APPENDIX I(a)

LINEAR PROGRAMMING

Linear programming is a mathematical tool of budgeting. It is a convenient tool and a systematic method of determining the optimum combination of activities or inputs so as to maximize the income or minimize the cost within the limits of available resources.

First evolved by Dantzig (1944) during the second world war out of a necessity to specify ship routes for quickest movement at least cost, the method is most popular in optimization exercises.

The technique of linear programming is based on the processes of matrix algebra. It helps find out the optimal mathematical solution which maximizes some stated objective within the specified limits.

The difference between marginal analysis and linear programming is that the problem dealing with inequalities of resources cannot be handled by the usual marginal analysis approach whereas linear programming can do it. The difference between linear programming and budgeting is only of (i) the number of opportunities considered and (ii) calculations involved. Budgeting may reject outright some of the activities on the basis of experience of the
entrepreneurs whereas linear programming may suggest combination of all enterprises to optimize the quantity considered.

In mathematical terms, we can set the problem to be solved by linear programming method as follows (Assume that we are faced with a maximizing problem).

\[ \text{Max } Z = C' X \]

subject to

\[ AX < b \]

and \[ X \geq 0 \]

where \( C \) is a column vector representing coefficients of the objective function; \( X \) is the column vector representing the activities. \( A \) is the matrix of technical coefficients and \( b \) is the constraint column vector.

The solution to a linear programming problem involves a series of calculations which, though can be done by hand, requires the use of computer for most practical situations. The validity of the solution depends upon the accuracy of the data in terms of identifying the constraining framework and the realistic specification of the problem. Heady (1954) appears to be the first agricultural economist to suggest and attempt the application of linear programming to resource management in agriculture. Since then the method has been progressively applied to see whether or not the available resources are allocated optimally.
Linear programming can serve as an important management aid to the farmers; provided certain assumptions, as listed below, are tenable for the situation deemed relevant.

Assumption of Linear Programming

The application of the technique of linear programming imposes a number of restrictions to be followed. The basic concept in a linear programming technique is that of a 'process' or 'activity'. The basic assumptions are:-

i) Linearity

It means absence of interaction between resources and activities i.e. the resources required for producing n units of an activity are n times the resources used for each unit of that activity and secondly, the total quantity of any resource must be equal to the sum of the total of that resource required for different activities. Let $X_i$ denote different levels of activities and $b$ denotes the amount of available resources, then the linearity relationship is of the form $a_iX_1 + a_iX_2 = b$. The simplest way to explain linearity is "to double the production", "all the resources must be doubled".

The assumption is inherent in the very definition of linear programming where both the objective function as well as the input-matrix is composed of linear constraints.
ii) **Divisibility or Continuity**

According to this assumption it is possible to produce fractions of output and use fractions of resources. The linear programming solution provides mathematically exact answers involving very small fractions, though in certain cases it may not be difficult to visualise the use of fractions while in some cases it may be practically illogical to use fractions. For example linear programming can provide a solution of 3.2 buffalows and 4.6 cows, but farmer cannot have 3 or 4 buffalows or 4 to 5 cows. In such cases it may be advisable to re-run the matrix to get values without fractions but profitable.

iii) **Additivity or Independence**

It is assumed that processes or activities are additive and there is no interaction between any two activities. Hence, resources required by one enterprise are independent of whether another enterprise is included or not. In actual farm situation, however, there are many examples of dependence among the enterprises. For example, the sequence in which the crops are grown on the same piece of land affects the input-output relationships for various crop enterprises in the rotation. Hence in the case of complimentary relationship between two crops we have to take the crop combination involving both the crops, as a separate activity (Desai, 1963).
iv) **Finiteness**

This condition implies that the opportunities open to a farmer as well as his resource constraints are not unlimited. From the point of choice of crops or crop combinations, this assumption is valid as farmers are interested in a comparatively small number of alternative activities.

v) **Single-Valued Expectations (Exact Data)**

All the coefficients in linear programming are assumed to be known with certainty, i.e. the exact data, and not the probable data are used.

vi) **Short Term Static Model**

The linear programming model is a short-term static model providing the optimum values which may change continuously. If the solution is not widely different from the existing one, it may be easily applied, otherwise it may take a long run to find the applicability of linear programming solution.

vii) **Non-Negative Level**

The activities in the linear programming solution should appear at a non-negative level in any case. This is a mathematical requirement of the model and arises from practical situations, because negative levels of crop activities have no economic meaning. The condition is written as

\[ X_j \geq 0 \quad j=1, \ldots, n \]
To apply linear programming technique for finding the optimum solution, we need to form the technological matrix which contains the data. It is explained below.

Technological Matrix

The technological matrix is composed of input coefficients which relate to the input restrictions with the processes or activities in the programme. The input coefficients are the resource requirements per unit of process or activity included in the programme and their accuracy is vital for obtaining meaningful results. The unit can be any of the inputs i.e. per unit of variable capital, per unit of labour or per unit of land. Of all these land is relatively scarce, therefore, per unit requirements of this factor can be justified and we have used this measure for determining relative efficiency of both the techniques of production. The data for input coefficients is taken for individual farmers selected in our sample. The detailed information in this regard was provided by Bagai & Soni (1979).
APPENDIX I(b)

Input Restrictions in Linear Programming

In farm production a linear programming problem does not exist unless resources are restricted or limited. The following resources have been considered as restrictions for our programme.

i) **Land**

Though the input restriction of land is there in almost every country in the world, but in a highly populated country like India its effect is highly felt [Ref. Desai (1963), Gotsch & Yusuf (1975)]. So, whatever land is available to individual farmer, is considered as a land which can't be increased. The land restrictions are estimated for each crop. We have not classified land as owned and tenanted land and have consequently treated all land as owned land.

Apart from the total area, the farmer's operation is restricted by the type of the soil and irrigation facilities on the farm. So, a distinction is made between "irrigated land" and "unirrigated land". To be more precise, we have also distinguished between two types of land restrictions:

a) Land (Kharif)

b) Land (Rabi)
This distinction is kept because farmer's operation is restricted in the sense that the land available to the farmer in both the seasons is fixed and can't be increased.

ii) Labour

The quantity and the quality of labour available for the farm work is the next important constraint to be considered. Though it looks rather surprising that in a labour surplus economy labour is a restriction, but it is very much there especially in the peak period, in the Punjab state which has experienced Green Revolution [Ref. Frankel (1971)]. That is why labour is taken as an important constraint while talking of agricultural policy and linear programming. Seasonal distribution of the labour requirement is an important consideration [Karan Singh & Kahlon (1981)]. Labour is more restrictive in certain periods of the year than others - particularly in the peak periods when most of the harvesting or cutting is to be done on the fields. Considering this we have considered two peak periods restrictions for labour. These periods are:-

1) April - June

In this period fields have to be prepared and kharif crops are to be sown after the first monsoon break during this period. Moreover, crops sown during this period are more labour intensive at their sowing period e.g. paddy and maize.
2) September - December

In this period kharif crops are to be harvested and rabi operations are to be undertaken. Labour availability during these periods determine the production pattern on the farm.

Farm labour is drawn from two sources - family unit and hired labour [Ref. Karan Singh & Kahlon (1981)]. Gotsch (1975) and Dawson (1983) also consider two types of farm labour viz family labour and total labour; where total labour includes family labour and the hired labour on the farm. The hired labour, in general, falls into two categories viz. permanently hired and casual labour.

So, for our study we have also maintained the distinction between hired labour and family labour. Permanently hired labour, like the family labour is treated as fixed factor, as our objective is to construct a planning framework for maximizing the returns to the fixed farm resources.

Family labour (consisting of farmer and his family members) and permanently hired labour have been categorised as labour I; while casually hired labour is depicted as labour II in our study. The casually hired labour is to be taken as a constraint, because during peak period (considered above) such labour is required on the farm and the availability of such labour would be treated as given during this period. There is an upper limit to the
availability of both the labours - type I and type II - during the peak periods, hence the labour restriction is quite justifiable in this time. So, taken together the labour restrictions will be:

(I) Labour I (April-June)
(II) Labour II (September-December)
(III) Labour I (April-June)
(IV) Labour II (September-December)

While considering labour restrictions and input coefficients of labour, a day of eight hours is taken as a unit of measurement and labour coefficients are worked out in terms of man-hours spent on different crops and expressed in terms of per-unit of land.

iii) **Irrigation**

The available water supply was another constraint which needed to be considered; because even though the land inventory takes into account whether the land is irrigated, the quantum of irrigation available and whether it restricts the production programme needs to be assessed. Considering this, we have taken the irrigation hours during the period September-November, serving as a constraint for this purpose. For this is the period during which the requirements of artificial irrigation facilities are the maximum.
Moreover, while considering this constraint we have observed that though tubewells and pumpsets are the main sources of irrigation, still canal water is used in some cases. So, we needed to standardise the total hours of irrigation used per acre of land of a particular crop. We followed the following assumption in this case that canal water irrigates four times faster than the tubewell water. All the other variations in the source of water like diameter of the pipe, nature of soil, size of canal outlet, were assumed to be same for all farms, within reasonable limits.

iv) Manure

This was the next constraint considered in our study. The stocks of manure available to the farmer should be known in advance; because most of the manure is home produced and its production can't be increased arbitrarily. Hence the maximum availability of farm manure is another constraint; which a farm management study can't ignore.

The constraint of fertilizer was ignored by us as we considered it to be an item needed in the farming process; which can be purchased according to the need and money available with the farmer. So, instead of treating it as a separate constraint, it was accounted for in the cash constraint, which is the next restriction considered by us.
v) **Cash Restrictions**

The non-availability of sufficient finance is one of the important constraints in crop production particularly in India. The farmers experience great hardship in obtaining short term credit which is required for cash expenditure in crop production. And the farmers have very little capital of their own to finance their working expenditure on the farm.

Taking into consideration these points we considered the total cash available with the farmer for the farming purposes. For considering the total cash spent by farmer, the two periods are considered - Kharif and Rabi periods. As both these periods pertain to producing different crops and the amount available with the farmer in both these periods is also fixed, so both these periods have been considered as two different resource restrictions regarding availability of cash.

1) Cash (Kharif)

2) Cash (Rabi)

For both these restrictions, the amount of cash taken in consideration is the cash as spent for hiring labour (payment made in cash or kind), purchasing seed, fertilizers, pesticides, irrigation charges, maintenance and repair of machinery, operational expenses of running owned machinery and miscellaneous expenses.

The depreciation amount of owned agricultural machinery was considered only in case of one objective.
function "farm business income (net)". For this objective function, the depreciation of owned machinery was allocated to different crops on the basis of hours of use of that particular machinery for that particular crop. However, certain implements were used exclusively for one or two crops and the depreciation of these was added to the account of those particular crops e.g. the depreciation amount of the "sugarcane cutter" was added to the cash spent on sugarcane only. As is obvious from the definition of the objective function - farm business income (gross) - the depreciation amount was not considered in this case.

The cash expenses for both these objective functions were allocated to different crops in a farm household. The cash expenses, as discussed above, do take into consideration the amount of money spent on maintenance of bullocks, land revenue and land rent; though these three have been considered as fixed capitals for evaluating our objective functions.

Using the above stated restrictions, linear programming technique is applied to optimize the "farm business income (gross)" and "farm business income (net)" of cultivating households.