ENERGY REQUIREMENT IN AGRICULTURAL SECTOR: A LINEAR PROGRAMMING APPROACH

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Preface

The Central Institute of Agricultural Engineering, Bhopal has been running an All India Coordinated Research Project on Energy Requirement in Agricultural Sector (ERAS). The Co-ordinated project has 12 coordinating centres spread all over the country. Under this project a large volume of data has been collected on uses of Human Labour, Animal labour, Diesel, Electricity, Seed Rate, Farmyard Manure (FYM), Fertilizer, Chemicals, Machinery, Canal, etc. These are then converted into Mega Joule / hectare (MJ/ha) using internationally accepted conversion factors. The energy uses are also available on agricultural operations like tillage, sowing, bund making, fertilizer application, transportation, harvesting, threshing, post harvest operations, etc. Dr. Dipanker De, Project Co-ordinator, visited Indian Agricultural Statistics Research Institute (IASRI) for consultations concerning the analysis of this large volume of data collected. This formed the basis of a very strong association of IASRI with this project. Over the time this association has grown so strong that IASRI organized a training programme for the scientists of various co-ordinating centres in the AICRP on ERAS during March 27 - April 5, 2000. The main theme of the training programme was related to the statistical techniques involved in the analysis of data collected under this project and the use of software packages to undertake the analysis of data. The topics covered were essentially regression analysis, regression diagnostics, response surface methodology, optimization techniques, linear programming, etc.

The scientists of the IASRI also participated in the Co-ordination committee meeting held at IASRI during April 2000. During the training programme, the various statistical procedures to be used for the analysis of ERAS data were discussed and finalized. It was also decided that linear programming technique would be employed to ERAS data. In this regard two approaches for defining the objective function were discussed. The first approach considers the objective function as the fitted multiple linear regression equation. This is actually the procedure that was proposed in the initial stages of discussions by IASRI and then followed up by co-ordinating centre of the project. However, a close scrutiny reveals that such an objective function may be ***error prone like it may have large standard error of the estimated response, the regression coefficients may also have large standard errors, and moreover, many of the regression coefficients may not be significantly different from zero.*** Therefore, it was felt that the use of such an objective function might be avoided. The second option of the objective function is that we consider the data of energy usage and productivity of each farmer as a separate activity and define the objective function and constraints. The Deputy Director General (Agricultural Engineering), ICAR, therefore, advised that IASRI and Dr. De, Project Co-ordinator, ERAS, discuss the technique threadbare and a detailed report giving various statistical analytical aspects along with solved examples on the same be submitted to him.

IASRI scientists held detailed discussion with the project Co-ordinator and his colleagues and finalized the procedure. The procedure was illustrated with the help of the data pertaining to Sihoda on wheat crop. In order to review the general applicability of the methodology, the co-ordinating unit applied this procedure on some more data sets. The results of the analysis obtained from these data sets are also included in this report. We hope that the methodology finalized in this report would be extremely useful in bringing out the meaningful information from this gold mine of data.

We express our deep sense of gratitude to Dr. Anwar Alam, DDG (Engineering) for imposing faith in IASRI and entrusting it with the responsibility of analyzing this data the results of which would be of immense use in policy making for determining the energy requirements in Agricultural Sector. We are also thankful to Dr NSL Srivastava, ADG (Engineering), for his very kind support and encouragement provided during the course of investigation. The training programme organized at IASRI indeed helped us in getting an insight into the problem.

Our sincere most thanks are due to Dr S.D.Sharma, Director, IASRI for providing moral support, encouragement and for providing all the facilities at IASRI during the course of this investigation. His tips during the course of investigation have been very fruitful. Our thanks are also due to Dr. Gyanendra Singh, Director, CIAE, Bhopal, for his kind support and help from time to time during the entire period of running of this project.

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1. Introduction

The data on various aspects of energy usage in agricultural production system is being collected from the farmers of the selected villages in different agro-climatic zones under the All India Co-ordinated Research Project on Energy Requirement in Agricultural Sector. The information is collected on uses of Human Labour, Animal labour, Diesel, Electricity, Seed Rate, Farmyard Manure (FYM), Fertilizer, Chemicals, Machinery, Canal, etc. These are then converted into Mega Joule / hectare (MJ/ha) using internationally accepted conversion factors. The energy uses are also available on agricultural operations like tillage, sowing, bund making, fertilizer application, etc. Adding the energy levels from different sources generates the total energy used for crop production that forms another factor in the study. The data available on yields are converted into per hectare basis. As of now, the data is available on yield (kg/ha or MJ/ha), energy used (MJ/ha) from various sources and total energy used (MJ/ha).

Among various uses of the data, one use is for establishing the relationship between yield and total energy; yield and other sources of energy like human labour, animal labour, diesel, electricity, FYM, fertilizers, chemical, machinery, irrigation, canal, etc.; to find out the optimum values of the various energy sources for maximum productivity. For this purpose, first order and second order response surfaces can be fitted. A pertinent question that arises here is as to whether a single regression equation (or response surface) will adequately describe the relationship for all categories of farmers under consideration or will different regressions be required for each category of farmers? A complete description of the response (the best fit of data) would be obtained by allowing each category to have its own regression equation (or response surface). This would be inefficient, however, if the responses were similar over all categories; the researcher would be estimating more parameters than necessary. On the other hand, a single regression equation (or response surface) to represent the response for all categories will not adequately characterize any one group and could be very misleading if the relationships differed among categories. It is, therefore, desirable to fit a separate response surface for each category of farms and test for homogeneity of regression equations (or response surfaces). If the regression equations are homogeneous then it is advisable to fit a common regression equation to the entire data set. Otherwise the analysis should be carried out separately for each category. The various categories of farmers may be made on the basis of irrigated or rainfed, electricity use or non-use, bullock or tractor use, based on productivity levels like low ($\leq$ *2000* Kg/ha), medium (*2000 - 3250* Kg/ha), high ($\geq$ *3250* Kg/ha), etc. or based on the ratio of total energy to yield (energy-yield ratio) like high (< *3.50*), medium (*3.50 - 4.00*), low (*4.00 - 5.00*), very low $\geq$ *5.00.* The choice of categorization would depend upon the purpose of analysis.

The second objective is to obtain the optimum energy levels for different sources like human energy, animal energy, diesel energy, electrical energy, FYM energy, fertilizer energy, machinery, irrigation, etc. to maximize the yield. To achieve this, we require fitting at least a second order response surface. If second order response surface is a good fit, then one can obtain the co-ordinates of the stationary point by equating the first derivative of the fitted second order response surface equal to zero. The nature of the stationary point

(point of maxima, minima or a saddle point) can be established through canonical analysis. If the stationary point is a saddle point and lies within the input range, then one can explore the response surface in the vicinity of the stationary point. This exploration gives various combinations of input variables for a desired output in the vicinity of the predicted response at the stationary point. One can choose the input combination based on the practical considerations. For more details on this one may refer to **Reference Manual** for the Training Programme on ***"Energy Requirement in Agricultural Sector: Analytical Techniques and Statistical Software Packages"*** held at IASRI, New Delhi during March 27 - April 5, 2000.

However, using several sets of data, it has been observed that most of the time the regression coefficients are not significantly different from zero, particularly the second-degree coefficients; and/or saddle point lies outside the input range. It seems that the energy usage has not yet reached the saturation stage or plateau. In other words, the relationship of yield with energy levels of various factors appears to be linear in nature. Therefore, to obtain the levels of various inputs that maximize the yield per hectare, recourse is to be made to the use of Linear Programming (LP). In LP problem, the objective function and the constraints are very important. Therefore, one has to be cautious in defining the objective function and constraints. In the initial stages, it was thought that one should fit a multiple linear regression, and use the fitted multiple linear regression equation as an objective function and availability of the energy from different sources like human, animal, diesel, electricity, machinery, etc. as constraints. However, a close scrutiny reveals that such an objective function may be ***error prone like it may have large standard error of the estimated response, the regression coefficients may also have large standard errors, and moreover, many of the regression coefficients may not be significantly different from zero.*** Therefore, the use of such an objective function is to be avoided. The second option of the objective function is that we consider the data of energy usage and productivity of each farmer as a separate activity and define the objective function and constraints in Section 2.

2. Linear Programming Approach

In this section, we shall describe the procedure of defining the objective function and constraints for obtaining the optimum solution [yield or production maximization (average energy use basis, improved practice basis, energy minimization, etc.)] for the Energy Requirement in the Agricultural Sector Data. We explain the problem of yield maximization in section 2.1. The problems of production maximization and energy minimization can be handled in a similar fashion and have also been explained in this section.

2.1 Yield Maximization

Let X_i denote the area allocated according to the energy usage of activity i in hectares and Y_i denote the yield (kg/ha) from the activity i. Then the objective function is:

$$maximize \;\; yield \; = \sum_{i=1}^{n} Y_i X_i \tag{2.1}$$

subject to constraints

(1) $H_1 \leq \sum_{i=1}^{n} h_i X_i \leq H_2$

where h_i = human energy level for activity i, MJ/ha

H_1 = Lower bound on human energy available per activity

H_2 = Upper bound on human energy available per activity

(2) $A_1 \leq \sum_{i=1}^{n} a_i X_i \leq A_2$

where a_i = animal energy level for activity i, MJ/ha

A_1 = Lower bound on animal energy available per activity

A_2 = Upper bound on animal energy available per activity

(3) $D_1 \leq \sum_{i=1}^{n} d_i X_i \leq D_2$

where d_i = Diesel energy level for activity i, MJ/ha

D_1 = Lower bound on diesel energy available per activity

D_2 = Upper bound on diesel energy available per activity

(4) $E_1 \leq \sum_{i=1}^{n} e_i X_i \leq E_2$

where e_i = electricity energy level for activity i, MJ/ha

E_1 = Lower bound on electricity energy available per activity

E_2 = Upper bound on electricity energy available per activity

(5) $S_1 \leq \sum_{i=1}^{n} s_i X_i \leq S_2$

where s_i = seed energy level for activity i, MJ/ha

S_1 = Lower bound on seed energy available per activity

S_2 = Upper bound on seed energy available per activity

(6) $F_1 \leq \sum_{i=1}^{n} f_i X_i \leq F_2$

where f_i = fertilizer energy level for activity i, MJ/ha

F_1 = Lower bound on fertilizer energy available per activity

F_2 = Upper bound on fertilizer energy available per activity

(7) $$M_1 \le \sum_{i=1}^{n} m_i X_i \le M_2$$

where m_i = machine energy level for activity i, MJ/ha

M_1 = Lower bound on machine energy available per activity

M_2 = Upper bound on machine energy available per activity

(8) $$C_1 \le \sum_{i=1}^{n} c_i X_i \le C_2$$

where c_i = chemical energy level for activity i, MJ/ha

C_1 = Lower bound on chemical energy available per activity

C_2 = Upper bound on chemical energy available per activity

(9) $$FY_1 \le \sum_{i=1}^{n} fy_i X_i \le FY_2$$

where fy_i = Farm yard manure energy level for activity i, MJ/ha

FY_1 = Lower bound on Farm yard manure energy available per activity

FY_2 = Upper bound on Farm yard manure energy available per activity

(10) $$CL_1 \le \sum_{i=1}^{n} cl_i X_i \le CL_2$$

where cl_i = Canal energy level for activity i, MJ/ha

CL_1 = Lower bound on Canal energy available per activity

CL_2 = Upper bound on Canal energy available per activity

(11) $$T_1 \le \sum_{i=1}^{n} t_i X_i \le T_2$$

where t_i = total energy consumed by activity i in MJ/ha

T_1 = Lower bound on total energy available per activity in MJ/ha

T_2 = Upper bound on total energy available per activity in MJ/ha

It may be worthwhile mentioning here that the upper bound on total energy should not exceed the sum of upper bounds on all other constraints. Similarly, the lower bound on total energy should not be less than the sum of lower bounds on all other energy sources.

Similarly one may define some more constraints on other sources of energy depending upon the requirement of the situation, if available, and use in the activities. Besides the energy sources, one may also define the constraints on the energy available for different agricultural operations or any other set as required. One can see that for $X_1 = 1, X_2 = X_3 = ... = X_n = 0$, we get Y_1 and the solution is same as the energy usage by that activity. Hence, one can see that the objective function has logical interpretation. One has to define one more constraint

$$\sum_{i=1}^{n} X_i = 1$$

This ensures that we are interested in maximization of yield per hectare basis and giving equal weight to each of the activities.

In this procedure, average consumption of different energy levels can always be taken as upper bounds on different energy sources like human, animal, diesel, electricity, machinery, fertilizer, farm yard manure, chemical, total energy, etc. It is important here that the number of activities or decision variable included in the basis will be less than or equal to the number of constraints in it. When no explicit lower bounds are specified, LP assumes that the lower bounds are zero.

Once we get the solution for $X_i' s$, say X_i^*'s one can get the values of objective function (*i.e.* the value of the maximum yield) as

$$\text{Optimum Yield} = \sum_{i=1}^{n} Y_i X_i^* \tag{2.2}$$

The usage of various energy sources can be obtained using the expressions

$$\text{Human Energy} = \sum_{i=1}^{n} h_i X_i^*$$

$$\text{Animal Energy} = \sum_{i=1}^{n} a_i X_i^*$$

$$\text{Diesel Energy} = \sum_{i=1}^{n} d_i X_i^*$$

$$\text{Electrical energy} = \sum_{i=1}^{n} e_i X_i^*$$

$$\text{Seed Energy} = \sum_{i=1}^{n} s_i X_i^*$$

$$\text{Fertilizer Energy} = \sum_{i=1}^{n} f_i X_i^*$$

$$\text{Machine Energy} = \sum_{i=1}^{n} m_i X_i^*$$

$$\text{Chemical Energy} = \sum_{i=1}^{n} c_i X_i^*$$

$$\text{Farmyard manure energy} = \sum_{i=1}^{n} fy_i X_i^*$$

$$\text{Canal Energy} = \sum_{i=1}^{n} cl_i X_i^*$$

$$\text{Total Energy} = \sum_{i=1}^{n} t_i X_i^*$$

We know that $t_i = h_i + a_i + d_i + e_i + s_i + f_i + m_i + c_i + fy_i + cl_i$, therefore, one can see that the sum of the energy usage from different sources shall be equal to the total energy usage.

Note 2.1: For each of the activities, the data pertaining to various agricultural operations or any other subset can also be used in the similar fashion to get the optimum energy required operation wise. For example, we have the data on bund making, say *(bm)ᵢ* where *(bm)ᵢ* is the energy used for bund making by the i^{th} activity ; *i=1,…,n,* then $\sum_{i=1}^{n}(bm)_i X_i^*$ gives the optimum energy required for bund making.

2.2 Illustration

In this section, we shall illustrate the Linear programming approach described in Section 2.1 using the data pertaining to Sihoda for wheat crop. In this data set, there were 96 farmers out of which 17 were marginal, 32 were small, 32 were medium and 15 were large farmers. The average usage of different energy sources (MJ/ha) category wise, overall and average yield (kg/ha) obtained are given in Table1.

Table 1: Average usage of different energy sources (MJ/ha) category wise, overall and average yield (kg/ha)

	Marginal	Small	Medium	Large	Combined
Human	889.53	779.19	884.59	934.93	858.20
Animal	0	0	0	0	0
Diesel	1578.12	1638.56	1795.81	2362	1793.31
Electricity	2309.24	2118.78	2622.81	3067.40	2468.74
Seeds	1485.82	1491.81	1508.97	1483.00	1495.09
FYM	0	0	0	0	0
Fertilizer	4916.59	4752.72	5196.59	4743.33	4928.23
Machinery	260.88	262.28	289.59	394.40	291.78
Chemical	2.41	8.19	20.34	24.40	13.75
Total Energy	11442.58824	11051.53	12318.72	13009.47	11849.10
Yield	2878.12	2701.78	2800.44	2945.47	2803.97

It may be noted that all values pertaining to animal and farmyard manure energy are zero; hence, these two sources have been excluded from the further discussion in this illustration.

The data were analyzed using the values of average usage of different energy sources as upper bounds except that of yield. The activities included in the Basis along with coefficients (value) and optimum yield in different categories of farmers and on the combined data are given in Table 2.

Table 2: Activities included in the Basis along with coefficients (value) and the optimum yield (kg/ha).

Category	Activities included In basis	Respective values	Optimum yield (kg/ha)
Marginal	$X_{1}^{*}, X_{2}^{*}, X_{13}^{*}, X_{16}^{*}$	*0.24458989, 0.16789194, 0.11616792, 0.47135035*	3109.663
Small	$X_{5}^{*}, X_{7}^{*}, X_{22}^{*}, X_{26}^{*}$	*0.02879975, 0.29132696, 0.47043776, 0.20943553*	3202.117
Medium	$X_{5}^{*}, X_{7}^{*}, X_{17}^{*}, X_{23}^{*}, X_{26}^{*}$	*0.09766384, 0.16979504, 0.12924683, 0.17095576, 0.43233853*	3071.510
Large	$X_{3}^{*}, X_{6}^{*}, X_{9}^{*}, X_{13}^{*}, X_{14}^{*}$	*0.14527934, 0.22780643,0.09548847, 0.01934153, 0.51208423*	3209.509
Combined (Overall)	$X_{16}^{*},X_{24}^{*},X_{39}^{*},X_{43}^{*}$	*0.20611057, 0.45002608, 0.24344999, 0.10041336*	3554.845

Please note that the activity numbers are for the respective categories.

To make the exposition clear, for category 1, if we allocate 1 hectare of land as per proportions of X_{1}^{*}, X_{2}^{*}, X_{13}^{*} and X_{16}^{*}, we can get a yield of 3109.663 Kg. ***This procedure helps us in identifying the farmers using energy efficiently for energy usage.*** The farmers or activities included in the basis may be considered as model farmers.

The dual value usage of energy sources and range (minimum and maximum values) of energy of these sources for which the current basis remains optimal obtained for different categories of farmers and on the combined data through the dual solution of problems and right hand side ranges are given in Tables 3.1 to 3.5. For a better understanding, the complete output obtained from LP88 is given in ANNEXURE-I for category-I farmers.

Table 3.1: Usage of energy of different sources, range of the energy within which the current basis remains optimal and respective dual values for marginal farmers

Energy Source	Usage	Slack	Dual value	Minimum Energy	Maximum Energy
Human	889.5300	0.0000	0.91251878	863.7560	907.8518
Diesel	1502.8753	75.2447	0.00000000	1502.8750	NONE
Electricity	2282.9524	26.2876	0.00000000	2282.9520	NONE
Seeds	1425.0825	60.7375	0.00000000	1425.0830	NONE
Fertilizer	4916.5900	0.0000	0.04017164	4413.7160	5075.6620
Machinery	260.8800	0.0000	7.35269790	257.5220	263.3433
Chemical	0.0000	2.4100	0.00000000	0.0000	NONE
Total Energy	11277.9100	164.6898	0.00000000	11277.9100	NONE

The slack is the difference of the upper bound and energy usage. The energy source for which the slack is zero is binding whereas a positive value of slack denotes that the source is non-binding.

Table 3.2: Usage of energy of different sources, range of the energy within which the current basis remains optimal and respective dual values for small farmers

Energy Source	Usage	Slack	Dual value	Minimum Energy	Maximum Energy
Human	779.1880	0.0000	0.889220	774.2742	808.1363
Diesel	1638.5600	0.0000	0.857028	1635.1340	1663.4620
Electricity	1954.3670	164.4128	0.000000	1954.3670	NONE
Seeds	1383.1270	108.6828	0.000000	1383.1270	NONE
Fertilizer	4560.5740	192.1458	0.000000	4560.5740	NONE
Machinery	262.2800	0.0000	6.378872	257.1926	262.7490
Chemical	4.3666	3.8234	0.000000	4.3666	NONE
Total Energy	10582.4600	469.0368	0.000000	10582.4600	NONE

Table 3.3: Usage of energy of different sources, range of the energy within which the current basis remains optimal and respective dual values for medium farmers

Energy Source	Usage	Slack	Dual value	Minimum Energy	Maximum Energy
Human	829.9713	54.6227	0.000000	829.9713	NONE
Diesel	1793.7090	2.1011	0.000000	1793.7090	NONE
Electricity	2622.8100	0.0000	0.218673	2618.9300	2710.7390
Seeds	1508.9700	0.0000	0.423494	1501.4150	1542.0760
Fertilizer	5196.5900	0.0000	0.026668	5167.8620	5264.2730
Machinery	289.5900	0.0000	0.363549	282.2832	289.7291
Chemical	12.6670	7.6730	0.000000	12.6670	NONE
Total Energy	12254.3100	64.3928	0.000000	12254.3100	NONE

Table 3.4: Usage of energy of different sources, range of the energy within which the current basis remains optimal and respective dual values for large farmers

Energy Source	Usage	Slack	Dual value	Minimum Energy	Maximum Energy
Human	883.4714	51.4616	0.000000	883.4714	NONE
Diesel	2362.0000	0.0000	0.993984	2255.5520	2496.907
Electricity	2518.1990	549.2012	0.000000	2518.1990	NONE
Seeds	1483.0000	0.0000	2.642473	1475.8370	1543.288
Fertilizer	4743.3300	0.0000	0.161821	3590.5990	5053.687
Machinery	340.9765	53.4236	0.000000	340.9765	NONE
Chemical	24.4000	0.0000	2.355349	23.0303	37.93588
Total Energy	12355.3800	654.1234	0.000000	12355.3800	NONE

Table 3.5: Usage of energy of different sources, range of the energy within which the current basis remains optimal and respective dual values for combined data

Energy Source	Usage	Slack	Dual value	Minimum Energy	Maximum Energy
Human	858.0000	0.0000	0.09248149	827.3821	934.4148
Diesel	1767.7151	25.5949	0.00000000	1767.7150	NONE
Electricity	2320.2176	148.5224	0.00000000	2320.2180	NONE
Seeds	1256.3131	238.7769	0.00000000	1256.3130	NONE
Fertilizer	4928.2300	0.0000	0.15839703	4607.0040	5160.3140
Machinery	291.7800	0.0000	9.69329430	278.1346	296.6512
Chemical	6.3004	7.4496	0.00000000	6.3004	NONE
Total Energy	11428.5560	420.5439	0.00000000	11428.5600	NONE

In the dual problem solution, the dual value indicates the extent to which the value of the objective function will change with a unit change in the corresponding energy source, given that the current optimal basis remains feasible. For example, in case of marginal farmers the dual value of human is 0.91251878, meaning thereby that by increasing the availability of resource (Human) by one unit, the yield increases by 0.91251878 per unit increase in human provided the human value lies between 863.75604 - 907.85178. Similarly the dual value of machinery is 7.3526979 indicating that the change in value of yield will be 7.3526979 Kg/ha for a unit change in the value of machinery provided the energy from the machinery sources lies between 257.52147 - 263.34333 MJ/ha and provided the current optimal basis remains the same.

The above solutions have been obtained for the upper bounds on the constraints as the average usage for that particular source of energy. However, one may change these bounds on the basis of their availability and obtain the optimum yield for that particular availability situation. This may be applicable to any of the energy sources under examination.

Remark 2.2.1: One may be interested in maximizing the production rather than the yield maximization. For this problem the LP model remains the same as that of yield maximization except that the upper bounds on various constraints should be given as total availability of the energy source wise in place of averages. In this one may give the equality bound on the area as the area available with that category. However, a caution is needed that the constraints on the energy sources are to be proportioned as the total availability and area under that category. For example in Category I (marginal farmers), there are 17 farmers, the total availability of energy sources is for 17 hectare. One may convert them for availability of 13 hectares by multiplying the total availability by (13/17). The optimum production obtainable through LP solution is 13 times the solution obtained for yield maximization. The energy usage of different sources is also 13 times that of the yield maximization. Hence, the two problems are related.

Therefore, we can say that one can solve either a yield maximization problem or production maximization problem.

Remark 2.2.2: One may be interested in maximization of total returns in place of yield. For this purpose yield is multiplied by the price of the crop, similarly the energy consumption with respect to different sources is multiplied by their respective values. The LP problem can be defined on these cost values similar to the one defined above for yield maximization and energy minimization. It is important to note here that the solution remains the same except the multiplicities in the data. However, if the economic values change from farmer to farmer in the data set, then the solution may change.

Maximization using both upper and lower bounds

We have also tried the maximization of yield by giving lower and upper bounds to the availability of various energy sources as given by the AICRP on ERAS. The bounds are given as under

Source	**Lower Bound**	**Upper Bound**
Human	857.98	958.00
Diesel	1789.58	2622.40
Electricity	1848.43	2464.57
Seeds	1499.91	1838.00
Fertiliser	4915.44	5493.00
Machinery	291.25	406.50
Chemical	13.75	13.75
Total	**11216.34**	**13796.22**

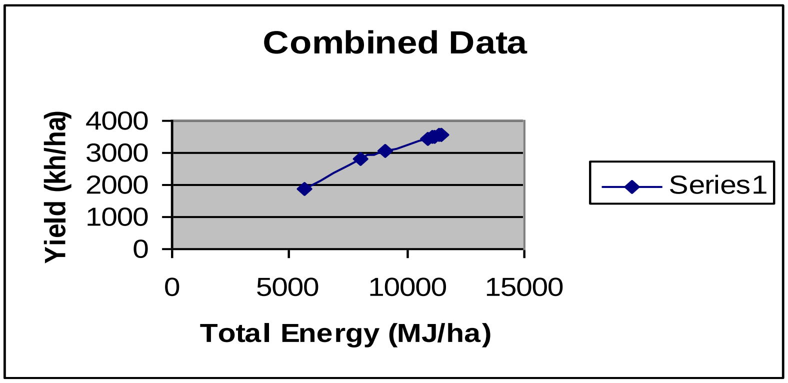
The total is the sum of all the upper bounds. To give lower and upper bounds, it is desired that the particular source of energy is defined in two rows and one row is used for lower bound and another for upper bound. The results obtained are given in ANNEXURE-II.

2.3 Parameterization

For performing the parametric programming, we utilized the data on combined file. We started with an upper bound on Total Energy as 11849.1 MJ/ha (the average availability) and obtained the usage, the minimum and maximum values for total energy for which the current basis remains optimal, the optimum yield at this usage. Then, we change the upper bound on the total energy as the value of minimum total energy and obtained the results. The process is continued till the range in the two successive steps becomes same or an infeasible solution is attained. The solutions obtained are given in the following tables.

Upper Bound Defined on Total Energy	**Usage of Total Energy**	**Range for which Current Basis remains optimal**		**Yield (Kg/ha)**
		Minimum Energy	**Maximum Energy**	
11849.10	11428.556	11428.556	None	3554.845
11428.50	11428.500	11408.424	11428.556	3554.837
11408.40	11408.400	11204.756	11408.424	3552.009
11204.70	11204.700	11088.585	11204.756	3521.662
11088.50	11088.500	10872.176	11088.585	3503.948
10872.10	10872.100	9081.131	10872.176	3463.534
9081.13	9081.130	8065.756	9081.131	3065.822
8065.75	8065.750	5615.000	8065.756	2831.351
5615.00	5615.000	5615.000	8065.756	1853.000

The graphs of Total input Energy (MJ/ha) and Yield (kg/ha) for the above are given as below:



One can see from parameterization that if the usage goes down to the level of 9081.13 MJ/ha from 11428.556 Mj/ha the yield level goes down to 3065.82 Kg/ha from 3554.85 Kg/ha i.e. a loss of 489.03 Kg/ha with a saving of 2347.43 Mj/ha of energy, which shall be sufficient enough for about 0.25 ha of extra land that may give rise to extra 750 Kg/ha. Therefore, if it is not possible to provide the optimum level of energy to each of the farmers, then this saving can result into a benefit to the society.

The technique of parameterization as discussed above on total energy can also be used for any other source of energy.

In order to review the general applicability of the methodology developed, some more data sets on wheat and soybean were analyzed using What’s Best Software. The analysis was carried out on the actual data sets as well as the simulated data sets. The simulation was done by making use of the results on maximum obtainable yield in the area with recommended application rates of seeds and fertilizers obtained in the Cropping Systems Research. These results are discussed in Sections 3 and 4.

3. Wheat Cultivation in Kanaria in M.P.

In this section, we make use the data of wheat cultivation in village Kanaria in M.P (collected by JNKVV Centre) for two years 1988 and 1998. This will enable us to see the effect of change in cultivation practices. In both these data sets outlier(s) were detected and removed before application of LP.

(A) Wheat, 1988

The data pertains to 110 farmers out of whom 84 farmers used bullock alone for farm operations and 26 farmers used both bullocks and tractor. All 110 farms were irrigated. Since cultivation practices differ in bullock and mixed farms, they were segregated into two groups.

As discussed in Section 2, for an initial examination, the average use of each of the energy sources is considered as upper limit of the constraints. This gives an insight to the extent to which the farms operated in terms of energy use. The results obtained are the following:

Bullock farm , irrigated

	Yield (kg/ha)	HUMAN	ANIMAL	ELECT	SEED	FERT	MACH	Total Energy (MJ/ ha)	Ene prod
Optimum	3028.74	968.00	1203.62	2380.00	1430.83	2592.00	320.00	8894.45	0.34
Av. Energy Use as Constraint		968.00	1264.00	2380.00	1528.00	2592.00	320.00	9052.00	0.25
Min	1235.00	627.00	761.00	240.00	1162.00	512.00	193.00	5385.00	0.15
Max	4520.00	1665.00	1963.00	4833.00	2369.00	7279.00	421.00	14548.00	0.39
Average	2296.51	967.82	1263.80	2380.05	1528.40	2592.31	319.83	9052.20	0.25

Mixed farm, irrigated

	Yield (kg/ha)	HUMAN	ANIMAL	DIESEL	ELECT	SEED	FERTILIZER	MACHINERY	Total (MJ/ ha)	Ene prod
Optimum	3375.02	876.29	452.71	1218.00	3257.00	1533.00	3990.43	408.00	11735.43	0.29
Constraint		964.00	613.00	1218.00	3257.00	1533.00	3999.00	408.00	11992.00	0.26
Min	1757.00	637.00	38.00	273.00	1652.00	1165.00	2452.00	287.00	9234.00	0.19
Max	3706.00	1207.00	1360.00	2550.00	5144.00	1853.00	5460.00	522.00	14374.00	0.36
Average	3058.46	964.38	613.42	1217.69	3257.00	1533.46	3999.15	407.81	11992.92	0.26

Results above indicate that on average, the bullock farms used 9052.2 MJ/ha of Total energy to achieve a yield level of 2296.51 kg/ha with energy productivity of 0.25 kg/MJ. Under the given production system, the optimum energy consumption (based on actual performance of the group of farmers) of 8894.45 MJ/ha can give a yield of 3028.74 kg/ha with better energy productivity of 0.34 kg/MJ. The saving in energy has been in use of bullock and seed. For mixed farms, a similar scenario emerges with increase in energy productivity from 0.26 to 0.29 kg/MJ and increase in yield from 3058.46 to 3375.02 kg/ha. The enhanced energy-use efficiency can be achieved through better use of human and animal energy. All other energy sources were fully utilised, indicating that scope exists for increasing their uses for higher yield.

(B) Wheat, 1998

Data of II round survey indicate that a significant change in cultivation practices had taken place in the area. Out of 73 farmers cultivating wheat, the number of bullock farms has decreased to 6, mixed farms have grown to 55 and 12 tractor farms existed. One farm in each category did not use irrigation, and they were eliminated for the study. Irrigation was provided from tube wells by using electric motors.

Use of LP with average energy used as constraints for energy sources indicate the following:

Mixed farm, irrigated

	Yield (kg/ha)	HUMAN	ANIMAL	DIESEL	ELECT	SEEDS	FERTIL	MACH	Total Energy	Ene prod
Optimum	3710.511	837.4956	565	1051	4253	1849	4942	462.6541	13960.1497	0.266
Constraint		838	565	1051	4253	1849	4942	483	13981	0.217
Min	1235	507	60	150	1478	969	1021	267	5919	0.145
Max	4493	1799	1285	2250	6304	2608	11891	670	19986	0.286
Av	3032.218	837.5455	565.1273	1050.7273	4152.8364	1849.2	4941.5636	482.9273	13879.9273	0.218

Animal farm, irrigated

	Yield (kg/ha)	HUMAN	ANIMAL	ELECT	SEEDS	FERTIL	MACH	Total Energy	Ene prod
Optimum	2940.472	878.9571	1009.904	4678.9722	1959	4302.28	374.8813	13203.9950	0.223
Constraint		910	1022	4710	1959	4356	455	13412	0.214
Min	2718	874	910	4468	1808	3601	299	12561	0.193
Max	3097	994	1172	5172	2204	5089	499	14763	0.233
Av	2868	910.4	1022	4710.4	1959	4355.6	455	13412.4	0.214

Tractor farm, irrigated

	Yield (kg/ha)	HUMAN	DIESEL	ELECTR	SEEDS	FERT	MACH	Total Energy	Ene prod
Optimum	3287.807	592.1404	2334	4581.7416	1903	5033	463.66857	14907.5506	0.221
Constraint	2797.818	747	2334	4954	1903	5033	493	15464	0.181
Min	791	407	1820	1583	1271	983	313	6989	0.113
Max	3805	1383	4194	9593	2543	8842	845	23156	0.257
Av	2797.818	747.3636	2333.636	4954.3636	1903.3636	5033.182	492.7273	15464.6364	0.182

The results indicate that based on the performance of the farms in each category, the average energy-use of various energy sources can provide significantly higher yield (thereby giving higher energy productivity) than the average yields obtained. This implies that energy resource management by majority of the farmers through adoption of cultivation practices can be improved upon as adopted by some of the farmers to achieve higher yield with investment of similar pattern of energy. Most of the energy sources were utilised fully, indicating that possibility exists for achieving higher yields through use of greater quantum of energy resources.

In order to examine the above possibility, an improved situation of energy-use pattern was defined by considering the following:

1. Use of recommended seed and fertiliser rate for the area
2. Use of recommended package of practices for various unit operations through use of improved implements with different power sources

The considered recommended package of practices for irrigated wheat cultivation for mixed farm in the region are as following:

Energy source	Energy used in existing situation (MJ/ha)	Energy value in improved situation (MJ/ha)	Remarks
Human	837.55	931.63	Additional 94.08 (MJ/ha) or 6 labour days for harvesting and threshing of yield obtained in improved situation
Animal	565.13	565.13	This is animal energy available with farmer and farmers are bound to use this level. Addition energy for tillage will met by the tractors
Diesel	1050.73	2115.5	Add 1567.67 MJ of diesel energy for additional 9.28 hrs of tractor for 2 tillage with disc harrow
Electricity	4152.84	4152.84	Sufficient for 3 irrigation and threshing
Seed	1849.20	1617.00	Use 110 kg seed in improved situation. Presently farmers using 126 kg seed (excess than recommended)
Fertilizer	4941.56	6709.00	Use of 100 kg N, 40 kg P, 30 kg K
Machinery	482.93	553.47	Add energy for additional 5.73 hrs tractor use

The above improved situation was used as constraints in the LP model for mixed farm. The results are as following:

Improved situation

	Yield (kg/ha)	HUMAN	ANIMAL	DIESEL	ELECT	SEEDS	FERTIL	MACH	Total Energy	Ene prod
Improved	3957.81	873.23	532.72	1299.72	4152.84	1617.00	6709.00	526.26	15710.77	0.252
Constraint		931.63	565.13	2115.50	4152.84	1617.00	6709.00	554.00	16645.10	

Results indicate that yield of wheat crop can further be enhanced to 3957.81 kg/ha (from 3710.5 kg/ha) with additional energy input of 1750.6 MJ/ha. It would be seen that the major additional energy input is from fertiliser, human, animal, diesel, machinery energy use has been further optimised based on performance of farmers as reflected from surplus energy compared to allocation made through constraints.

Resource Constraint Options

Option is also available to examine effects of limited availability of some of the key resources. For example, availability of animal power in general is on decreasing trend. For examining the possibility of energy resource allocations with diminishing animal energy availability in future, we can restrict animal energy resource suitably. It is important to note that all options under examination are presumed to operate in the given situation of cultivation. Thus, when available data set has reasonably large variation in cultivation practice or in farm management, the results will be more dynamic.

Results of an example of such a situation with reducing bullock energy availability is given below:

Improved situation

	Yield (kg/ha)	**HUMAN**	**ANIMAL**	**DIESEL**	**ELECT**	**SEED**	**FERT**	**MACH**	**Total Energy**	**Ene prod**
Improved	3957.81	873.23	532.72	1299.72	4152.84	1617.00	6709.00	526.26	15710.77	0.252
Animal <20% Opt	3920.73	813.99	427.00	1405.40	4152.84	1617.00	6709.00	492.72	15617.94	0.251
Animal <30% Opt	3872.71	784.05	373.00	1492.64	4152.84	1617.00	6709.00	481.74	15610.27	0.248
Average	3032.22	837.55	565.13	1050.73	4152.84	1849.20	4941.56	482.93	13879.9273	0.218

It may be seen that with decreasing bullock energy availability, diesel energy use has increased for completion of farm operations. Correspondingly human energy consumption has been decreasing with increasing use of tractors. Variation in yield is not significant due to seed and fertiliser application rates are same. Under such situation, our main interest is not on impact on yield, but energy resource allocation. Since information on physical quantities of major inputs is available in EXCEL spreadsheet, they can be retrieved easily.

Simulated data sets

One important feature of the procedure adopted is that LP searches for best solution among the performance of the farmers available in the data set. This, in other words, means that in case maximum potential yield of the area has not been achieved by the farmers (for not using required inputs, farm operations not completed adequately, etc), or the cultivation practices adopted do not reflect the recommended ones. LP will not be able to locate such situations in data set and therefore not give corresponding solutions. Examination of various data sets has revealed that such situations do exist.

For mixed farming case, results of “Cropping Systems Research” indicating maximum obtainable yield in the area with recommended application rates of seed and fertilisers were considered. For other energy inputs, the data of the farmers were examined and energy-use patterns of most efficient farmers achieving high rate of yield was considered. Simulated data sets were accordingly prepared and used in conjunction with the data set for LP application.

	Yield (kg/ha)	**HUMAN**	**ANIMAL**	**DIESEL**	**ELECTR**	**SEEDS**	**FERTIL**	**MACH**	**Total Energy**	**ene prod**
I-1	4830	846.45	639.73	1058	4603.5	1900	8206	556.27	17809.95	0.271
I-2	4500	846.45	639.73	1058	4603.5	1900	7550	556.27	17153.95	0.262
I-3	4300	846.45	639.73	1058	4603.5	1900	7000	556.27	16603.95	0.259

The results of LP application is as following:

	Yield (kg/ha)	HUMAN	ANIMAL	DIESEL	ELECTR	SEEDS	FERTIL	CHINERY	Total Energy	ene prod
opt imum	4329.66	783.96	493.06	1283.79	4152.84	1900.00	8206.00	483.33	17302.97	0.250
Constraint: Full fertilizer &seed rate recommended		873.23	532.72	1299.72	4152.84	1900.00	8206.00	526.26	17490.77	
Optimum	4575.77	857.61	532.72	1299.72	5000.00	1823.65	8206.00	504.69	18224.39	0.251
Constraint: Electricity increased		873.23	532.72	1299.72	5000.00	1900.00	8206.00	526.26	18337.93	

In the first set of result, the energy resource allocations were maintained at the levels of optimum solution with improved package of practices. With use of the simulated data sets, increase in yield from 3957.81 kg/ha to 4329.66 kg/ha is obtainable with optimised energy resource allocation. Among the energy resources electricity, seed and fertiliser remained fully utilised. Maximum possible yield of 4575.77 kg/ha is possible with Increased electricity availability from 4153 MJ/ha to 5000 MJ/ha.

4. Soybean cultivation in Madhya Pradesh

Soybean is the major crop cultivated in Kharif covering about 44 per cent of area under food crops in the state in Kharif season. Average yield of soybean in the state is about 1012 kg/ha. About 70 per cent of area under soybean in the country is in M.P, providing 64.4 per cent of national production.

Energy audit in 5 soybean-producing villages (Phanda, Jamburdi Hapsi, Kanadia, Berkhedi and Sonsa) conducted during 1997-1999 covered 275 farms. Majority of farms (205) use combination of bullock and tractor power (mixed farming) for cultivation. Out of the total number of farms, rainfed cultivation was undertaken in 239 farms.

Out of 205 mixed farms, 186 farmers (77.8 per cent) did not apply irrigation. These farms constitute 67.6 per cent of total number of farms surveyed, and therefore studied. The average yield of these farms was 1089 kg/ha, close to the state average. The average, maximum and minimum yields and source-wise energy consumptions of the farms are as following:

	Yield (kg/ha)	HUMAN	ANIMAL	DIESEL	ELECT	SEED	FYM	FERT	CHEM	MACH	TOTAL ENERGY	ene prod
Av	1089	963.595	404.2	1609.44	224.922	1353.4	166.88	1227.5	56.7676	266.486	6267.14	0.1787
Max	1977	2649	1298	4145	704	1923	1423	3514	297	543	11592	0.3099
Min	371	308	60	273	0	908	0	49	0	139	3008	0.0518

Use of electricity has been only for threshing of crop. Only 5 farms had practiced manual threshing.

Optimal yield with average energy use

Based on average energy use of the different energy sources, optimisation of resource use indicated that maximum yield of 1527 kg/ha can be obtained, signifying that 40.2 per cent of additional yield than the average yield can be obtained by using same quantity of energy inputs. Since the optimisation is done based on actual performance of the sample size, it appears that the energy resource management by the majority of farmers has been sub-optimal.

Yield (kg/ha)	HUMAN	ANIMAL	DIESEL	ELECT	SEED	FYM	FERT	CHEM	MACH	TOTAL ENERGY	ene prod
1527.03	974	409	1607	225	1353	135.57	1278	49.7893	267	6298.4	0.2431

Energy productivity in the process can improve from 0.179 to 0.243 kg/MJ. Operation-wise, the optimal solution does not envisage significant change in energy use pattern as compared to the average energy use.

Use of improved package of practices

Recommended package of practices was considered for assessment of uses of various energy resources. Mixed farming poses a peculiar situation with respect to use of various farm power resources. When the situation in the state is considered, various regions are under consideration where availability of animals and tractors vary. In many parts of the state, hiring of tractor for critical operations like seedbed preparation and sowing are in practice. Experiences of field survey indicate that farms where hiring charges are paid immediately are attended on priority than those where payment is made later on. It is presumed that farms owning draught animals would prefer to use the animals to the maximum, availability of actual time for various operations being the guiding factor for selection of power source for an operation. Reported data by JNKVV centre indicates the same trend. Thus, maximum uses of available animals were considered for the operations, the balance being met by tractor operated implements. Threshing was considered to be done by electric motor operated thresher for energy efficiency. Seed and fertiliser application rates are considered as per recommendation for the state.

Operation	Practice
Summer ploughing	Animal operated bakhar
Seedbed preparation after rain	Animal cultivator/ Bakhar x 1 +Tractor duckfoot cultivator x 1
Sowing	Partly by tractor and partly by bullock seed drill (40:60)
Intercultivation	Manual
Harvesting	Manual
Threshing	Electric motor operated thresher
Transportation	Partly by tractor trailer and partly by animal cart

The optimum use of different energy resources for the improved package of practices obtained through linear programming is given below.

Yield (kg/ha)	HUMAN	ANIMAL	DIESEL	ELECT	SEED	FYM	FERT	CHEM	MACH	Total Energy	ene prod
1854.7	1003.8	445	1861.1	452.576	1523.3	481.3	1665	0	365.94	7798.1	0.238

The results indicate that with 23.8 per cent increase in energy consumption from 6298.4 MJ/ha to 7798 MJ/ha, the farmers can obtain 21.5 % additional crop yield with improved cultivation practices. The optimised energy use requires 4 – 13 % higher human, animal, seed energy. Fertiliser energy increase is about 30 %. Machinery and electricity energy use has increased for timely completion of operations.

Simulated data for potential yield

The maximum potential yield obtainable in the State has been determined through experiments conducted under AICRP on Cropping systems Research. Results indicate variation in potential yield ranging between1789 to 2243 kg/ha at stations located in different agro-climatic zones. Six simulated data sets were generated for each yield levels, using corresponding seed and fertiliser application rates and improved operational package of practices as indicated above. Slight variations in energy allocations were built in for better LP response.

The simulated data sets were included with the farmer data sets to optimise energy use and resource allocation for maximum potential yield of the crop.

Set No	**Yield (kg/ha)**	**HUMAN**	**ANIMAL**	**DIESEL**	**ELECT**	**SEED**	**FYM**	**FERT**	**CHEM**	**MACH**	**Total Energy**	**ene prod**
S1	2243	1110	579	1028	352	1428	178	2012	178	279	7144	0.314
S2	2126	1083	771	982	310	1526	163	2426	193	270	7724	0.2752
S3	2074	1074	569	994	299	1417	163	2426	148	261	7351	0.2821
S4	2276	1039	806	1125	369	1562	178	2012	202	306	7599	0.2995
S5	1789	1063	553	968	334	1391	166	2012	166	265	6918	0.2586
S6	1832	1042	753	1125	313	1435	193	2012	205	290	7368	0.2486

Maximisation of yield for improved cultivation practices gave the following resource allocation:

Yield (kg/ha)	**HUMAN**	**ANIMAL**	**DIESEL**	**ELECT**	**SEED**	**FYM**	**FERT**	**CHEM**	**MACH**	**Total Energy**	**ene prod**
2273.85	1155.02	750	1090.69	358.901	1495	330.06	2450	188.522	299.472	8117.7	0.2955

It may be seen that maximum yield of 2273.85 kg/ha is feasible to be obtained with investment of 8118.7 MJ/ha of energy.

As compared to optimised existing practice, animal energy use would increase by 83.4 per cent signifying better use of available renewable energy resource. As a consequence, diesel use would reduce by 32.1 per cent. The recommended fertiliser use for 48.9 per cent higher yield would entail use of 98.7 per cent additional fertiliser energy. Electricity consumption increase is for threshing additional crop harvested. Total energy use would increase by 28.9 per cent.

Fig 1. gives a graphical presentation of the various energy use scenarios discussed above. The actual energy use patterns of the farmers indicate that the farms belonging to the peak regime of the regression model (group B) had obtained average yield of 1425 kg/ha by investing average total energy of 7825 MJ/ha. Farmers falling in the two adjacent tapering sides of the regression curve (groups A,C) had lower average yields. Farms using higher total energy (group C) appear to be less managed as even with use of higher quantity of fertiliser, tillage , weeding and harvesting energy could have lower yield than group B.

Direct energy use

Use patterns of direct energy resources in production agriculture is of special interest for planning purpose. Direct energy resources are used in the farms for execution of different farm operations. The trend of uses of direct energy resources have been dynamic in the country with major shift to commercial sources as electricity and diesel. With large and continuing investments by the farmers on power sources using electricity and diesel, it has become imperative to ensure timely and adequate supplies of these resources so that investments made are fully exploited. Proper uses of the energy resources are equally important for reducing wasteful uses of the scarce commodities.

Optimisation of energy resources for production agriculture, as explained above, provides an opportunity to

- assess the patterns of changes in requirements of the energy resources for different cultivation systems (business-as-usual, improved practice) at different levels of productivity
- estimate the consumption of the direct energy resources at different levels of productivity
- estimate the future requirements of different energy resources for a catchment area

Fig 2 indicates the patterns of direct, animate and direct commercial energy consumptions at different yield levels of soybean when cultivated with optimised energy resource allocations in business-as-usual and improved practices. The total direct energy consumption in business-as-usual practice would be more than the improved practice, the difference being higher at lower productivity levels. The pattern is governed by the consumption pattern of direct commercial energy.

Fig 3 represents the energy consumption pattern for improved cultivation practice. Total energy consumption increases with increase in productivity, the share of indirect energy increasing faster than that of direct energy due to nearly five times increased use of fertiliser for productivity increase from 1000 to 2250 kg/ha. Energy productivity shows a fast improvement till about yield of about 1700 kg/ha, and then slows down. Total direct energy consumption rate increases with increase in productivity, mainly due to increased consumption rate in tillage, harvesting, threshing and transportation. Energy consumption in tillage operation nearly doubles with increase in productivity from 1000 to 2250 kg/ha due to continuous shift to tractor use in order to ensure timeliness in operation.

		Source-wise energy consumption, MJ/ha				Opeartion-wise energy consumption, MJ/ha						
Yield (kg/ha)	**Ene prod**	**HUMAN**	**ANIMAL**	**DIESEL**	**ELECT**	**TILLAGE**	**SOWING**	**WEEDING**	**SPRAYING**	**HARVEST**	**THRESH**	**TRANSPT**
2250	0.311	1095	627	1049	356	1204	367	375	83	352	493	535
2200	0.313	1155	616	965	346	1142	361	422	78	344	482	529
2100	0.309	1155	635	896	330	1085	350	469	69	331	463	519
1900	0.300	1155	674	760	300	972	328	565	52	305	425	501
1700	0.292	1155	713	623	270	859	307	660	34	278	387	482
1500	0.283	1152	750	488	240	748	286	750	17	252	349	462
1300	0.273	1090	750	398	210	667	276	750	5	233	308	430
1100	0.262	933	690	379	180	636	285	604	0	224	265	378
1000	0.255	824	640	393	166	638	296	482	0	223	242	345

Fig 4 reflects the changing pattern of direct energy resource consumption rate with productivity. While human energy consumption averages to 1100 MJ/ha, rise in total direct energy has been mainly due to increase in diesel consumption rate.

Per cent saving in energy consumption through optimised resource allocation using present and improved cultivation practices are given below:

			Yield, kg/ha							
Energy resource		Unit	1700	1600	1500	1400	1300	1200	1100	1000
Human	Actual	man-h/ha	594.05	548.32	501.63	425.45	455.17	506.06	436.21	504.29
	Present practice, optimised	% saving			0.94	14.00	24.72	4.91	-13.92	1.46
	Improved practice, optimised	% saving	0.80	-7.47	-17.14	-34.41	-22.17	-5.17	-9.17	16.67
Animal	Actual	ani-h/ha	37.26	48.96	46.11	24.36	42.91	48.37	44.28	44.24
	Present practice, optimised	% saving			12.18	-66.26	5.64	16.29	8.54	8.46
	Improved practice, optimised	% saving	-89.50	-48.16	-61.05	-204.88	-73.04	-51.46	-54.34	-43.34
Diesel	Actual	l/ha	42.50	30.49	30.25	38.90	24.14	27.03	25.20	29.36
	Present practice, optimised	% saving			10.34	32.89	4.57	45.64	49.68	62.85
	Improved practice, optimised	% saving	73.98	67.71	71.32	79.77	70.73	76.03	73.31	76.24
Electricity	Actual	kWh/ha	19.12	19.03	22.64	25.39	25.10	23.01	23.78	35.88
	Present practice, optimised	% saving			16.71	25.72	24.85	20.10	30.28	58.73
	Improved practice, optimised	% saving	-18.55	-12.49	11.01	25.58	29.73	28.81	36.38	61.32

Optimized resource requirement for cultivation of soybean in one thousand ha in M.P at different levels of productivity through present and improved cultivation practices can be estimated as given below.

			Yield, kg/ha							
			2250	**2100**	**2000**	**1800**	**1500**	**1400**	**1200**	**1000**
Human	Actual	man-day,'000					62.70	53.18	63.26	63.04
	Actual optimum	man-day,'000					62.12	45.74	60.15	62.12
	Improved optimum	man-day,'000	69.83	73.66	73.66	73.66	73.45	71.48	66.53	52.53
Animal	Actual	ani pair-day,'000					2.88	1.52	3.02	2.76
	Actual optimum	ani pair-day,'000					2.53	2.53	2.53	2.53
	Improved optimum	ani pair-day,'000	3.88	3.93	4.05	4.29	4.64	4.64	4.58	3.96
Diesel	Actual	l, '000					30.25	38.90	27.03	29.36
	Actual optimum	l, '000					27.12	26.10	14.69	10.91
	Improved optimum	l, '000	18.62	15.92	14.70	12.27	8.67	7.87	6.48	6.98
Electricity	Actual	MWh					22.64	25.39	23.01	35.88
	Actual optimum	MWh					18.86	18.86	18.38	14.81
	Improved optimum	MWh	29.81	27.70	26.44	23.93	20.15	18.89	16.38	13.88

5. Discussion

The discussions just described pertain to the situations when the interest is in maximization of productivity given the constraints on the availability of different energy sources. This gives the energy requirements for achieving the optimum yield levels. It may be worthwhile mentioning here that the optimum yield levels are attainable if the energy levels of different activities as obtained from the solution are fully utilized as per the activities included in the basis. Otherwise at the energy levels as obtained from the solution, the optimum yield may not be obtainable.

From policy makers' point of view, the minimum amount of energy required for attaining a given level of yield may be of importance. In order to answer this question, the LP problem may be reframed as a total energy minimization problem given the constraints on yield and other avctivities. For this purpose one may use the fact that the maximization of a function $f(X_1,X_2,\cdots,X_n)$ is equivalent to minimization of $-f(X_1,X_2,\cdots,X_n)$, in the sense that both problems result in the same optimal values of $X_i's$. Moreover the same data file as created for yield maximization problem can be used in this case also. The rows corresponding to yield and total energy are interchanged and the total energy values are given negative signs.

At the first instance one may be interested to see the solution of the energy minimization LP problem at the optimum level of yield obtained through the yield maximization model. It may be mentioned here that if the constraints on the various sources of energy are same as that of yield maximization problem, then the usage of various energy sources in the solution of the total energy minimization at optimum level of yield is same as that of yield maximization problem. The minimum of total energy obtained through this solution is also same as that of the total energy usage in the yield maximization problem. This justifies the use of LP problem of energy minimization. The results obtained are given in ANNEXURE-III.

From yield maximization section we know that the optimum yield for marginal farmers at present level of availability of energy is 3109.663 Kg/ha. Now suppose one wants to know the values of the energy requirements source wise to raise the yield level of marginal farmers to 3200 kg/ha from the present level of 3109.663 Kg/ha. The energy available for various sources in the changed scenario is given as under.

Situation	Human	Diesel	Electricity	Seeds	Fertilizer	Machinery	Chemical
I	930	1580	2310	1500	5000	270	3.000
II	1000	1700	2400	1485	5000	270	3.000

The energy required source wise for these situations is given in the following Table.

Energy Source	**Energy Usage for Situation (in MJ/ha)**	
	I	II
Human	930.0000	941.4569
Diesel	1497.6240	1493.5584
Electricity	2310.0000	2287.1531
Seeds	1353.2773	1354.2967
Fertilizer	4638.0447	4331.5077
Machinery	270.0000	270.0000
Chemical	0.4451	0.0000
Total	**10999.3911**	**10677.9728**

One can see that total energy required is less than the total energy required for the 3109.66334 kg/ha of yield. This may be due to change in scenario of the available yields.

As described above, the optimum yield is obtainable only when the energy usage of different sources as found in the solution is as per the basis. However, this would seldom be the case. Therefore, one may require extrapolating the energy levels of different activities as well as the total energy to attain the productivity levels as obtained through LP. For this it is necessary to find out the current energy use efficiency. The LP problem may then be restructured as minimization of total energy and give the upper bounds on constraints as average use and give constraint on yield equal to the average yield obtained at present.

For illustration the data on the marginal farmers was utilized. To attain the average yield level of 2878.12 Kg/ha, the requirement of various energy sources are:

Energy Source	**Usage as per LP**	**Average usage**
Human	889.53	889.53
Diesel	1578.12	1578.12
Electricity	2108.8182	2309.24
Seeds	1485.82	1485.82
Fertilizer	3804.6891	4916.59
Machinery	260.02992	260.88
Chemicals	1.8634071	2.41
Total Energy	**10128.8707**	**11442.58824**

In this case, ***the average usage on total energy is 11442.58824MJ/ha, whereas to attain the same yield levels the minimum total energy required is 10128.8707 MJ/ha.*** Therefore, the ***energy use efficiency is (10128.8707/11442.58824)=0.8852.***

To obtain the energy requirements from various sources for attaining the optimum yield as obtained through the LP model under the assumption that the energy use efficiency is as per the present levels, the energy usage from the model can be inflated by using the formula (optimum energy level required/Energy use efficiency). For example, to attain the yield of 3109.66334 kg/ha, the total energy required is 11277.91 MJ/ha and **the energy use efficiency is 0.8852, therefore, the actual total energy required under the assumption that the energy use efficiency remains the same is (11277.91/0.8852) =12741.407 MJ/ha.** The energy requirements for various energy sources can also be inflated using the energy use efficiency at the same levels as that of total energy. This will ensure that the projected energy requirements are greater than or equal to the usage obtained through LP. This procedure has been illustrated for category 1 farmers and can be similarly followed for other categories.

It may be worthwhile mentioning here that the extrapolation of energy levels is one way of handling the problem. However, other methods of circumventing this problem need attentions.

One important point to mention here is that this optimization is valid under the assumption of zero technical change. The positive rate of technical change may improve the energy use efficiency. Therefore, one may obtain the energy requirements for different situations of technical change and/or changing the energy use efficiency levels.

It may be noted that in case of a change in scenario in terms of energy availability from different sources the LP problem may result in a solution that may require less or more energy as compared to the solution obtained by taking the constraints as the average availability of energy sources.. Sometimes the solution may not exist. At other times the solution may not be feasible from practical considerations. In these situations one has to use judgement in choosing the constraints.

To end the discussion, it may be emphasized that LP is one of the many optimization techniques. There is a potential for exploring the other optimization techniques, particularly those involving quadratic, non-linear modeling, etc..

Fig. 1. Energy use in Soybean cultivation (Mixed farm, rainfed) in Madhya Pradesh

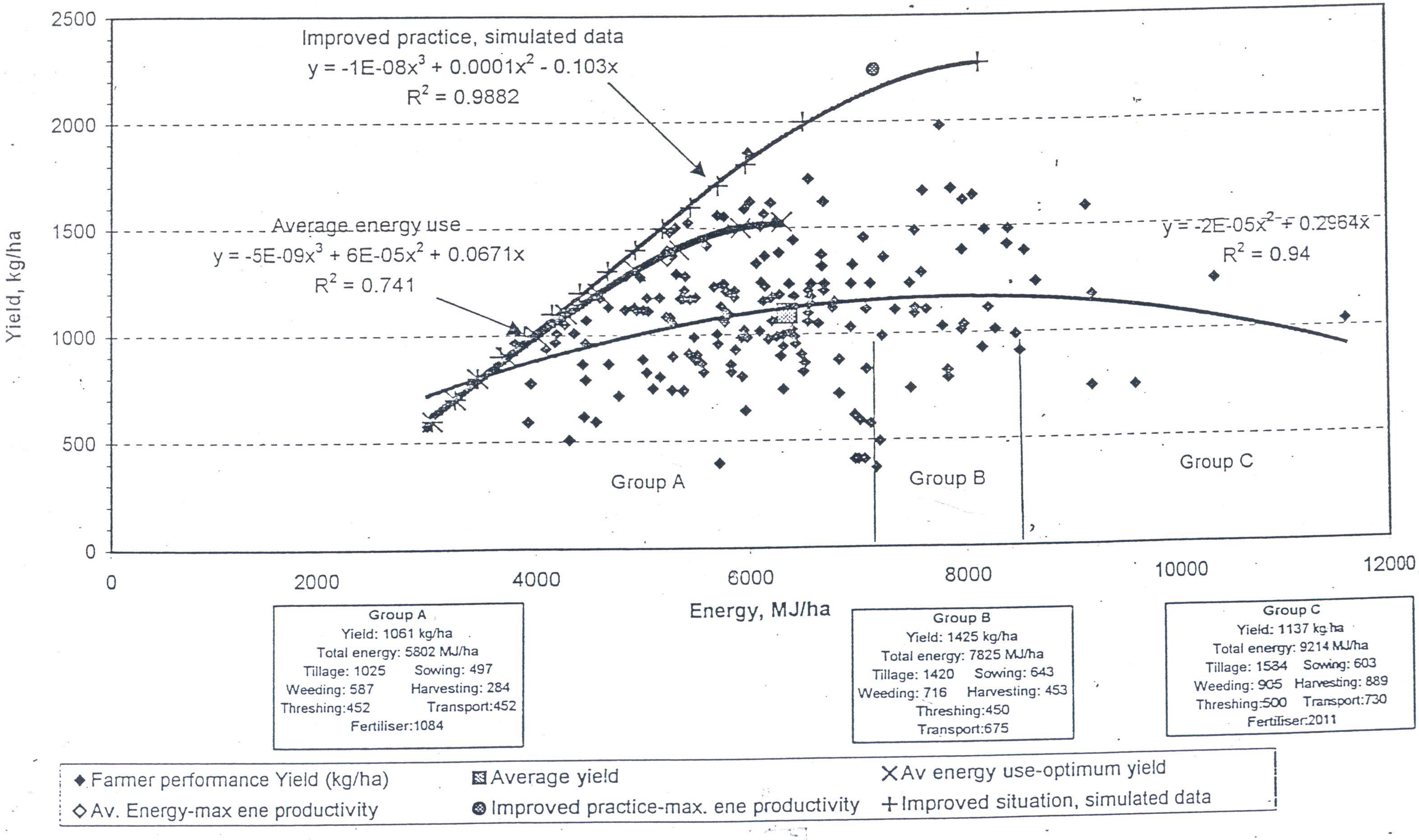


Fig. 2. MP - rainfed soybean mixed farm cultivation - comparison of direct energy use pattern

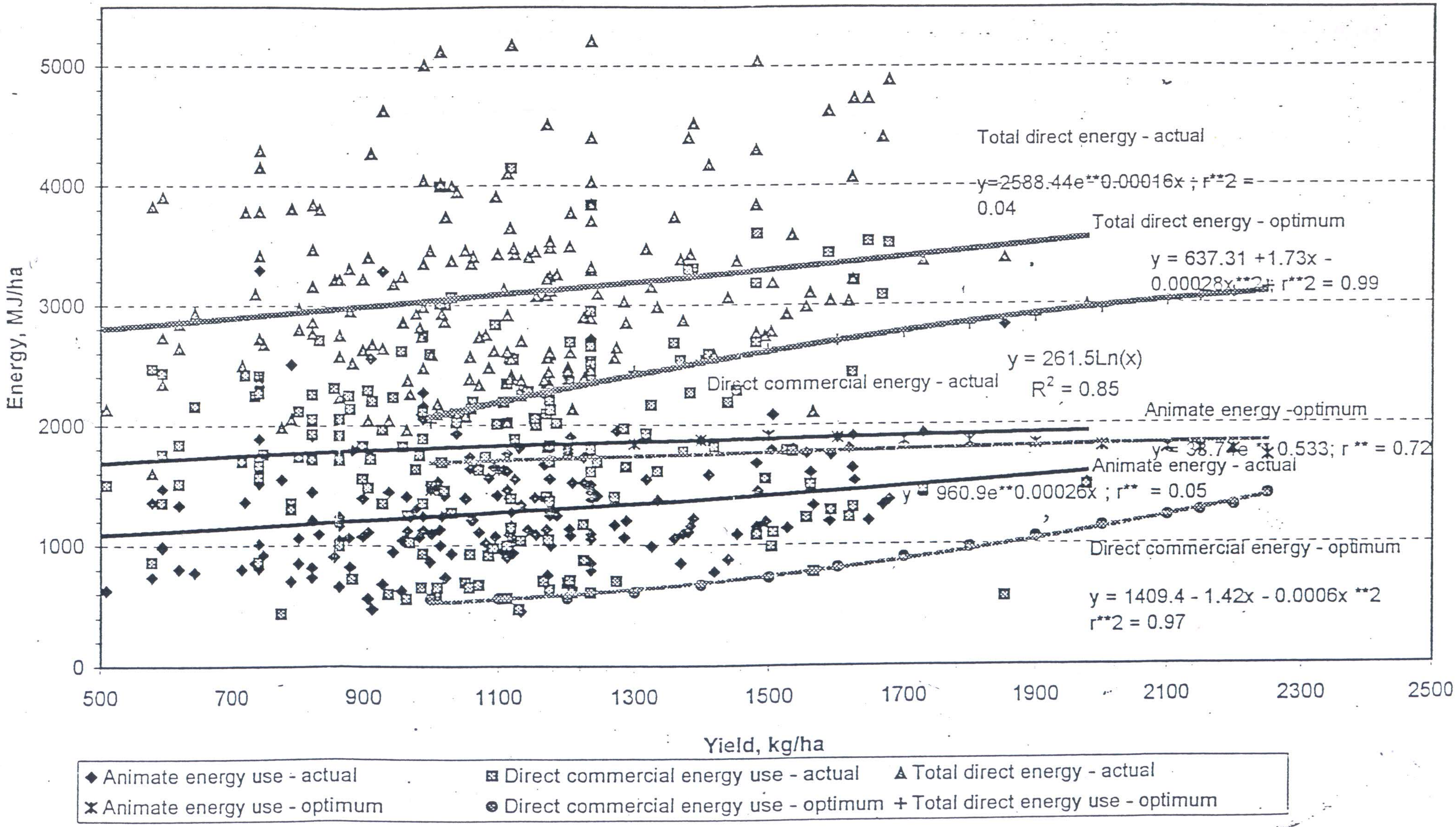


Fig. 3. Energy use in rainfed soybean cultivation in M.P with improved cultivation practices

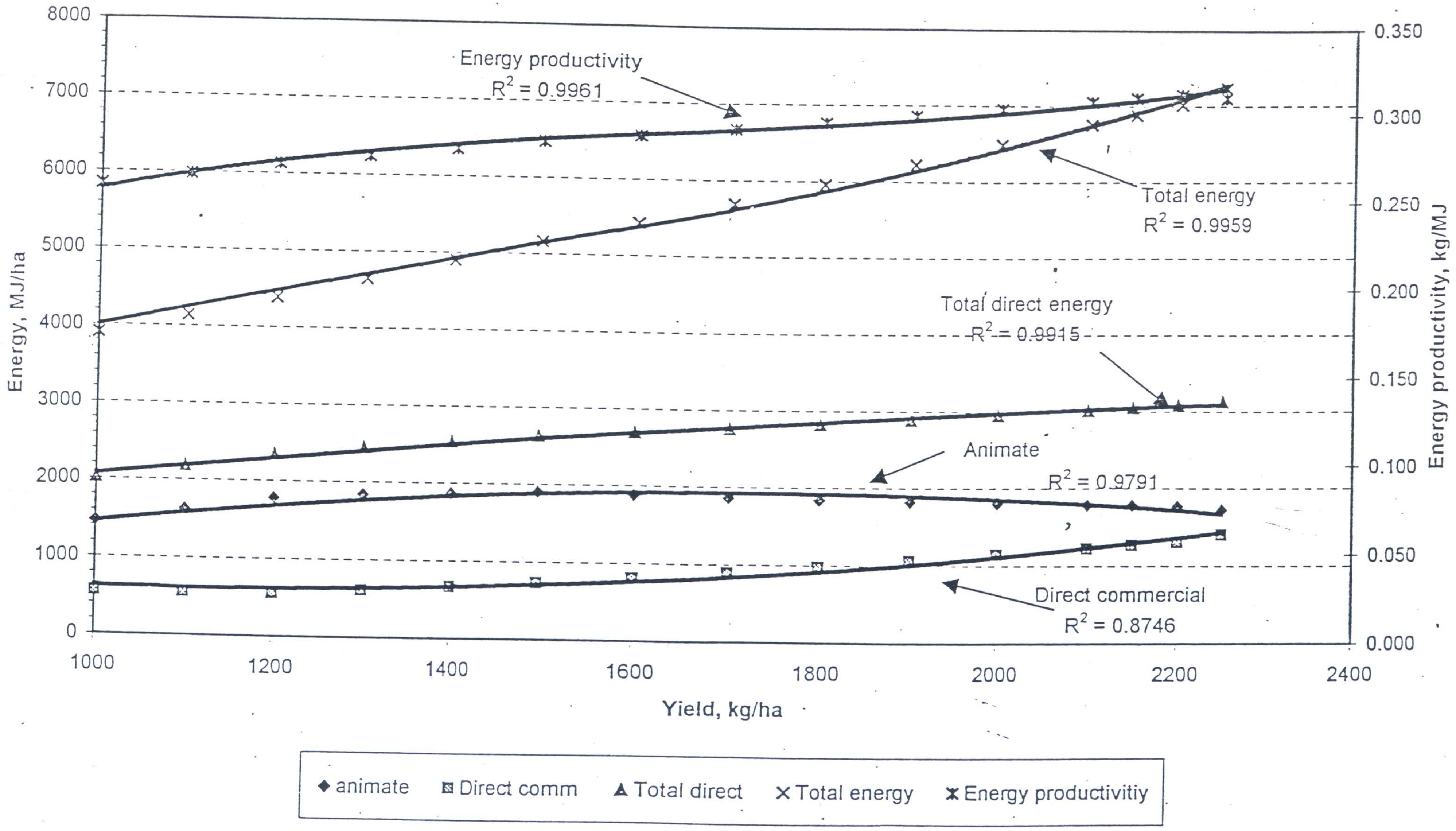
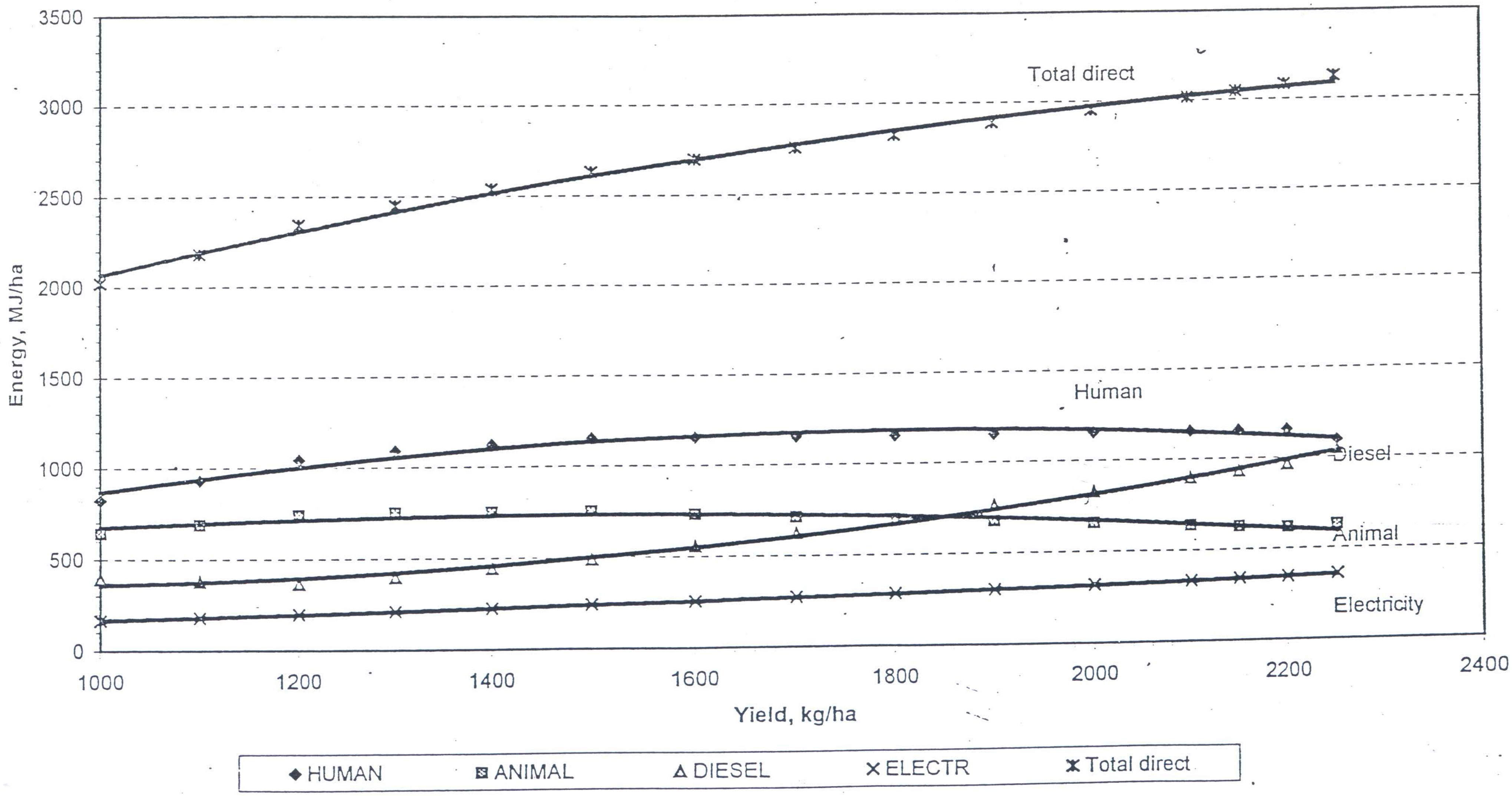


Fig. 4. Use pattern of direct energy sources for rainfed soybean cultivation in M.P under mixed farm with improved practices



ANNEXURE - I
Results of Yield Maximization using LP for Category-I Farmers

```
CHK10M1A     SOLUTION IS MAXIMUM        YIELD     3109.663340
             PRIMAL PROBLEM SOLUTION
VARIABLE     STATUS        VALUE        YIELD /UNIT    VALUE/UNIT     NET YIELD
 X.1         BASIS         .24458989     2824.0000      2824.0000      .00000000
 X.2         BASIS         .16789194     3231.0000      3231.0000      .00000000
 X.3         NONBASIS      .00000000     3020.0000      3480.4365     -460.43651
 X.4         NONBASIS      .00000000     2718.0000      3012.0809     -294.08091
 X.5         NONBASIS      .00000000     2404.0000      2909.1805     -505.18054
 X.6         NONBASIS      .00000000     2471.0000      2785.2520     -314.25200
 X.7         NONBASIS      .00000000     2965.0000      3260.1716     -295.17165
 X.8         NONBASIS      .00000000     2965.0000      3335.1922     -370.19223
 X.9         NONBASIS      .00000000     3000.0000      3004.5484     -4.5483968
 X.10        NONBASIS      .00000000     3198.0000      3670.5527     -472.55272
 X.11        NONBASIS      .00000000     2976.0000      3009.1584     -33.158441
 X.12        NONBASIS      .00000000     2762.0000      3180.5411     -418.54108
 X.13        BASIS         .11616792     2589.0000      2589.0000      .00000000
 X.14        NONBASIS      .00000000     2677.0000      3084.9424     -407.94242
 X.15        NONBASIS      .00000000     3089.0000      3248.4807     -159.48068
 X.16        BASIS         .47135025     3343.0000      3343.0000      .00000000
 X.17        NONBASIS      .00000000     2696.0000      2897.0230     -201.02298
 S.1         NONBASIS      .00000000     .00000000      .91251878     -.91251878
 S.2         BASIS         75.244739     .00000000      .00000000      .00000000
 S.3         BASIS         26.287580     .00000000      .00000000      .00000000
 S.4         BASIS         60.737508     .00000000      .00000000      .00000000
 S.5         NONBASIS      .00000000     .00000000      .04017164     -.04017164
 S.6         NONBASIS      .00000000     .00000000      7.3526979     -7.3526979
 S.7         BASIS         2.4100000     .00000000      .00000000      .00000000
 S.8         BASIS         164.68983     .00000000      .00000000      .00000000

CHK10M1A     SOLUTION IS MAXIMUM        YIELD     3109.663340
             DUAL PROBLEM SOLUTION
CONSTRAINT   STATUS       DUAL VALUE     RHS VALUE       USAGE          SLACK
HUMAN        BINDING       .91251878     889.53000      889.53000      .00000000
DIESEL       NONBINDING    .00000000     1578.1200      1502.8753      75.244739
ELECT        NONBINDING    .00000000     2309.2400      2282.9524      26.287580
SEED         NONBINDING    .00000000     1485.8200      1425.0825      60.737508
FERT         BINDING       .04017164     4916.5900      4916.5900      .00000000
MACH         BINDING       7.3526979     260.88000      260.88000      .00000000
CHEM         NONBINDING    .00000000     2.4100000      .00000000      2.4100000
TOTAL        NONBINDING    .00000000     11442.600      11277.910      164.68983
AREA         BINDING       182.27121     1.0000000      1.0000000      .00000000

CHK10M1A     SOLUTION IS MAXIMUM        YIELD     3109.663340
             RIGHT-HAND-SIDE RANGES
CONSTRAINT   STATUS       DUAL VALUE     RHS VALUE       MINIMUM        MAXIMUM
HUMAN        BINDING       .91251878     889.53000      863.75604      907.85178
DIESEL       NONBINDING    .00000000     1578.1200      1502.8753        NONE
ELECT        NONBINDING    .00000000     2309.2400      2282.9524        NONE
SEED         NONBINDING    .00000000     1485.8200      1425.0825        NONE
FERT         BINDING       .04017164     4916.5900      4413.7158      5075.6616
MACH         BINDING       7.3526979     260.88000      257.52147      263.34333
CHEM         NONBINDING    .00000000     2.4100000      .00000000        NONE
TOTAL        NONBINDING    .00000000     11442.600      11277.910        NONE
AREA         BINDING       182.27121     1.0000000      .97890036      1.0129595.
```

ANNEXURE-II

Yield maximization for Combined data using lower and upper bounds

```
CHKMCR1     SOLUTION IS MAXIMUM       yield     3673.892900
            PRIMAL PROBLEM SOLUTION
VARIABLE    STATUS        VALUE        yield /UNIT    VALUE/UNIT     NET yield
 X.1        NONBASIS     .00000000      2824.0000      3649.7082     -825.70820
 X.2        NONBASIS     .00000000      3231.0000      3770.7697     -539.76975
 X.3        NONBASIS     .00000000      3020.0000      3736.1018     -716.10180
 X.4        NONBASIS     .00000000      2718.0000      3787.3099     -1069.3099
 X.5        NONBASIS     .00000000      2404.0000      3752.3342     -1348.3342
 X.6        NONBASIS     .00000000      2471.0000      3416.2512     -945.25122
 X.7        NONBASIS     .00000000      2965.0000      3696.0003     -731.00029
 X.8        NONBASIS     .00000000      2965.0000      3604.3517     -639.35170
 X.9        NONBASIS     .00000000      3000.0000      3933.8915     -933.89148
 X.10       NONBASIS     .00000000      3198.0000      3805.0227     -607.02267
 X.11       NONBASIS     .00000000      2976.0000      3963.5253     -987.52526
 X.12       NONBASIS     .00000000      2762.0000      3713.0531     -951.05309
 X.13       NONBASIS     .00000000      2589.0000      3805.7319     -1216.7319
 X.14       NONBASIS     .00000000      2677.0000      3763.2185     -1086.2185
 X.15       NONBASIS     .00000000      3089.0000      3473.1427     -384.14266
 X.16       NONBASIS     .00000000      3343.0000      3967.6632     -624.66315
 X.17       NONBASIS     .00000000      2696.0000      3874.5692     -1178.5692
 X.18       NONBASIS     .00000000      2353.0000      3651.6350     -1298.6350
 X.19       NONBASIS     .00000000      2595.0000      3749.1916     -1154.1916
 X.20       NONBASIS     .00000000      2883.0000      3810.2593     -927.25931
 X.21       NONBASIS     .00000000      2409.0000      4043.1965     -1634.1965
 X.22       NONBASIS     .00000000      2965.0000      3685.9074     -720.90740
 X.23       NONBASIS     .00000000      3459.0000      4077.0311     -618.03110
 X.24       BASIS        .06569603      4236.0000      4236.0000      .00000000
 X.25       NONBASIS     .00000000      2689.0000      4208.7704     -1519.7704
 X.26       NONBASIS     .00000000      2817.0000      3678.5333     -861.53331
 X.27       NONBASIS     .00000000      2551.0000      3650.9167     -1099.9167
 X.28       NONBASIS     .00000000      3089.0000      3495.5799     -406.57991
 X.29       NONBASIS     .00000000      2548.0000      3720.2089     -1172.2089
 X.30       NONBASIS     .00000000      2566.0000      3796.9882     -1230.9882
 X.31       NONBASIS     .00000000      2081.0000      3805.4181     -1724.4181
 X.32       NONBASIS     .00000000      2712.0000      3445.8248     -733.82480
 X.33       NONBASIS     .00000000      2337.0000      3542.7098     -1205.7098
 X.34       NONBASIS     .00000000      2330.0000      3773.1292     -1443.1292
 X.35       NONBASIS     .00000000      2224.0000      3905.2765     -1681.2765
 X.36       NONBASIS     .00000000      2991.0000      3747.1651     -756.16512
 X.37       NONBASIS     .00000000      3058.0000      3399.6737     -341.67372
 X.38       NONBASIS     .00000000      2734.0000      3747.1442     -1013.1442
 X.39       NONBASIS     .00000000      3177.0000      3656.0878     -479.08776
 X.40       NONBASIS     .00000000      3055.0000      3097.1321     -42.132093
 X.41       NONBASIS     .00000000      2934.0000      3726.0792     -792.07921
 X.42       NONBASIS     .00000000      2636.0000      3539.4699     -903.46987
 X.43       NONBASIS     .00000000      1853.0000      4061.4082     -2208.4082
 X.44       NONBASIS     .00000000      2134.0000      4024.9399     -1890.9399
 X.45       NONBASIS     .00000000      2759.0000      3679.2836     -920.28358
 X.46       NONBASIS     .00000000      2647.0000      4039.5612     -1392.5612
 X.47       NONBASIS     .00000000      2770.0000      3434.2665     -664.26652
 X.48       NONBASIS     .00000000      2331.0000      3997.1369     -1666.1369
 X.49       NONBASIS     .00000000      2534.0000      3650.7479     -1116.7479
 X.50       NONBASIS     .00000000      2974.0000      3546.2394     -572.23938
```

```
X.51        NONBASIS     .00000000      2842.0000      3621.4200     -779.41997
X.52        NONBASIS     .00000000      2965.0000      3399.2626     -434.26259
X.53        BASIS        .07146178      3336.0000      3336.0000      .00000000
X.54        NONBASIS     .00000000      2907.0000      3851.9398     -944.93982
X.55        NONBASIS     .00000000      1977.0000      3990.0460     -2013.0460
X.56        NONBASIS     .00000000      3029.0000      3650.8077     -621.80771
X.57        NONBASIS     .00000000      2265.0000      3642.6456     -1377.6456
X.58        NONBASIS     .00000000      2696.0000      3503.4448     -807.44477
X.59        NONBASIS     .00000000      2903.0000      3709.1331     -806.13310
X.60        NONBASIS     .00000000      2824.0000      3452.0213     -628.02129
X.61        NONBASIS     .00000000      2652.0000      3720.5405     -1068.5405
X.62        NONBASIS     .00000000      2394.0000      3537.3353     -1143.3353
X.63        NONBASIS     .00000000      2788.0000      3539.8125     -751.81249
X.64        NONBASIS     .00000000      2520.0000      3573.2764     -1053.2764
X.65        NONBASIS     .00000000      2471.0000      3587.4103     -1116.4103
X.66        NONBASIS     .00000000      3212.0000      3370.4065     -158.40647
X.67        NONBASIS     .00000000      2931.0000      3277.4406     -346.44057
X.68        BASIS        .05390090      3150.0000      3150.0000      .00000000
X.69        NONBASIS     .00000000      1853.0000      4565.4033     -2712.4033
X.70        NONBASIS     .00000000      3295.0000      3601.0229     -306.02287
X.71        NONBASIS     .00000000      3089.0000      3585.0503     -496.05031
X.72        NONBASIS     .00000000      2903.0000      3758.9542     -855.95421
X.73        NONBASIS     .00000000      2306.0000      3788.0697     -1482.0697
X.74        NONBASIS     .00000000      2991.0000      3477.3676     -486.36756
X.75        NONBASIS     .00000000      3150.0000      3717.3506     -567.35055
X.76        NONBASIS     .00000000      2718.0000      3701.4773     -983.47731
X.77        NONBASIS     .00000000      2746.0000      3845.6315     -1099.6315
X.78        NONBASIS     .00000000      2974.0000      3546.2394     -572.23938
X.79        NONBASIS     .00000000      2788.0000      3267.9040     -479.90396
X.80        NONBASIS     .00000000      2965.0000      3371.1502     -406.15025
X.81        NONBASIS     .00000000      3000.0000      3847.6862     -847.68619
X.82        NONBASIS     .00000000      2965.0000      3701.9286     -736.92863
X.83        NONBASIS     .00000000      2775.0000      3636.8320     -861.83200
X.84        NONBASIS     .00000000      2669.0000      3412.0668     -743.06682
X.85        NONBASIS     .00000000      2992.0000      3688.8842     -696.88415
X.86        NONBASIS     .00000000      2920.0000      3481.2187     -561.21866
X.87        NONBASIS     .00000000      2718.0000      3620.2705     -902.27047
X.88        NONBASIS     .00000000      2746.0000      3421.9430     -675.94295
X.89        NONBASIS     .00000000      3015.0000      3636.2515     -621.25151
X.90        NONBASIS     .00000000      2636.0000      3598.2967     -962.29673
X.91        NONBASIS     .00000000      2965.0000      3544.8465     -579.84652
X.92        NONBASIS     .00000000      3089.0000      3683.0566     -594.05662
X.93        NONBASIS     .00000000      2780.0000      3632.4216     -852.42155
X.94        NONBASIS     .00000000      3089.0000      3249.7363     -160.73627
X.95        BASIS        .80894128      3693.0000      3693.0000      .00000000
X.96        NONBASIS     .00000000      3130.0000      3935.4120     -805.41197
S.1         BASIS        100.02000      .00000000      .00000000      .00000000
S.2         BASIS        12.213331      .00000000      .00000000      .00000000
S.3         BASIS        280.24895      .00000000      .00000000      .00000000
S.4         BASIS        338.09000      .00000000      .00000000      .00000000
S.5         BASIS        490.12676      .00000000      .00000000      .00000000
S.6         BASIS        43.538976      .00000000      .00000000      .00000000
S.8         BASIS        1264.2180      .00000000      .00000000      .00000000
S.9         NONBASIS     .00000000      .00000000      .43249763     -.43249763
S.10        BASIS        820.60667      .00000000      .00000000      .00000000
S.11        BASIS        335.89105      .00000000      .00000000      .00000000
S.12        NONBASIS     .00000000      .00000000      1.2399463     -1.2399463
```

```
 S.13       BASIS        87.433237      .00000000      .00000000      .00000000
 S.14       BASIS        71.711024      .00000000      .00000000      .00000000
 S.16       BASIS        1315.6820      .00000000      .00000000      .00000000

CHKMCR1     SOLUTION IS MAXIMUM         yield     3673.892900
            DUAL PROBLEM SOLUTION
CONSTRAINT  STATUS      DUAL VALUE      RHS VALUE       USAGE          SLACK
human       NONBINDING   .00000000      958.00000      857.98000      100.02000
diesel      NONBINDING   .00000000      2622.4000      2610.1867      12.213331
electr      NONBINDING   .00000000      2464.5700      2184.3211      280.24895
seeds       NONBINDING   .00000000      1838.0000      1499.9100      338.09000
fert        NONBINDING   .00000000      5493.0000      5002.8732      490.12676
mach        NONBINDING   .00000000      406.50000      362.96102      43.538976
chem        BINDING     -6.1815901      13.750000      13.750000      .00000000
total       NONBINDING   .00000000      13796.200      12531.982      1264.2180
HUMAN1      BINDING     -.43249763      857.98000      857.98000      .00000000
DIESEL1     NONBINDING   .00000000      1789.5800      2610.1867     -820.60667
ELECT1      NONBINDING   .00000000      1848.4300      2184.3211     -335.89105
SEED1       BINDING     -1.2399463      1499.9100      1499.9100      .00000000
FERT1       NONBINDING   .00000000      4915.4400      5002.8732     -87.433237
MACH1       NONBINDING   .00000000      291.25000      362.96102     -71.711024
Area        BINDING      5989.7719      1.0000000      1.0000000      .00000000
total1      NONBINDING   .00000000      11216.300      12531.982     -1315.6820


CHKMCR1     SOLUTION IS MAXIMUM         yield     3673.892900
            RIGHT-HAND-SIDE RANGES
CONSTRAINT  STATUS      DUAL VALUE      RHS VALUE      MINIMUM        MAXIMUM
human       NONBINDING   .00000000      958.00000      857.98000        NONE
diesel      NONBINDING   .00000000      2622.4000      2610.1867        NONE
electr      NONBINDING   .00000000      2464.5700      2184.3211        NONE
seeds       NONBINDING   .00000000      1838.0000      1499.9100        NONE
fert        NONBINDING   .00000000      5493.0000      5002.8732        NONE
mach        NONBINDING   .00000000      406.50000      362.96102        NONE
chem        BINDING     -6.1815901      13.750000      11.271142      32.539981
total       NONBINDING   .00000000      13796.200      12531.982        NONE
HUMAN1      BINDING     -.43249763      857.98000      846.93026      924.82168
DIESEL1     NONBINDING   .00000000      1789.5800        NONE         2610.1867
ELECT1      NONBINDING   .00000000      1848.4300        NONE         2184.3211
SEED1       BINDING     -1.2399463      1499.9100      1299.9633      1512.7982
FERT1       NONBINDING   .00000000      4915.4400        NONE         5002.8732
MACH1       NONBINDING   .00000000      291.25000        NONE         362.96102
Area        BINDING      5989.7719      1.0000000      .98950319      1.0055392
total1      NONBINDING   .00000000      11216.300        NONE         12531.982
```

ANNEXURE – III

Energy minimization at optimum Yield levels and average availability as constraints -Category-I farmers

```
 CHK10E1O    SOLUTION IS MINIMUM        TOTAL     11277.61139
            PRIMAL PROBLEM SOLUTION
VARIABLE    STATUS        VALUE        TOTAL /UNIT    VALUE/UNIT     NET TOTAL
 X.1        BASIS         .24402932     9782.0000      9782.0000      .00000000
 X.2        BASIS         .16704265     14352.000      14352.000      .00000000
 X.3        NONBASIS      .00000000     10270.000     -30612.188      40882.188
 X.4        NONBASIS      .00000000     10502.000     -15751.579      26253.579
 X.5        NONBASIS      .00000000     10309.000     -35362.675      45671.675
 X.6        NONBASIS      .00000000     13596.000     -14674.727      28270.727
 X.7        NONBASIS      .00000000     11919.000     -15033.909      26952.909
 X.8        NONBASIS      .00000000     10556.000     -23571.381      34127.381
 X.9        BASIS         .00073441     13315.000      13315.000      .00000000
 X.10       NONBASIS      .00000000     10713.000     -31419.058      42132.058
 X.11       NONBASIS      .00000000     10782.000      8126.0290      2655.9710
 X.12       NONBASIS      .00000000     11002.000     -26724.937      37726.937
 X.13       BASIS         .11635027     13490.000      13490.000      .00000000
 X.14       NONBASIS      .00000000     11145.000     -25864.076      37009.076
 X.15       NONBASIS      .00000000     11481.000     -3894.7793      15375.779
 X.16       BASIS         .47184335     10414.000      10414.000      .00000000
 X.17       NONBASIS      .00000000     10896.000     -6954.0399      17850.040
 S.1        NONBASIS      .00000000     .00000000     -79.293809      79.293809
 S.2        BASIS         75.368436     .00000000      .00000000      .00000000
 S.3        BASIS         26.227879     .00000000      .00000000      .00000000
 S.4        BASIS         60.972297     .00000000      .00000000      .00000000
 S.5        NONBASIS      .00000000     .00000000     -2.5578617      2.5578617
 S.6        NONBASIS      .00000000     .00000000     -664.39115      664.39115
 S.7        BASIS         2.4100000     .00000000      .00000000      .00000000
CHK10E1O    SOLUTION IS MINIMUM        TOTAL     11277.61139
            DUAL PROBLEM SOLUTION
CONSTRAINT  STATUS       DUAL VALUE     RHS VALUE       USAGE          SLACK
HUMAN       BINDING      -79.293809     889.53000      889.53000      .00000000
DIESEL      NONBINDING    .00000000     1578.1200      1502.7516      75.368436
ELECT       NONBINDING    .00000000     2309.2400      2283.0121      26.227879
SEEDS       NONBINDING    .00000000     1485.8200      1424.8477      60.972297
FERTI       BINDING      -2.5578617     4916.5900      4916.5900      .00000000
MACH        BINDING      -664.39115     260.88000      260.88000      .00000000
chem        NONBINDING    .00000000     2.4100000      .00000000      2.4100000
YIELD       BINDING       89.445714     3109.6600      3109.6600      .00000000
AREA        BINDING      -10431.604     1.0000000      1.0000000      .00000000

CHK10E1O    SOLUTION IS MINIMUM        TOTAL     11277.61139
            RIGHT-HAND-SIDE RANGES
CONSTRAINT  STATUS       DUAL VALUE     RHS VALUE       MINIMUM        MAXIMUM
HUMAN       BINDING      -79.293809     889.53000      889.52634      890.27079
DIESEL      NONBINDING    .00000000     1578.1200      1502.7516        NONE
ELECT       NONBINDING    .00000000     2309.2400      2283.0121        NONE
SEEDS       NONBINDING    .00000000     1485.8200      1424.8477        NONE
FERTI       BINDING      -2.5578617     4916.5900      4916.5068      4932.9700
MACH        BINDING      -664.39115     260.88000      260.87955      260.96759
chem        NONBINDING    .00000000     2.4100000      .00000000        NONE
YIELD       BINDING       89.445714     3109.6600      3109.0030      3109.6633
AREA        BINDING      -10431.604     1.0000000      .99998167      1.0039587
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