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Using Linear Programming Models for Generating Optimum Farm Plans - An Expository Analysis

The potential of linear programming models in farm management research is widely known. It is indeed a very powerful technique which can efficiently handle a large number of linear constraints and variables (activities) simultaneously. With the advent of recent computer revolution in India, this technique is likely to gain greater popularity and use in farm planning. Though the use of linear programming does ensure more precise results, yet it can not guarantee them automatically. A lot depends on the accuracy of the data used and the correct formulation of the linear programming model. Since there is absolutely no substitute for the accurate data, hence all types of farm management research implicitly assume the data to be correct. The role of model building comes as a next logical step, which forms the subject matter of this paper.

During the last about three decades, farm management experts have made very frequent use of linear programming models for analysing farm planning and other related problems, both at the micro and macro levels in India and abroad. A large number of post-graduate theses and research papers published in various journals of agricultural economics and related disciplines bear testimony to the fact that linear programming is a popular tool in the kit of modern agricultural economists engaged in seeking solutions to the farmers' problems. Unfortunately, this tool of economic analysis appears to have been widely sinned against as it is not used accurately most of the times. We have come across a number of M.Sc. and Ph.D. agricultural economics theses where linear programming models are very poorly built. Obviously, the quality of results is equally frustrating, without the researcher realising the gravity of the situation. Most such researches have found their way into the research journals, including this journal, and reported poor quality of results. The brevity of the linear programming models in the research journals, however, may often avoid detection of imperfections in them and ultimately in the final results presented by using them.

Limitations in the use of linear programming models for preparing optimum farm plans have already been realised by some researchers in the past (Dhawan and Kahlon, 1977; Sankhayan and Dhillon, 1977). Both these studies have, however, used too simplistic examples quite uncharacteristic of the present day agriculture. The former study does not even clearly mention the different components of the coefficients of working capital in respect of the production activities, which have been erroneously named as real activities. Both these studies give a wrong impression to the reader that the total gross margins can not be maximised from an optimum farm plan if gross returns were taken as the prices of the real activities in the maximisation model of linear programming. The over-simplification of the models in these studies was mainly due to non-availability of modern computers and efficient routines for solving the linear programming problems on them. With the recent computer revolution in India, things have changed tremendously. The researchers are now able to experiment with several alternate model formulations representing more realistic farm situations without bothering much about the size of the linear programming matrix becoming unnecessarily large.

Experience shows that human labour hiring in different periods during the planning period/year, purchase activities for other crucial modern agricultural inputs like fertiliser nutrients, irrigation, insecticides and pesticides, tractor time, etc., and borrowing of working capital have now become essential and to some extent unavoidable components of present day agriculture. These activities, therefore, must find a direct mention in the linear programming models of farm planning. This, however, makes the model complicated thereby enhancing the scope for mis-specifications at the stage of model building. It may ultimately reflect in terms of vitiated results of optimum farm plans, like the maximised value of the objective function (gross margins or net returns), cropping pattern, credit and capital requirements, human labour employment pattern, etc. In fact, at least two of these aspects are always studied whenever linear programming is used as a tool of farm planning.

The broad emphasis of this study is on having an in-depth probe into the variations of linear programming models for farm planning and their consequences in terms of the results of optimum farm plans. Further, an effort is made to suggest logically accurate and operationally simple formulations of linear programming models for preparing the optimum farm plans consistent with the present day realities on and around the farm.

A TYPICAL PUNJAB FARM FOR EXPERIMENTATION WITH MODEL BUILDING

Consider as a basis for experimentation with model building for preparing an optimum plan for the farm of Mr. Harchand Singh who can be treated as a typical Punjab farmer. His farm is located in Khamano Melewali village of Machhiwara block in Ludhiana district of Punjab State. The farmer is engaged in growing paddy, maize and jowar (fodder) in the *kharif* season and wheat, barely and berseem (fodder) in the *rabi* season. Besides, he also grows sugarcane as an annual crop on his farm. All the crop activities, except jowar and berseem, are produced mostly for the market. Jowar and berseem fodder growing activities in *kharif* and *rabi* seasons are intermediate fixed activities. Thus irrespective of their relative profitability, these crops must be grown by the farmer on some specified areas. These crops are intermediate in nature as they are not produced for the market but form an important and essential input for the dairy activity on the farm. The prices of these crop activities in the objective function are, therefore, treated as zero. Since dairy is also kept as a fixed activity by the farmer to meet his family requirements of milk and milk products, hence this too is not included in the farm planning model. It may be carefully noted that the agro-climatic and socio-economic environment on and around Mr. Singh's farm is quite characteristic of a typical farm in the Punjab State.

Crop Budgets

Detailed budgets on per acre basis for each of the eight crops for the year 1988-89 were prepared and the same are presented in Table I. The yield and price of each crop are also shown in the same table. It may be mentioned here that the requirements of working capital in different crop budgets did not include the expenses incurred on hiring of human labour and for purchasing the nitrogen and phosphorous fertiliser nutrients.

TABLE I. PRODUCTION ACTIVITIES (CROPS) ALONG WITH THEIR BUDGETS PER ACRE AS USED IN LINEAR PROGRAMMING MODELS FOR FARM PLANNING

Production resources	Production activities (x_j^P)							
	Paddy	Maize	*Arhar*	*Kharif* fodder-jowar	Sugarcane	Wheat	Barley	*Rabi* fodder-berseem
	x_1^P	x_2^P	x_3^P	x_4^P	x_5^P	x_6^P	x_7^P	x_8^P
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Land (acres):								
Kharif land	1	1	1	1	1			
Rabi land					1	1	1	1
Human labour (hours):								
January	0	0	0	0	7	15	53	14
February	0	0	0	0	7	7	8	12
March	0	0	0	0	646	6	7	12
April	0	0	0	6	111	109	128	18
May	0	0	16	14	87	0	0	16
June	0	58	0	14	14	0	0	0
July	175	13	1	6	14	0	0	0
August	37	9	1	11	71	0	0	0
September	27	19	7	4	7	0	0	52
October	24	49	0	5	14	0	0	17
November	0	0	90	201	19	18	7	12
December	0	0	75	0	19	13	13	12
Farmyard manure (tonnes)	6.19	8.40	0	0	0	0	0	0
Fertiliser nutrients (kg.)								
Nitrogen	75.54	48.42	46.00	46.00	65.71	60.47	43.50	36.80
Phosphorous	9.52	0	0	0	0	43.46	23.00	0
Working capital* (Rs.)								
Kharif	800.00	580.00	380.00	183.00	92.00	0	0	0
RAbi	0	0	0	0	1,003.00	537.50	348.00	480.00
Yield (qtl.)	20.90	12.80	6.10	-	25.48	21.70	15.00	-
Price (Rs./qtl.)	200.50	246.00	610.00	-	34.00	183.00	165.00	-
Gross returns (Rs.)	4,190.45	3,148.80	3,721.00	0	8,663.20	3,971.10	2,475.00	0
Gross margins** (Rs.)	3,390.45	2,568.80	3,341.00	-183.00	7,568.20	3,433.60	2,127.00	-480.00

* Does not include the expenses on hiring labour and fertiliser nutrients and the interest on working capital.
** Obtained by deducting the corresponding capital coefficients from the gross returns.

Activities, Constraints and Technical Coefficients

Necessary details on various activities, constraints and technical coefficients as obtained on Mr. Singh's farm are laid out in Table II.

TABLE II. SUMMARY OF THE MODEL CONSTRAINTS AND REAL ACTIVITIES FOR THE ILLUSTRATIVE FARM PLANNING PROBLEM

Constraints	Real activities						Product sale	Sign	Right-hand side	
	Crop production	Inpur purchase							Actual amount	Symbol
		Labour hiring	Fertiliser		Working capital					
	x_j^p	x_t^l	x_n^f	x_p^f	x_k^c	x_r^c	x_j^s			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Land (acres)										
1. *Kharif*	+1	0	0	0	0	0	0	≤	17.60	L_k
2. *Rabi*								≤	17.60	L_r
Human labour (hours)										
1. January								≤	600	H_1
2. February								≤	600	H_2
3. March								≤	600	H_3
4. April								≤	600	H_4
5. May								≤	600	H_5
6. June	$+a_{tj}$	-1	0	0	0	0	0	≤	600	H_6
7. July								≤	600	H_7
8. August								≤	600	H_8
9. September								≤	600	H_9
10. October								≤	600	H_{10}
11. November								≤	600	H_{11}
12. December								≤	600	H_{12}
Farmyard manure (tonnes)	$+a_j^m$	0	0	0	0	0	0	≤	114	F
Fertiliser nutrients (kg.)										
1. Nitrogen	$+a_j^n$	0	-1	0	0	0	0	≤		
2. Phosphorous	$+a_j^p$	0	0	-1	0	0	0	≤		
Working capital (Rs.)										
1. *Kharif*	$+a_j^k$	0	0	0	-1	0	0	≤	0	
2. *Rabi*	$+a_j^r$	0	0	0	0	-1	0	≤	0	
3. Limit	0	$+w_t$	$+f_n$	$+f_p$	+1	+1	0	≤	41,032.97	K
Crop area (acres)										
1. *Arhar*								≤	1.0	A_3
2. Jowar	+1							=	3.0	A_4
3. Sugarcane								≤	1.4	A_5
4. Berseem								=	2.5	A_8
Output allocation (qtl.)										
1. Paddy								=	0	
2. Maize								=	0	
3. *Arhar*								=	0	
4. Jowar								=	0	
5. Sugarcane	$-y_j$	0	0	0	0	0	+1	=	0	
6. Wheat								=	0	
7. Barley								=	0	
8. Berseem								=	0	
Objective functions with prices of production activities as:										
1. Gross returns (Rs.)	$+gr_j$	$-(1+i)w_t$	$-(1+i)f_n$	$-(1+i)f_p$	-(1+i)	-(1+i)			Model 1	
2. Gross margins (Rs.)	$+gm_j$	"	"	"	-i	-i			Model 2	
3. Zero (Rs.)	0	"	"	"	-(1+i)	-(1+i)	$+u_j$		Model 3	

Activities: The symbols used for different categories of real activities have the following meanings:

x_j^p = j-th crop production activity, j = 1, 2,..., 8; with acre as its unit. Budgets for these activities are given in Table I.

x_t^l = input purchase activity for human labour hiring during the t-th month, t = 1,2,...,12; starting from the month of January. Hour of man-equivalent work constituted its unit.

x_n^f, x_p^f = purchase activities for nitrogen and phosphorous fertiliser nutrients (kg.).

x_k^c, x_r^c = *kharif* and *rabi* borrowing activities for the working capital (Rs.).

x_j^s = sale activity for the j-th crop (qtl.).

Constraints: In all, 32 constraints were used as shown in Table II. Land (according to crop growing seasons), human labour (according to months), farmyard manure, nitrogen and phosphorous fertiliser nutrients and working capital during *kharif* and *rabi* and maximum limit on working capital use constituted the resource constraints on the farm. Maximum area constraints were used for *arhar* and sugarcane crops and equality constraints for the areas under jowar and berseem during the planning period. Output allocation constraint was used for each of the eight crops showing the condition that all that is produced on the farm is sold. The symbols used for the right-hand side coefficients in Table II have the following meanings:

L_k, L_r = acres of *kharif* and *rabi* land available for crop production on the farm.

H_t = availability of family labour hours on the farm during the t-th month.

F = tonnes of farmyard manure available on the farm.

K = amount of working capital used during both the crop growing seasons in the existing/optimum farm plan.

A_3, A_4, A_5, and A_8 = maximum/required area in acres under *arhar*, jowar, sugarcane and berseem crops on the farm respectively.

Technical coefficients: The symbols used for the different technical coefficients in Table II and in the subsequent sections are as follows:

a_{tj} = hours of human labour required during the t-th month to produce an acre of j-th crop.

a_j^m = tonnes of farmyard manure required to produce one acre of the j-th crop.

a_j^n, a_j^p = kilogrammes of nitrogen and phosphorous nutrients needed to produce an acre of the j-th crop.

a_j^k, a_j^r = rupees of working capital during *kharif* and *rabi* to produce an acre of the j-th crop.

y_j = yield of the j-th crop in quintals.

gr_j, gm_j = gross returns and gross margins per acre of the j-th crop in rupees.

w_t = wages per hour of human labour hired in rupees during the t-th month.

i = rate of interest (per cent).

f_n, f_p = prices of nitrogen and phosphorous nutrients (Rs./kg.).

u_j = price of the j-th crop produce (Rs./qtl.).

Resource Endowment Structure

The resource endowment structure of Mr. Singh's farm is spelt out fully in Table II. In each of the crop growing seasons, *kharif* and *rabi*, 17.60 acres of cultivated land was available, all of which was tubewell irrigated. Family labour in each month was restricted to 600 man-equivalent hours, which could, however, be supplemented through hiring at the rate of Rs. 3.00 per hour. There was no constraint on the availability of labour for hiring during any month, provided working capital was available to make the payment to the hired labour. Farmyard manure produced on the farm was restricted to only 114 tonnes during the year and the same could not be bought from the market. The working capital, including the amount spent on purchasing fertilisers and hiring human labour, was limited to Rs.41,032.97 during the year. The same could be supplemented by way of borrowing at the going rate of interest as long as it was profitable. The farmer owned a tractor which did not restrict production.

The alternate linear programming model formulations were done in respect of this farm only. It is quite easy to generate the models for any farming situation.

ALTERNATE FORMULATIONS OF LINEAR PROGRAMMING MODELS OF FARM PLANNING

There are at least three correct and relatively simple alternate formulations of the linear programming models for farm planning when prices (costs) of the purchased inputs are incorporated directly as the coefficients of the respective activities (variables) in the objective function which seeks to maximise the total net income (gross margins or returns to fixed farm resources) from the farm plans. The distinction among such formulations depends on whether gross returns or gross margins are used as the prices of the production activities in the objective function or using zero prices for the production activities along with input buying and product selling activities with their associated purchase or selling prices.

Thus the three types of linear programming model formulations, when costs of purchased inputs were incorporated directly in the objective function seeking maximisation of total gross margins on the farm, were as follows:

1. In the objective function, the prices associated with the crop production activities were the gross returns. Wages, prices of fertiliser nutrients and borrowing costs in the objective function included the principal plus interest. It was referred to as Model 1. No sale activities and output allocation constraints were required in this model.

2. The objective function contained the gross margins for the crop activities and interest as the cost coefficient of the working capital activities. In all the remaining aspects, the model formulation was the same as for Model 1. This was named as Model 2.

3. The sale activities for each of the crops were incorporated in the objective function. It necessitated the assigning of zero prices to the crop production activities. All the remaining characteristics of Model 1 were retained. Here, additional output allocation constraints were needed, one for each crop. This was termed as Model 3.

The formulations of the above three linear programming models for the example problem are now presented in detail. With a view to keep the models simple, we have intentionally avoided giving generalised versions of each of the models which can be easily deduced.

Model 1: Gross Returns Used as Prices of Production Activities in the Objective Function

Referring to Tables I and II for necessary details, this model for maximisation of total gross margins for the illustrative farm during a planning period of one year can be written as a linear programming problem as under:

$$\text{Maximise } \pi = \sum_{j=1}^{8} gr_j x_j^p - \sum_{t=1}^{12} (1+i) w_t x_t^l - \sum_{j=n,p} (1+i) f_j x_j^f - \sum_{j=k,r} (1+i) x_j^c$$

Subject to the following resource and other constraints:

$\sum_{j=1}^{5} x_j^p \leq L_k$ ... *Kharif* land

$\sum_{j=1}^{8} x_j^p \leq L_r$ ... *Rabi* land

$\sum_{j=1}^{8} a_{tj} x_j^p - x_t^l \leq H_t$ ... Human labour

$\sum_{j=1}^{8} a_j^m x_j^p \leq F$ ... Farmyard manure

$\sum_{j=1}^{8} a_j^n x_j^p - x_n^f \leq 0$ ... Nitrogen fertiliser

$\sum_{j=1}^{8} a_j^p x_j^p - x_p^f \leq 0$ ... Phosphorous fertiliser

$\sum_{j=1}^{8} a_j^k x_j^p - x_k^c \leq 0$ ... *Kharif* capital

$\sum_{j=1}^{8} a_j^r x_j^p - x_r^c \leq 0$ ... *Rabi* capital

$\sum_{t=1}^{12} w_t x_t^l + \sum_{j=n,p} f_j x_j^f + \sum_{j=k,r} x_j^c \leq K$ ...Capital limit

$x_j^p \leq A_j$ ... Maximum area under the j-th crop

$x_j^p = A_j$ ... Area under the j-th fixed crop activity and non-negativity restrictions:

$x_j^p,\ x_t^l,\ x_j^f,\ x_j^c \geq 0.$

It may be noted carefully that the owned working captial was paid at the same rate of interest, as the borrowed capital, being its opportunity cost. a_j^k and a_j^r working capital coefficients neither included the interest on working capital component nor the cost of hired labour and fertilisers for which separate purchase activities were provided for in the model.

Model 2: Gross Margins Used as Prices of the Production Activities in the Objective Function

Many farm management experts may intend to use gross margins as the prices of different production activities in a linear programming model of farm planning. In this case, the problem seeking maximisation of total gross margins for the farm during the planning period of one year is essentially the same as given in Model 1, except a change in the objective function. The changed objective function is as follows:

$$\text{Maximise} \quad \pi = \sum_{j=1}^{8} gm_j x_j^p - \sum_{t=1}^{12} (1+i) w_t x_t^l - \sum_{j=n,p} (1+i) f_j x_j^f - \sum_{j=k,r} i\, x_j^c$$

where $gm_j = gr_j - (a_j^k + a_j^r)$.

Except for the annual crops like sugarcane, either a_j^k or a_j^r will assume a zero value for the j-th crop production activity.

Model 3: Zero Prices for the Production Activities and Sale Prices for the Product Sale Activities in the Objective Function

Yet another alternate formulation of the linear programming model may be used for maximisation of the total gross margins for a farm during a given planning period. The difference in this model as compared to Model 1 is in respect of the objective function and additional output allocation constraints.

The objective function in this case can be written as:

$$\text{Maximise} \quad \pi = -\sum_{t=1}^{12} (1+i) w_t x_t^l - \sum_{j=n,p} (1+i) f_j x_j^f - \sum_{j=k,r} (1+i) x_j^c + \sum_{j=1}^{8} u_j x_j^s$$

where x_j^s are the sale activities for different crop products and u_j their respective per quintal sale prices. u_j is clearly zero for fodder activities in our example as it is not sold in the market.

The additional output allocation constraints needed to be added to Model 1 so as to obtain this model are:

$$-y_j x_j^p + x_j^s = 0, \quad \text{for all j.}$$

Here y_j is the per acre yield of the j-th crop in quintals. Obviously, the new variable x_j^s must also be non-negative. This model explicitly assumes that all that is produced is sold in the market. Whenever minimum consumption requirements also need to be met for some products, it can be easily incorporated in the model by replacing zeros on the right-hand side of the output allocation constraints by the consumption requirements for the farmer's family.

Corresponding Linear Programming Models where Input Purchase Activities are Used as Intermediate Activities

Models 1 to 3, as discussed above, can also be modified by treating labour hiring and fertiliser nutrient buying as intermediate activities, *i.e.*, with zero price for each in the objective function and putting their price coefficients in the relevant working capital constraint rows. For doing so, it is essential to split the labour hiring activities into *kharif* and *rabi* - as there are two working capital constraints. Besides, nitrogen and phosphorous nutrient buying activities need also to be split into two, *i.e.*, *kharif* nitrogen, *rabi* nitrogen, *kharif* phosphorous and *rabi* phosphorous buying activities. In our illustrative problem, six labour hiring activities, $x_{12}^l, x_1^l, \ldots, x_5^l$ are treated as *rabi* labour hiring activities and the rest of the six as *kharif* labour hiring activities. Similarly, x_n^{fk}, x_n^{fr}, x_p^{fk} and x_p^{fr} are the *kharif* nitrogen, *rabi* nitrogen, *kharif* phosphorous and *rabi* phosphorous fertiliser nutrient buying activities. In these models with intermediate input buying activities, some of the constraints will undergo changes as indicated below:

$$\sum_{j=1}^{8} a_j^n x_j^p - x_n^{fk} - x_n^{fr} \leq 0 \qquad \text{... Nitrogen fertiliser}$$

$$\sum_{j=1}^{8} a_j^p x_j^p - x_p^{fk} - x_p^{fr} \leq 0 \qquad \text{... Phosphorous fertiliser}$$

$$\sum_{j=1}^{8} a_j^k x_j^p + w_{12} x_{12}^l + \sum_{j=1}^{5} w_j x_j^l + f_n x_n^{fk} + f_p x_p^{fk} - x_k^c \leq 0 \qquad \text{... \textit{Kharif} capital}$$

$$\sum_{j=1}^{8} a_j^r x_j^p + \sum_{j=6}^{11} w_j x_j^l + f_n x_n^{fr} + f_p x_p^{fr} - x_r^c \leq 0 \qquad \text{... \textit{Rabi} capital}$$

$$x_k^c + x_r^c \leq K \qquad \text{... Capital limit}$$

The method of linear programming model formulations in Models 1 to 3, and their three corresponding models with input buying used as intermediate activities, ensure that the results of the optimum farm plans would be identical in all respects.

Optimum Farm Plans

Optimum farm plans were obtained for our illustrative farm by restricting the working capital use to that of the existing plan, *i.e.*, Rs. 41,032.97, and then by allowing working capital use to the extent that it was profitable, which amounted to Rs. 44,347.17, by using each of the six alternative models suggested above. It was found that the optimum plans obtained with the restricted availability of working capital by using each of the six alternative models were identical in every respect. The same was also true when the working capital was made unrestricted. The optimum plans so obtained for the illustrative farm are detailed in Table III. The corresponding existing farm plan is also presented in the same table. The total gross margins, cropping pattern, human labour hired during each period, fertiliser nutrients used and working capital used in *kharif* and *rabi* seasons were identical in each of the two types of optimum farm plans, irrespective of the linear programming model used out of the total of six models proposed.

Incidentally, the optimisation through linear programming resulted only in a marginal increase of Rs. 912.79 in the objective function, *i.e.*, total gross margins, showing an increase of 1.29 per cent in the gross margins as compared to that obtained in the existing farm plan. Even optimisation with unrestricted capital did not increase the total gross margins significantly. The increase was only Rs. 1,482.10 over that obtained in the existing plan by the farmer accounting for 2.09 per cent rise in the total gross margins. It was, therefore, brought out by the study that Mr. Singh has been planning his farm quite efficiently. In fact there may be no allocation inefficiencies at all if we realise our failure perhaps in not being able to capture all the preferences and goals of the farmer adequately and completely. However, this finding may not be of much significance to the objectives of the present work.

TABLE III. EXISTING AND OPTIMUM FARM PLANS BY USING LINEAR PROGRAMMING MODELS 1 TO 3 AND THEIR CORRESPONDING ALTERNATIVE MODELS WITH LABOUR HIRING AND FERTILISER PURCHASE ACTIVITIES AS INTERMEDIATE ACTIVITIES

Objective function/ Real activity	Existing farm plan	Optimum farm plans with	
		Restricted working capital	Unrestricted working capital
(1)	(2)	(3)	(4)
Objective function			
Total net income* ((Rs.)	70,786.40	71,699.19	72,268.50
Real activities			
Crop (acres)			
Paddy	8.40	8.07	12.85
Maize	3.80	4.05	0.00
Arhar	1.00	1.00	1.00
Jowar	3.00	3.00	3.00
Sugarcane	1.40	1.40	0.75
Wheat	12.70	13.70	14.35
Barley	1.00	0.00	0.00
Berseem	2.50	2.50	2.50
Human labour hiring (hours)			
March	417.60	416.60	0.00
April	1,130.70	1,111.70	1,110.40
July	958.00	903.75	1,678.40
November	325.20	396.20	395.55
Fertiliser nutrients purchased (kg.)			
Nitrogen	1,998.80	2,002.35	2,163.76
Phosphorous	654.91	672.24	746.03
Working capital** used (Rs.)			
Kharif	9,981.80	9,865.11	11,278.66
Rabi	9,778.45	9,967.95	9,664.94
Total working capital*** used (Rs.)	41,032.97	41,032.97	44,347.17

* Equals total gross margins from the plan less the interest on the working capital.
** Includes all components of working capital except those used for hiring labour and purchaseing fertilisers.
*** Does not include interest on working capital.

Effect of Inclusion of Interest Component in the Working Capital Coefficients on the Optimum Farm Plans

In the foregoing discussion of the alternate formulations of linear programming models for preparing optimum farm plans, interest on working capital was not considered as a constituent of the working capital coefficients, a_j^k and a_j^r, for various production activities. The linear programming models were so formulated that the total interest cost on the entire working capital used, owned as well as borrowed, was deducted from the objective function directly. Many researchers may, however, include the interest cost on working capital in the individual capital coefficients and arrive at the gross margin estimates by deducting the corresponding coefficients from the gross returns for each production activity. One would, therefore, naturally feel interested in knowing the effect of such a change in the working capital coefficients (and in the gross margin coefficients) on the optimum farm plans obtained by using the six alternate linear programming models suggested earlier. The answer to such a question is quite simple. As long as a few necessary compensating modifications are effected in each of the suggested model formulations, the optimum farm plans obtained would remain unchanged in all respects.

The working capital coefficients and constraints in Models 1 to 3 would now be as follows:

$$\sum_{j=1}^{8}(1+i)\, a_j^k x_j^p - x_k^c \leq 0 \qquad \text{... \textit{Kharif} capital}$$

$$\sum_{j=1}^{8}(1+i)\, a_j^r x_j^p - x_r^c \leq 0 \qquad \text{... \textit{Rabi} capital}$$

Constraint on working capital limit in its modified form will appear in Models 1 to 3 as given below:

$$\sum_{t=1}^{12}(1+i)\, w_t x_t^l + \sum_{j=n,p}(1+i)\, f_j x_j^f + \sum_{j=k,r} x_j^c \leq (1+i)K \qquad \text{... Capital limit}$$

Certain minor changes required to be made in the objective functions of Models 1 to 3 are given as under:

Model 1. Replace the term $\sum_{j=k,r}(1+i)x_j^c$ with $\sum_{j=k,r} x_j^c$.

Model 2. Reduce the term $\sum_{j=k,r} i\, x_j^c$ to zero.

Model 3. The term $\sum_{j=k,r}(1+i)x_j^c$ needs to be changed to $\sum_{j=k,r} x_j^c$ as in Model 1.

Similarly, suitable corresponding modifications in the objective function as well as in the constraints are needed to be incorporated in the models where input purchases are treated as intermediate activities.

The above suggested modifications were effected in the alternate six suggested models for the example farm so as to confirm our assertion. It was indeed observed that the results of the two types of optimum plans - with restricted and unrestricted capital availability - remained unchanged in all respects.

Other Variations of the Linear Programming Model of Farm Planning

Twenty-four more variations of the linear programming model of farm planning, 12 each with restricted and unrestricted availability of working capital, were generated by simulating conditions which one or more researchers were found using in their works. For example, the working capital coefficients which included all costs, including those for the inputs with separate buying activities, were considered in the working capital coefficients, the prices associated with the labour hiring and fertiliser buying activities in the objective function were also considered without interest components in Models 1 to 3. It was found that the results of the optimum plans were not only different from those obtained with the help of Models 1 to 3 but also logically and arithmetically wrong in respect of various parameters. We have, therefore, intentionally avoided the detailed discussion of such model formulations and the results obtained therefrom so as not to confuse the readers with unnecessary details.

CONCLUSIONS

A study of different variations of linear programming models for preparing optimum farm plans brings out clearly the importance of arithmetic logic in model building. The accuracy of the results of the optimum farm plans depends on the correctness of using logic in model building. Inaccuracies will immediately creep in wherever logic is lost sight of. It is possible to obtain correct results through optimisation, irrespective of the use of gross returns or gross margins as the prices of production activities/variables, if the linear programming model of farm planning is carefully formulated. Even an alternative model with zero prices for the production activities and separate buying and selling activities for inputs and products can generate identical results through the optimisation process. On the basis of this study, it may be concluded that *(a)* it is essential in all the models not to include the cost of those inputs in the working capital coefficients for which separate buying activities are provided in the model. *(b)* It is optional to use interest as a component of individual working capital coefficients provided the form of the model used is consistent with such a situation.

Of the three models of linear programming suggested for obtaining precise results through optimisation, Model 3 is logically very clear and easy to understand. The only shortcoming of this model is that it increases the number of real activities and constraints each generally by the number of production activities. It, therefore, results in an enlarged problem matrix. But keeping in view the availability of very efficient routines and modern computers, it can hardly be considered as a serious limitation any longer. Model 1 too is easy to understand and has a relatively smaller matrix size as compared to Model 3. Of the three alternate models suggested, model 2 is certainly more complex and, therefore, its use may be avoided unless it is properly understood. The same conclusions also apply to the corresponding models with intermediate input buying activities. Finally, one should be careful in not using wrong model formulations inconsistent with the arithmetic logic while using linear programming for obtaining optimum farm plans.

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