogen fertiliser purchased (i = 23, 24; *kharif, rabi*)

$$\sum_{j=1}^{16} a_{pij} X_{cj} - X_{pi} = 0$$ .... phosphorus fertiliser purchased (i = 25, 26; *kharif, rabi*)

$$\sum_{j=1}^{16} a_{pij} X_{cj} - X_{pi} = 0$$ .... potassium fertiliser purchased (i = 27, 28; *kharif, rabi*)

$$\sum_{j=1}^{16} a_{pij} X_{cj} - \sum_{j=17}^{19} a_{pij} - X_{pi} \leq F_i$$ .... (i = 29; farmyard manure)

$$\sum_{j=1}^{16} a_{bij} X_{cj} + \sum_{j=17}^{19} a_{bij} X_{dj} - X_{bi} \leq W_i$$ .... (i = 30, 31 working capital; *kharif, rabi*)

$$\sum_{j=17}^{19} a_{bij} X_{dj} - X_{bi} \leq M_i$$ .... medium-term capital (i = 32)

$$X_{cj} \leq A_i$$ .... maximum area requirement (i = 33, 34; maize-pea and okra-cauliflower)

$$\sum_{j=1}^{16} Y_{cij} X_{cj} - X_{csi} = C_{csi}$$ .... minimum consumption requirement (i = 35, ..., 44; rice, maize, wheat, mash, sesamum, linseed, potato, pea, toria, cauliflower)

$$\sum_{j=17}^{19} Y_{dij} X_{dj} - X_{dsi} = C_{dsi}$$ .... minimum milk consumption requirement (i = 45, 46; *kharif*, *rabi*)

$$\sum_{j=1}^{16} Y_{fdij} X_{cj} - \sum_{j=17}^{19} a_{fdij} \geq C_{df}$$ .... fodder requirement (i = 47, 48; green and dry fodder)

$X_{cj}, X_{dj}, X_{hj}, X_{pj}, X_{sj} \geq 0$ .... non-negativity restriction.

here

- Z = total net energy from all the activities (mega joules-MJ),[6]
- E_{cj} = energy used in jth cropping system through seed, pesticides and owned bullock labour (MJ),
- X_{cj} = level of jth crop activity (ha),
- E_{dj} = energy used in jth dairy milch animal through concentrates and medicines (MJ),
- X_{dj} = level of jth dairy activity (No.),
- E_{hj} = energy input through hired factors (MJ/unit),
- X_{hj} = level of jth hiring activity (man-day, bullock pair day or tractor hour),
- E_{pj} = per unit energy content of j-th purchased input (MJ/unit),
- X_{pi} = level of j-th purchased activity (kg or t),
- E_{bi} = energy used for j-th borrowing activity (MJ),
- X_{bi} = level of jth borrowing activity (Rs.),
- E_{si} = energy content of jth commodity sold (MJ/qtl),
- X_{si} = level of jth commodity sold (qtl),
- A_{ui} = unirrigated area (ha),
- A_{ri} = irrigated area (ha),
- a_{hij} = amount of ith resources required by one unit of j-th activity,
- H_i = family labour available in ith month (man-day),
- B_i = owned bullock labour in ith month (bullock-pair day),

F_i = farmyard manure available (t),
W_i = working capital available during iith season (Rs.),
M_i = medium-term dairy capital available (Rs.),
A_j = maximum manageable area under j-th crop rotation (ha),
Y_{cs} = yield of s-th crop (qtl/ha),
Y_{ds} = yield of s-th dairy milch animal (qtl/animal),
C_{cs} = minimum home consumption requirement of s-th crop/commodity (qtl),
C_{ds} = minimum home consumption requirement of s-th dairy product/milk (qtl),
Y_f = yield of f-th fodder (qtl/ha),
C_{df} = requirement of f-th fodder for animals other than milch animals (qtl)

The following sets of activities were used in the model:

(a) *Crop Activities (X_{cj})*

The crop activities consisting of different cropping systems/crop rotations under different farm situations in the study area were grouped into two categories on the basis of irrigation as under:
(i) Unirrigated crop activities

X_1 Rice - wheat
X_2 Maize - wheat
X_3 Mash - wheat
X_4 Sesamum - wheat
X_5 Sorghum (fodder) - barley (fodder)

(ii) Irrigated

X_6 Rice - wheat
X_7 Rice - linseed
X_8 Rice - berseem (fodder)
X_9 Rice - potato
X_{10} Rice – wheat + mustard
X_{11} Maize - wheat
X_{12} Maize - toria - wheat
X_{13} Maize - potato - wheat
X_{14} Maize - pea
X_{15} Sorghum (fodder) - berseem (fodder)
X_{16} Okra - cauliflower

(b) *Dairy Activities (X_{djs})*

X_{17} Local cow
X_{18} Crossbred cow
X_{19} Buffalo

(c) *Hiring Activities* (X_{hjs})

X_{20} to X_{31} Monthwise human labour hiring-in (July to June),

X_{32} to X_{37} Bullock labour hiring-in for peak working months (May, June, July, October, November and December),

X_{38} to X_{39} Tractor hiring-in (*kharif* and *rabi*).

(d) *Purchasing Activities* (X_{pjs})

X_{40} to X_{41} Nitrogen purchasing (*kharif* and *rabi*),

X_{42} to X_{43} Phosphorus purchasing (*kharif* and *rabi*),

X_{44} to X_{45} Potassium purchasing (*kharif* and *rabi*),

X_{46} Farmyard manure purchasing.

(e) *Borrowing Activities* (X_{bjs})

X_{47} and X_{48} Working capital borrowing (*kharif* and *rabi*),

X_{49} Medium-term daily capital borrowing.

(f) *Selling Activities* (X_{sjs})

X_{50} Paddy

X_{51} Maize

X_{52} Wheat

X_{53} Mash

X_{54} Sesamum

X_{55} Linseed

X_{56} Potato

X_{57} Toria

X_{58} Pea (green pods)

X_{59} Okra

X_{60} Cauliflower

X_{61} and X_{62} Milk selling (*kharif* and *rabi*).

To develop optimum plans by maximising net returns, the energy coefficients in the objective function were replaced, *ceteris paribus*, by monetary values.

III

ENERGY INPUTS AND OUTPUT

In this section an attempt is made to throw light on the energy inputs and output in existing cropping systems and milk production/milch animals. Further, the sourcewise energy requirement in various cropping systems and milch animals under recommended technology is also discussed.

(i) *Energy Inputs and Outputs at Existing Technology*

The sourcewise existing energy use pattern in various cropping systems reveals that the highest proportion of energy supplied to different cropping systems was from chemical fertilisers[7] except in vegetable-based rotations wherein the major source of energy was human labour, followed by chemical fertilisers and farmyard manure (FYM). However, in rice-potato rotation, the major proportion of energy was supplied through FYM, followed by human labour. The amount of energy used through pesticides and herbicides was negligible due to low infestation of the crops by insect-pests and diseases and sufficient family labour available for manual weeding in various crops. The energy used through the implements and machineries was higher in those rotations which included wheat crop, revealing thereby that wheat threshing was mostly done by power thresher in the study area.[8]

The total amount of energy used in the production was the highest in maize-potato-wheat rotation (38 GJ/ha),[9] followed by rice-potato (27 GJ/ha), maize-toria-wheat (25 GJ/ha), which was mainly due to greater use of FYM, seed tubers and human labour in potato crop.[10] The least energy use was observed in sesamum-wheat rotation which was due to low use of high energy inputs, especially FYM and chemical fertilisers in sesamum crop which is generally grown on marginal lands that are away from the farm house. Overall, around 15 per cent of total energy used in these cropping systems was through human labour[11] for different farm operations which included both family labour as well as hired-in human labour.Hence, it can be inferred that hill farms are more human labour intensive than their counterparts in the plains. The largest amount of energy under unirrigated conditions was used in rice-wheat (18 GJ/ha), followed by maize-wheat rotation (17 GJ/ha).

Livestock being complementary to crop farming, almost all the sampled households maintained one or more units of livestock. Large farmers were having more animals compared to small farmers due to greater availability of dry and green fodder. Among dairy animals, buffaloes were most popular on small farms whereas crossbred cows on large farms, which was mainly due to the fact that small farms had limited land for growing fodder crops/grazing animals that was necessary for crossbred cows. Obviously, the daily energy requirement to maintain a crossbred cow is the highest (33 GJ/animal), followed by buffalo (29 GJ/buffalo) and local cow (17 GJ/animal). The sourcewise energy inputs reveal that dry fodder and green fodder are the main sources of energy for milch animals of hill areas.

From the existing net energy output and energy output-input ratios in different cropping systems and dairy animals, it could be inferred that crops were energy generating activities, whereas dairy animals were energy consuming enterprises. This was because of the fact that the crops captured solar energy[12] by the process of photosynthesis and produced economic products with higher energy values. Contrarily, dairy animals consume more quantity of plant products.and generate in turn, animal products of better quality but less energy resulting in negative net energy output.

On small farms, among the crop enterprises, sorghum-berseem rotation emerged as the most efficient rotation with a net energy output of 110 GJ/ha leading to an energy output-input ratio of 5.86. This was due to the multi-cutting practices on these crops resulting in greater biomass production. Contrary to this, vegetable rotation of okra-cauliflower was the least energy efficient with only

19 GJ/ha of net energy output and energy output-input ratio (2.17). This was because of the low caloric value, despite their high mineral and vitamin contents. Similarly, those rotations which included potato and other vegetable crops were relatively less energy efficient.

The cropping systems were more energy efficient under irrigated conditions than under unirrigated conditions. This was because of the higher yield under irrigated conditions as the irrigation[3] did not involve substantial energy input other than human labour, implying thereby that energy efficiency of crops can be greatly improved through irrigation in the study area.

The existing net energy output and energy output-input ratios in different cropping systems on large farms revealed that the large farms also exhibited the same pattern of energy input-output relationship as on the small farms with a few exceptions. Sorghum-berseem and rice-berseem rotations were more energy efficient on large farms as compared to those on small farms. This was because of the reason that the large farms allocated better land for fodder crops to maintain larger number of crossbred cows than on small farms.

As far as energy efficiency of dairy animals is concerned, in terms of net energy output the buffalo performed better than the crossbred cows and the local cow was found to be the least efficient which was mainly due to her low milk yield leading to low energy output. However, in terms of total energy output, the crossbred cow turned to be the highest energy yielder (50 GJ/animal), followed by buffalo (47 GJ/animal) and local cow (12 GJ/cow).

(ii) *Energy Requirement under Improved Technology*

The sourcewise energy requirement in various cropping systems and milch animals under improved technology visualised the largest amount of energy required through chemical fertilisers, thereby indicating the fertiliser intensive nature of improved technology developed by the farm scientists. Consequently, the proportion of the fertiliser energy, needed for various cropping systems, varied from 29 per cent in sesamum-wheat to as high as 59 per cent of total energy input in rice-linseed rotation. The next important source of energy for improved levels of technology was FYM. However, in the case of rice-linseed and maize-potato-wheat rotations, the requirement of human labour energy was also substantial.

The total amount of energy inputs required to adopt improved technology in the study areas was the highest in maize-potato-wheat rotation (59 GJ/ha), followed by maize-toria-wheat (44 GJ/ha). Therefore, it may be concluded from the above that intensive farming (with three or more crops) would require higher amount of energy inputs. The least energy intensive rotation was found to be sorghum-barley (21 GJ/ha). However, one would have to examine the net energy output in order to know about the efficiency of different cropping systems.

The net energy return in various cropping systems under improved technology revealed that crops give much higher amounts of energy output than the energy input. The highest net energy was obtained from maize-potato-wheat rotation (140 GJ/ha), followed by sorghum-berseem (123 GJ/ha). It was mainly due to the higher energy output in the former and the lower energy input required by the latter. So far as the energy output-input ratio is concerned, sorghum-berseem was the most efficient (6.51), followed by rice-berseem (6.02). On the other hand, okra-cauliflower was found to be the least energy efficient with a net energy of 31 GJ/ha and energy output-input ratio of 1.81. Like existing technology, under improved technology also, the cropping systems with irrigated conditions were more energy efficient as compared to unirrigated conditions due to obvious reasons stated earlier.

It is noted that with improved feeding and management practices of Jersey crossbred cows reared at Himachal Pradesh Krishi Vishvavidyalaya main campus dairy farm and of the buffaloes at the Regional Research Station dairy farm at Dhaulakuan, energy inputs and output in milk production under improved technology were almost the same for both categories of milch animals. As such, the difference in the use of energy inputs for these two species of animals was not pronounced as compared to that on sampled farms. However, the buffalo under recommended technology utilised more energy, particularly due to its higher body-weight. On the other hand, the crossbred cow (Jersey cross) was again found to be efficient in terms of energy output due to its more milk production and less requirement of energy inputs as compared to that of a buffalo. Consequently, the energy output-input ratio was higher in the case of crossbred cow than in a buffalo.

(iii) *Technological Energy Gaps*

The gaps in the total energy requirement under improved technology[14] compared to that actually used by the farmers in different cropping systems are analysed and discussed (Table 1). It is apparent from the table that there is vast scope on small farms to increase net energy output from various existing cropping systems by adopting improved technology. At the same time, the improved technology needs the increased use of energy inputs. The highest increase in net energy output is possible in rice-berseem (150 per cent) which demanded 33 per cent increase in energy input. Similarly, net energy from maize-potato-wheat can be doubled by adopting the improved technology which demanded 55 per cent increase in energy inputs. However, in the case of sorghum-berseem, the farmers used marginally higher amount of energy than required under improved technology. This was because of the higher use of nitrogenous fertilisers than recommended but no use of phosphatic fertilisers was observed in these crops, under the existing practices.

There is more scope for increasing net energy output by adopting improved technology under irrigated conditions as compared to that under rainfed conditions. This issue emerged from the fact that the percentage increase in net energy output under improved technology over existing technology in rice-wheat and maize-wheat rotations was more under irrigated conditions than under unirrigated conditions. Similarly, there is very less scope for increasing net energy from mash-wheat and sesamum-wheat rotations under rainfed conditions by adopting improved technology.

The gap between existing and improved technology was relatively less on large farms than on small farms. This was due to the fact that the large farmers were more progressive than the small ones. However, sesamum-wheat and sorghum-berseem rotations showed that there was a decline in net energy output by adopting improved technology compared to the existing technology. This can be attributed to the fact that in the case of sesamum-wheat rotation, the improved technology needed more than double the amount of energy inputs as compared to the existing technology. But in the case of sorghum-berseem, it seems to be an enigma because the yield of sorghum fodder reported by the farmers was much higher than the yield expected from recommended technology. Apparently,

TABLE 1. ENERGY INPUT AND NET ENERGY OUTPUT UNDER EXISTING VIS-À-VIS IMPROVED TECHNOLOGY FROM IMPORTANT FARMING SYSTEMS

(GJ/ha/year)

Cropping system	Energy input			Net energy output		
	Existing	Improved	Per cent increase*	Existing	Improved	Per cent increase*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Small farms			
Unirrigated						
Rice-wheat	19	32	68.42	43	67	55.81
Maize-wheat	17	29	70.59	57	68	19.30
Mash-wheat	19	23	21.05	48	47	-2.08
Sesamum-wheat	14	30	114.29	36	36	0.00
Irrigated						
Rice-wheat	19	34	78.95	65	106	63.08
Rice-linseed	12	22	83.33	38	70	84.21
Rice-berseem	18	24	33.33	48	120	150.00
Rice-potato	27	43	59.26	60	86	43.33
Rice-wheat-mustard	22	34	54.54	93	120	29.03
Maize-wheat	15	34	126.67	57	100	75.44
Maize-toria-wheat	24	44	83.33	68	115	69.18
Maize-potato-wheat	38	59	55.26	70	140	100.00
Sorghum-berseem	23	22	-4.35	110	123	11.82
Okra-cauliflower	16	39	143.75	19	31	63.16
			Large farms			
Unirrigated						
Rice-wheat	18	32	77.78	45	67	48.89
Maize-wheat	17	29	70.59	53	68	28.30
Mash-wheat	16	23	43.75	47	47	0.00
Sesamum-wheat	14	30	114.29	43	36	-16.28
Sorghum-barley	12	21	75.00	44	62	40.91
Irrigated						
Rice-wheat	20	34	70.00	68	106	55.88
Rice-linseed	17	22	29.41	34	70	105.88
Rice-berseem	20	24	20.00	72	120	66.67
Maize-wheat	18	34	88.89	58	100	72.41
Maize-toria-wheat	23	44	91.30	66	115	74.24
Maize-pea	11	30	172.73	50	90	80.00
Sorghum-berseem	22	22	0.00	157	123	-21.66
Okra-cauliflower	16	39	143.75	22	31	40.91

* Per cent increase or decrease in improved technology over the existing technology.

there is an urgent need to revise the recommendations on the basis of up-to-date field trials.

The net energy output from rice-linseed can be doubled by adopting improved technology which demands about 30 per cent more energy input as compared to the existing technology. On small farms, the scope for increasing net energy, by adopting improved technology, was more under irrigated conditions than under unirrigated conditions. This was due to the fact that fertilisers and irrigation are complementary inputs. Therefore, the government should give immediate attention to improve the irrigation facilities together with the extension of improved techniques to the farmers of the study area.

IV

ENERGY/RETURNS OPTIMISED PLANS

After knowing the existing energy use pattern in the farming systems of the farmers and reviewing the possibilities of increasing net energy through the adoption of improved technology, it is imperative to optimise the use of scarce energy inputs and enterprise combinations for generating energy efficient plans. Commensurate with this objective of the paper, we briefly discuss the existing farming systems (P_0) and optimum farm plans by maximising net energy vis-a-vis net returns as stated earlier.

(i) *Existing Farm Plan*

The existing farmers plan (P_0) exhibited an integrated crop-livestock farming system which had evolved in due course of time in order to meet the subsistence requirements with a minimum risk (Table 2). On both the farm situations, cereals dominated arable land use, and pulses, vegetables and oilseeds were also grown on limited area. The major cropping systems were rice-based on irrigated lands and maize-based on unirrigated lands. Rice-wheat and maize-wheat rotations occupied nearly three-fourths of the total cropped area. Commercial crops like potato, green peas, okra and cauliflower were also grown but on a limited scale.

The cropping systems depend not only on geographic and other environmental factors, but also are influenced by other components of farming systems, notably livestock. The farmers maintained local cows, crossbred cows and buffaloes on their farms, however, small in number, to supply milk for family consumption and farmyard manure for the farm. Large farms maintained more milch animals as compared to small farms, simply because of greater availability of green and dry fodder.

One way of boosting agricultural production from the limited land is its proper management. Therefore, most of the arable lands in the study area were double cropped and triple cropping was also observed under irrigated conditions. The cropping intensity was marginally higher on small farms (201 per cent) than on large farms, which was mainly due to low land-labour ratio in the case of the former.

(ii) *Energy and Returns Efficient Plans*

The energy and returns efficient plans generated at the existing and improved level of technology exhibited significant variation compared to that of the farmer's plan (P_0). However, energy optimised plans did not show marked differences in area allocation under returns efficient plans (Table 2).

Energy optimising plan under existing technology (P_0) on small farms suggested the same cropping system as the return optimising plan (P_3) except for a minor increase in the area under rice-wheat+mustard rotation and exclusion of the rice-potato rotation from the optimum plan. This was due to the low energy returns from potato tubers and higher requirement of input energy in this crop. The net energy maximising plan on large farms deviated considerably from the net return maximising plan. Two rotations, viz., rice-berseem and okra-cauliflower were dropped from the plan, whereas 20.65 per cent of the total cropped area was allocated to rice-wheat (irrigated). To compensate the loss in fodder production, the area under sorghum-berseem increased by more than double. The exclusion of vegetable crops from the system was due to their low energy value and higher need of fertiliser energy and human energy. The area under maize-toria-wheat marginally decreased in this plan. Therefore, the cropping intensity in net energy maximising plan was lower than that in net return maximising plan. One major change in this plan was the exclusion of crossbred cows from the plan and inclusion of three buffaloes. This was because of the lower need of energy inputs like green fodder, concentrates and medicines for buffaloes as compared to crossbred cows. Milk being a product of low energy value, the higher milk yield from crossbred cows did not compensate the higher need of energy input.

Energy optimising farm plan under improved technology (P_2) differed considerably from returns optimising plan (P_4) under improved technology. The maize-toria-wheat and sorghum-berseem rotations did not enter the energy optimising farm plan, since these rotations required large amounts of energy inputs especially through chemical fertilisers. To compensate the fodder supply for milch animals, the area under rice-berseem rotation got doubled. Furthermore, the area under rice-potato decreased by one-third due to low energy output-input ratio of potato crop. The only rotation added over the net return maximising plan was rice-wheat-mustard. However, the scale of maize-wheat under irrigated conditions and that of maize-wheat and mash-wheat under rainfed conditions remained unchanged. Similarly, the only one crossbred cow included in the previous plan remained unchanged. The cropping intensity decreased from 225 per cent in net returns maximising plan to 218 per cent in net energy maximising plan due to the elimination of triple crops maize-toria-wheat from the plan. The minimum home consumption need of oilseeds was met by mixed cropping of mustard in wheat crop.

On the contrary, the net energy maximising plan under improved technology on large farms was much compatible with that under net return maximising plan except the allocation of about one per cent of the total cropped area under rice-wheat by decreasing the area under maize-wheat unirrigated from 40.57 per cent to 39.49 per cent of the total cropped area. There was an exchange of area between two crop rotations included for irrigated land. The area under rice-berseem decreased from about 25 per cent to 6 per cent and the area under maize-toria-wheat increased from about 32 per cent to 50 per cent leading to an increase in cropping intensity from 229 per cent to 248 per cent. However, a major change in the dairy component of the farming system was observed under this plan. The crossbred cows were dropped from the plan and in their place one buffalo entered. The study suggested the need to have a fresh look at energy-feed relationship while developing improved crop varieties/systems.

TABLE 2. ENERGY AND RETURNS EFFICIENT PLANS ON SMALL AND LARGE FARMS

(per cent area)

Farming systems	Small farms					Large farms				
	P_0	P_1	P_2	P_3	P_4	P_0	P_1	P_2	P_3	P_4
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Unirrigated										
Rice-wheat	13.33	-	-	-	-	9.01	-	-	-	-
Maize-wheat	16.88	28.76	35.37	28.76	35.37	19.60	39.09	39.49	39.09	40.57
Mash-wheat	10.91	13.35	6.74	13.35	6.74	3.27	3.33	1.85	3.33	1.85
Sesamum-wheat	0.98	-	-	-	-	7.05	-	-	-	-
Sorghum-barley	-	-	-	-	-	3.49	-	-	-	-
Irrigated										
Rice-wheat	38.54	-	-	-	-	40.86	20.65	-	-	-
Rice-linseed	1.65	-	-	-	-	1.08	-	-	-	-
Rice-berseem	2.34	-	20.49	-	9.47	0.89	-	5.89	13.06	24.60
Rice-potato	4.03	-	5.23	1.44	14.56	-	-	-	-	
Rice-wheat-mustard	3.70	27.30	12.13	26.06	-	-	-	-	-	-
Maize-wheat	3.12	-	-	-	-	6.43	-	-	-	-
Maize-toria-wheat	0.66	-	-	-	6.74	1.53	23.38	50.35	29.04	31.64
Maize-potato-wheat	1.31	18.78	19.42	18.58	19.42	-	-	-	-	-
Maiza-pea	-	-	-	-	-	2.79	6.67	-	6.67	-
Sorghum-berseem	0.66	11.19	-	11.19	7.09	0.89	5.55	-	2.15	-
Okra-cauliflower	1.19	-	-	-	-	1.78	-	-	5.33	-
Others	0.61	0.62	0.62	0.62	0.62	1.33	1.33	1.33	1.33	1.33
Cropping Intensity	201	217	218	217	225	199	221	228	226	229
Dairy animals										
Local cows	0.41	-	-	-	-	0.38	-	-	-	-
Crossbred cows	0.17	-	1	-	1	0.76	-	-	4	6
Buffaloes	0.49	1	-	1	-	0.71	3	1	-	-

* Number of milch animals maintained/suggested.

V

ENERGY INPUTS DEMAND AND RETURNS

The agricultural sector is one of the major consumers of energy inputs for various operations done on and off the field. The level of productivity of farming depends upon the level of energy inputs applied in various farm operations. Therefore, it becomes imperative to estimate the demand ts along with net energy output and net returns generated by the optimal plans on small and large farms (Table 3).

TABLE 3. ENERGY INPUTS DEMAND AND ENERGY OUTPUT/RETURNS OF OPTIMAL PLANS

(per farm)

	Small farms					Large farms				
Particulars (1)	P_0 (2)	P_1 (3)	P_2 (4)	P_3 (5)	P_4 (6)	P_0 (7)	P_1 (8)	P_2 (9)	P_3 (10)	P_4 (11)
1. Chemical fertilisers (kg)										
N	59.02	95.46	175.43	95.63	179.50	201.39	237.47	696.44	247.46	708.15
P_2O_5	13.63	14.74	91.60	15.03	99.73	36.23	42.33	358.65	55.85	393.78
K_2O	10.74	12.33	43.16	12.54	60.30	27.13	32.58	263.42	.43.28	310.74
Total (NPK)	83.39	122.43	310.19	123.20	339.53	264.75	312.38	1,318.58	346.59	1,412.67
2. Working capital (Rs.)	3,010	4,225	4,849	4,353	4,969	4;075	5,237	7,542	7,651	7,756
3. Human labour (man-days)	353	347	346	347	330	965	934	774	1,054	1,217
4. Tractor (hours)	1.01	2.07	2.27	2.80	2.95	6.07	9.32	13.64	13.94	26.78
5. Net energy output (MJ)	7264	10743	31106	-	-	51910	95412	145017	-	-
Increase over P_0 (per cent)	-	47.89	328.22	-	-	-	83.80	179.36	-	-
Increase over P_1 (per cent)	-	-	189.55	-	-	-	-	51.99	-	-
6. Net Returns (Rs.)	3,291	-	-	4,681	22,023	24,197	-	-	40,352	1,00,720
Increase over P_0 (per cent)	-	-	-	61.92	661.78	-	-	-	66.76	316.25
Increase over P_3 (per cent)	-	-	-	-	370.48	-	-	-	-	149.60
7. Net energy per rupee investment (MJ)	2.41	2.54	6.41	-	-	12.74	18.22	19.22	-	-
8. Net returns per rupee investment (Rs.)	1.09			1.48	4.43	5.94	-	-	5.27	12.98

It may be visualised that energy optimal plans demanded comparatively low level of major inputs like chemical fertilisers, human labour, traction power and working capital as compared to returns efficient plans. The superiority of energy optimal plans can be judged in terms of increased net energy or reduced energy inputs over the net returns optimal plans. As mentioned earlier, energy efficient plans saved crucial energy inputs like human labour, chemical fertilisers and traction power, implying thereby the superiority of energy optimal plans over the net returns maximising plans.

The ultimate objective of optimisation of farming system was to maximise net energy output and net returns. As far as energy optimisation was concerned, all the energy optimal plans generated higher net energy on both the farm situations. By using optimisation technique, the net energy under existing technology increased by 48 per cent over the farmer's plan under small category and the adoption of improved technology boosted net energy output by 190 per cent over the optimal plan developed with existing technology. Further, the optimisation and improved technology altogether increased net energy output on small farms by 328 per cent. Similar trends were observed on large farms wherein the optimisation resulted in an increase of 84 per cent in net energy output which was quite higher than that on small farms. This confirms the larger scope of energy optimisation on large farms as compared to that on small farms. Further, the adoption of improved practices on large farms increased net energy output by 52 per cent over the optimised net energy output from the existing technology which was much less than the increase in net energy on small farms due to adoption of improved technology. This revealed that as far as net energy output was concerned, small farmers have larger scope for adopting improved technology, whereas large farmers have better scope for optimisation.

The net returns in the existing plan (P_0) on small farms was Rs. 3,291 and it increased by 62 to 370 per cent in the optimal plans. The net returns per rupee investment also increased from Rs. 1.09 under the farmer's plan to Rs. 4.43 in the optimal plan. Similarly, the net returns and returns per rupee investment showed marked increase in the returns optimised plan of large farms over their existing plan. In the energy optimal plans, the net energy per rupee investment also increased over the farmer's plan on both the categories. The net energy per rupee investment and net returns per rupee investment showed increase with the farm holding size, which indicates that large farmers are more energy efficient and returns efficient than the small farmers which may be due to more education and awareness of the former than the latter, though this trend is reverse in the plain areas (Singh and Subbarayan, 1986).

To sum up, the study concludes that the farmers have to compromise very little in terms of net returns if they are to adopt energy optimised plans. Since the energy optimal plans showed saving of energy intensive inputs like chemical fertilisers, human labour and traction power to a large extent as compared to that of returns optimised plans, it implied that the farmers in hills are more energy conscious in using the energy inputs wisely and judiciously. Therefore, the policy makers and planners should lay more emphasis on energy maximising plans because these can generate higher monetary returns and save energy inputs for making agriculture sustainable. For this, it is suggested that short duration training on farm management extension should be arranged for the hill farmers, particularly small farmers so that they may be able to understand the importance of judicious allocation/use of scarce energy inputs to have more energy efficient, economically viable and sustainable farming systems. Further, to make agriculture more sustainable, incentives should be given to the farmers to adopt energy optimising farm plans which will save energy inputs for future use. It is also suggested that to make the small farms more energy conscious and efficient, small sized machinery and equipments that suit the needs of hill farmers should be manufactured on priority and

ANNEXURE 1. ENERGY EQUIVALENT UNITS OF VARIOUS FARM INPUTS AND OUTPUTS

Particulars (1)	Physical units (2)	Energy equivalent unit (MJ) (3)
Rice seed	kg	14.70
Wheat seed	kg	14.70
Berseem seed	kg	19.68
Potato seed	kg	1.65
Mustard seed	kg	25.00
Maize seed	kg	14.70
Toria seed	kg	25.00
Péa seed	kg	13.19
Mash seed	kg	14.70
Sesamum seed	kg	25.00
Linseed	kg	25.00
Sorghum seed	kg	14.70
Barley seed	kg	14.70
Okra seed	kg	20.92
Cauliflower seed	kg	125.60
Rice straw	qtl	376.81
Wheat straw	qtl	820.61
Maize stover	qtl	293.08
Berseem fodder	qtl	177.23
Sorghum fodder	qtl	261.92
Barley fodder	qtl	177.23
Potato tuber	qtl	260.00
Okra fruit	qtl	550.00
Pea pods	qtl	550.00
Cauliflower curd	qtl	100.48
FYM	qtl	30.00
Chemicals (a.i.)	kg	120.00
Nitrogen	kg	61.55
Phosphorus	kg	12.56
Potassium	kg	6.70
Human labour	man-days	15.68
Bullock labour	Bullock pair-days	64.56
Tractor	hours	331.59
Milk	kg	2.81
Groundnut cake	kg	16.16
Ready made mix	kg	13.68
Wheat bran	kg	12.44
Tractor trailor	per ton per km	4.86

cost effective basis. Moreover, there is an urgent need to replenish the soil fertility by adopting modern technologies like green manuring, organic recycling and bio-fertilisers to reduce the dependency on chemical fertilisers which heavily depend on imported energy resources such as petroleum products, etc. Above all, modern agro-techniques should be assessed not only in monetary terms but also in energy terms so as to make the farming community more energy conscious for the sustainability of agriculture, particularly, in the hill regions of the country.

NOTES

1. Kangra valley of Himachal Pradesh (North India) includes 12 blocks, viz., Baijnath, Bhawarana, Dehra, Indora, Kangra, Lambagran, Nagrota Surian (in place of Mangwal which have submerged in Pong dam, Nagrota Bhawan, Nurpur, Panchrukhi, Paragpur and Rait (Pant, 1995).

2. The primary data relate to demographic parameters (cost, family size, age, education, occupation, etc.), economic parameters (like inventory of land, farm buildings, livestock, farm machinery and implements, cropping pattern, income, human labour, bullock labour, etc.) and energy input-output of different crop rotations/farming systems, resource availability along with prices of inputs purchased and outputs sold and problems/constraints experienced by the sample farmers. The secondary data relate to the profile of study area, recommended practices of different crops/crop rotations, etc., were taken from the package of practices for *kharif* and *rabi* crops developed/ published by Himachal Pradesh Krishi Vishvavidyalaya, Palampur. For details, see Pant (1995).

3. Various researchers used different energy values in their studies but the ones that fit into the framework of the present study were considered in the analysis (see Mittal *et al.*, 1985; Patel *et al.*, 1982 and Pimentel, 1980). Also see Annexure 1.

4. The estimates of sourcewise and operationwise energy use could not be given in the text due to space limitation. However, the interested readers may obtain them from the senior author.

5. LINDO (Linear, Interactive and Discrete Optimizer) systems, Solan School, MIT (1984) was used to generate optimum plans in this study.

6. Mega Joule is a unit of energy and 1 MJ = 10^6 joules, and 4.18 joules = 1 calorie.

7. Similar results have been reported by earlier studies conducted in other states. For details, see Saini *et al.* (1986).

8. Similar results were reported by an earlier study conducted in hilly regions of Himachal Pradesh. See Bhati *et al.*

9. GJ stands for giga joule; 1 GJ = 10^9 joules.

10. The studies already conducted in other states reported that about 30 per cent of the energy use in potato crop was through seed tubers. See Yadav *et al.* (1991).

11. A study conducted in Haryana reported that the proportion of human labour energy used in different crops varied from 2 to 4 per cent of the total energy use. For details, see Pandey *et al.* (1995). Another study in the same state reported that the proportion of human labour energy to the total energy input was 9 and 4 per cent in rice and wheat crops respectively. See Patel *et al.* (1983).

12. Due to data constraints, the amount of energy used by the crops from sun, rainfall and soil could not be included for estimating the total of energy use in agriculture.

13. The main source of irrigation in the study area is *kuhl* which is just like a small canal.

14. Existing technology refers to farmers' technology and improved technology means technology recommended by HPKV farm scientists.

REFERENCES

Adhaoo, S.H. (1981), *Optimisation of Energy Inputs for Crop Production*, Ph.D. Thesis, Division of Agricultural Engineering, Indian Agricultural Research Institute (IARI), New Delhi (Unpublished).

Bell, R.D. and T.J. Willcocks (1982), "Energy Conservation in Mechanisation of Agriculture in Developing Countries", Proceedings of the Second International Seminar on Energy Conservation and the Use of Renewable Energies in the Bio-industries, held at Trinity College, Oxford, on 6-10 September 1982.

Bender, D.A.; R.M. Peart, D.H. Doster, J.R. Barrett and M.O. Bagby (1984), "Energy Crop Evaluation by Linear Programming", *Energy Agriculture*, Vol. 3, pp. 199-210.

Bhati, J.P.; M.S. Rathore and R. Swarup (1981), "Energy Requirements for Agriculture: Some Methodological Issues and Prospective for Hill Agriculture", Paper presented at the National Seminar on "Pattern of Energy Utilization and Returns in Different Farming Systems in India", March 16-18, IARI, New Delhi.

Gopalakrishanan, C.; E.N. Koffi-Tessio and G.H. Khaleghi (1985), "Energy Price Increase and Its Impact on Agricultural Production: Evidence from Hawali", *Energy Agriculture*, Vol. 4, pp. 179-188.

Mittal, V.K.; J.P. Mittal and K.C. Dhawan (1985), *Research Digest on Energy Requirements in Agricultural Sector*, College of Agricultural Engineering, Punjab Agricultural University, Ludhiana.

Ozkan, H.E. and J.C. Frisby (1980), "Determining Production Policies for Crops to Maximise Net Energy Return", Paper presented at the Asian Society of Agricultural Economists National Energy Symposium, *Agricultural Energy*, Vol. 2, Asian Society of Agricultural Economists, St. Joseph, Michigan, U.S.A.

Painuly, J.P.; J.K. Parikh and D.R. Shah (1992), "Rural Energy System and Agriculture: Alternative Scenarios for Gujarat", *Economic and Political Weekly*, Vol. 27, No. 34, August 22, pp. 1801-1809.

Pandey, R.N.; J.C. Karwasra and K. Aggarwal (1995), *Energy Utilization Pattern in Haryana Agriculture (A Farm Level Study)*, Research Bulletin No. 15, Department of Agricultural Economics, Haryana Agricultural University, Hisar.

Pant, K.P. (1995), *Economics of Energy Management in Hill Agriculture*, M.Sc Thesis, Department of Agricultural Economics, Himachal Pradesh Krishi Vishvavidyalaya. Palampur (Unpublished).

Patel, R.K.; A.S. Saini and R.V. Singh (1983), "Energy in Agriculture", *Economic Affairs*, Vol. 28, No. 2, pp. 715-723.

Patel, R.K.; R.V. Singh; A.S. Saini and R.C. Nagpal (1982), "Energy Input and Cost of Milk Production", *Agricultural Situation in India*, Vol. 36, No. 11, February, pp. 791-796.

Pimentel, D. (1980), *Handbook of Energy-Utilization in Agriculture*, C.R.C. Press, Boca Raton, Florida, U.S.A.

Pimentel, D.; L.E. Hurd, A.C. Bellotti, M.J. Forester, I.N. Oka, O.D. Sholes and R.J. Whitman (1973), "Food Production and the Energy Crisis", *Science*, Vol. 182, pp. 443-449.

Pimentel, D.; W. Dritschilo, J. Krummel and J. Kutzman (1975), "Energy and Land Constraints in Food Protein Production", *Science*, Vol. 190, pp. 754-761.

Saini, A.S.; R.K. Patel and R.V. Singh (1986), "Energy Use in Rice-based Farming System in India", *International Rice Research Newsletter*, Vol. 11, No. 4, pp. 42-43.

Sen, D.; S.K. Nanda and B. Bhattacharya (1986), "Pattern of Energy Use in Rural Areas", *Journal of Rural Development*, Vol. 5, No. 4, pp. 397-436.

Singh, I. and M. Subbarayan (1986), "Optimal Use of Energy Inputs on Different Size-Groups of Farms in Meerut District of Uttar Pradesh", *Indian Journal of Agricultural Economics*, Vol. 41, No. 1, January-March, pp. 59-70.

Sirohi, A.S.; B.M. Sharma; C. Singh and R. Dayal (1991), "Optimisation of Energy Inputs in Production of Major Crops in the Union Territory of Delhi", Paper presented at the National Seminar on "Pattern of Energy Utilization and Returns in Different Farming Systems in India" March 16-18 at Indian Agricultural Research Institute, New Delhi.

Yadav, R.N.; R.K.P. Singh and S. Prasad (1991). "An Economic Analysis of Energy Requirements in the Production of Potato Crop in Bihar Sharif Block of Nalanda District (Bihar)", *Economic Affairs*, Vol. 36, No. 2, pp. 112-119.