Application of LP for Agricultural Land Allotment: Difference between Modelling and Reality

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Decision making in the agriculture sector is complex, with nature, economics, profit calculations and long-terms goals playing their roles side-by-side. One critical aspect in agriculture is allotment of land for production of multiple crops. This paper illustrates an example of land allotment for agriculture in a setting where a land produces four crops at the same time. While linear programming model generated a particular set of outputs recommending particular pieces of land to be allotted for specific crops, reality was far different. It was found that land allotment was guided by a mix of factors - business and nature - and was dependent on the available supply of the crop in the market and whether a crop can withstand a sudden change in climate.

Keywords: Linear programming, Agriculture, Land allotment, Climate, India

2023. In Saroj Hiranwal & Garima Mathur (eds.), *Artificial Intelligence and Communication Technologies*, 219–224. Computing & Intelligent Systems, SCRS, India. https://doi.org/10.52458/978-81-955020-5-9-23

1 Introduction

Decision making in the agriculture sector is a complex problem, particularly since agriculture output is significantly dependent on the vagaries of nature. One primary concern is how to allot a piece of land for producing multiple crops at the same time. Optimisation models demand that the land available for cultivation be allotted among the crops in a manner that total profit from the total piece of land is maximised. Often it has been observed, that the nature of allotment of land among the crops in real-life setting does not reflect the recommendations of the optimisation models. This paper describes a situation where a particular piece of land grows four crops at the same time. The aim was to allot the total piece of land among the four crops in such a manner that the profit from the total piece of land is maximised. A simple linear programming model was developed and a solution generated. However, the optimal solution showing the desirable allotment of land among the four crops was way different from reality. It is seen that there are other factors – some measurable and some intuitive, that contribute to decisions relating to agriculture.

The arrangement of the paper is thus: first we present relevant literature on application of mathematical models for different decisions pertaining to agriculture. Next we present the case in hand – we describe the problem, apply linear programming and discuss the reasons for mismatch between theory and practice.

2 Literature Review

Agriculture contributes to about 17.8% of Gross Value Added (GVA) in India. The percentage has remained stable over a period of time (2015-2020). Not only the country is self-sufficient, but there is surplus output from agriculture. Land used for cultivating different crops in descending order are: food grains, rice, wheat, cereals, pulses, oilseeds, sugarcane and cotton. In recent years, there is an increased effort toward 'doubling of farmers income' and policies are being framed, infrastructure and government instruments being put in place to achieve the same [8].

Use of mathematical models in agriculture sector for various decisions making is fairly new. Modelling techniques are mostly used in the domain of forecasting the yield of crops. This is important as the nation needs to have food surplus. Also, forecasts help to identify weak areas and in turn help frame government policies and put in place procedures to help farmers to increase output from land. Forewarning crop pests and diseases are also being modelled mathematically to help the farmers [9]. Time series models have been extensively used for forecasting crop yield (Choudhury and Jones [3]). Very recently, machine learning models are also being used for predicting crop yield (Klompenburga et al. [4]).

Kundu et al. [5] present an ensemble model to predict crop yield in the Indian state of Telengana. The model applies weights to equation-based, tree-based, machine-learning based, and memory-based models to present an ensemble model that predicts agriculture output in a more precise manner than individual forecast models. Variables considered for this study are: weather and soil characteristics, and irrigation and fertiliser usage.

Alotaibi and Nadeem [1] present a review of applications of linear programming (LP) for different decision-making issues in agriculture. They opine that LP can help in determining the optimal crop pattern and production-planning (sowing) pattern for food crops. They also opine that LP can frame profit maximisation problems given the limiting resources of water supply, labour and use of fertiliser.

Nidumolu et al. [6] opine that their multiple stakeholders in agriculture. Prominent among them are farmers, government departments and agricultural scientists. They frame an interactive multiple goal linear programming (IMGLP) model that prioritises goals of crop selection (among a choice of multiple crops), profit, and minimum water usage and government priorities. They present different scenarios and use IMGLP for the different scenarios. The uniqueness of the model lies in that it presents farmers and authorities with different options based on different happening of events.

Bouma [2] opine that the decision on land use system is a three-tier decision; (a) at the strategic level - government; (b) tactical level - agricultural scientist level to discuss the crop rotation pattern, application of fertilisers etc.; and (c) operational level - farmer level, to implement it. In a theoretical statement, they opine that linear programming can serve a tool to compare options at the tactical level. This can help the farmers at the operational level to a great extent.

Wankhade and Lunge [7] use linear programming for allocating of agricultural land to major crops. They use a maximisation of profit model to allocate land among different crops. Variables considered for this model are the total available land, minimum land per crop, target total yield, labour hours, machine hours, and usage of pesticides.

While research acknowledges the relevance of optimisation models, very few speak on the reasons behind the difference between theory and practice. This paper presents such a case and explains the reasons of difference between different recommended using optimisation models and actual output in practise.

3 Objectives of the Study

The objectives of the study are:

a. Determine the optimal mix of land allotment for producing multiple crops
b. Explain the reasons for mismatch between recommended land allotment using mathematical models and actual allotment of land to multiple crops

4 An Example

We consider a real-life case of a piece of land, 25 hectares in area, on the border area between the states of Madhya Pradesh and Rajasthan in India. The land grows five crops – wheat, onion, garlic, mustard and soy seeds (from which soybean oil is extracted). The sowing and harvesting season for the crops are presented in Table 1 below. The crop, the month when the crop is sowed, and the harvesting month is shown. For example, Wheat is sown through the months of November and December of a year and harvested during the months of March and April of the succeeding year.

Table 1: Sowing and harvesting season for crops

Crop	Sowing Month	Harvesting Month
Wheat	November-December	March-April
Onion	November-December	March-April
Garlic	November-December	March-April
Mustard Seed	November-December	March-April
Free Month (no cropping)	May-June	May-June
Soy Plant (seed)	July-August	October

Major activities involved in production are:

a. Preparing the land for seeding (rowing of the seeds)
b. Seeding – rowing of the seeds
c. Weeding
d. Activities like tilling the land, electricity for watering the field, transport for carrying the harvest away from the field and to selling points etc.

Since wheat, onion, garlic and mustard seeds are sowed and harvested during the same months, it is important to allot the total land among these four crops in such a manner that the profit from agriculture is maximised.

It is important to know the cost of cultivation per acre of land. This, alongwith probable profits is presented in Table 2 below. For example, wheat can generate a profit of Rs. 64,000 per acre of land cultivated. To cultivate 1 acre of land of wheat, Rs.1400 worth of seeds have to be purchased; Rs.1200 has to be spent on preparing one acre of land for cultivation, a weeding cost of Rs.1200, labour cost of Rs.1900 and fertiliser cost of Rs.2200 is incurred.

Table 2: Per acre data on cultivation

Variables	Wheat	Onion	Garlic	Mustard	Total available resource (Rs.)
Profit(Rs. Per acre)	**64000**	**264000**	**120000**	**58000**	
Cost of seeds (Rs. Per acre)	1400	6000	12000	500	35000
Land Preparation cost (Rs. Per acre)	1200	2000	1600	1200	30000
Weeding cost (Rs. Per acre)	800	3000	2500	1150	35000
Labour, electricity and other costs (Rs. Per acre)	1900	10000	9000	1150	90000
Fertilizer cost (Rs. Per acre)	2200	5000	8000	2000	100000

Since the objective is to allot the total land among these four crops in such a manner that the profit from agriculture is maximised, we formulate the problem as a linear programming problem with the following objective and constraints. We assume that all the produce can be sold at government supported minimum support price. We also assume that a total of 25 acres of land is available.

Let,

X_1 be the acres of land allotted for wheat cultivation

X_2 be the acres of land allotted for onion cultivation

X_3be the acres of land allotted for garlic cultivation

X_4 be the acres of land allotted for mustard cultivation

Then the objective function is:

Max $Z=64000x_1+264000x_2+120000x_3+58000x_4$

Subject to:

$1400x_1+6000x_2+12000x_3+500x_4 \leq 35000$ (seed requirement constraint)

$1200x_1+2000x_2+1600x_3+1200_4 \leq 30000$ (land preparation constraint)

$800x_1+3000x_2+2500x_3+1150x_4 \leq 35000$ (weeding constraint)

$1900x_1+10000x_2+9000x_3+1150x_4 \leq 90000$ (labour, electricity and other constraints)

$2200x_1+5000x_2+8000x_3+2000x_4 \leq 100000$ (fertiliser constraint)

$x_1+x_2+x_3+x_4\leq 25$ (land availability constraint)

Situation 1: Land cultivation as per optimisation model

The output generated using python jupyter for the above model is produced below:

Maximum_Profit: Rs. 21,78,709.64
X_1 (land allotted for wheat) = 0 acres
X_2 (land allotted for onion) = 4.35 acres
X_3 (land allotted for garlic) = 0 acres
X_4 (land allotted for mustard) = 17.74 acres

The linear programming solution shows that no production land should be used to cultivate wheat or garlic. The total land usage should be 22 acres, wherein the total land available is 25 acres. This happens due to having a '≤' constraint for land cultivation or usage.

Situation 2: All land is cultivated ("All land usage")

If we assume that all land is to be cultivated, we set the land availability constraint as: $x_1+x_2+x_3+x_4=25$. The revised optimal results are as follows:

Maximum_Profit: Rs. 16,00,000
X_1 (land allotted for wheat) = 25 acres
X_2 (land allotted for onion) = 0
X_3 (land allotted for garlic) = 0
X_4 (land allotted for mustard) = 0

Clearly, the profits are reduced if all land is cultivated. Thus, the LP formulation as provided under Situation 1 without having a binding constraint of "all land usage" appears to give a satisfactory output that should be acceptable to the farmer.

The two situations are presented in Table 3 below:

Table 3: Profit and land allotment based on Situation 1 and Situation 2

Description	**Land constraint not imposed**	**All land is cultivated**
Profit	**21,78,709.64**	**16,00,000**
X_1 (land allotted for wheat)	0	25
X_2 (land allotted for onion)	4.35	0
X_3 (land allotted for garlic)	0	0
X_4 (land allotted for mustard)	17.74	0

Reality:

In reality the land is cultivated and profit obtained by the farmer is as per the following pattern (Table 4):

Table 4: Profit and land allotment based on practise (reality)

Description	**Land cultivation**
X_1 (land allotted for wheat)	15-17 acres
X_2 (land allotted for onion)	3-4 acres
X_3 (land allotted for garlic)	5-6 acres
X_4 (land allotted for mustard)	2-3 acres
PROFIT (Rs.)	**Rs. 24,68,000**

Clearly, the profit obtained by farmers using their intuition is much more (Rs.24,68,000) than the ones modelled using linear programming (Rs.21,78,709 under Situation 1 and Rs.16,00,000 under Situation 2).

5 Explanation and Discussions

Though mathematical models are designed to obtained optimality, on-the-ground situations may differ based on certain conditions. The above example presented such a case. Clearly, the area allotted for particular crops were way different in reality than the ones recommended by the models. The primary reason lay in not the non-effectiveness of the model, but the hard reality. Wheat is cultivated the most, though its profit contribution per hectare is comparatively less. Still wheat is cultivated in larger quantity because wheat as a crop is not reactive to sudden change in weather conditions like high or low rainfall or a storm. The crop sustains in odd weather. Thus, profit is ensured. The model predicted the maximum allotment of land for mustard cultivation as its resource consumption is low. But mustard plants are not as sturdy as wheat and are amenable to sudden changes in climate like heavy rain. The farmers may lose the entire produce of a year if they allot all land for mustard cultivation.

Wheat is a crop required and used in every home under all conditions – irrespective of income of a family. It is a staple food item for most of the country. Thus, even if end-market price rises, the population will buy the product. But the same is not the case with onion, garlic or mustard. People will buy less of these products if the end-market price rises. Thus, profit is ensured if the farmer devotes land to wheat.

However, then why does the farmer not allot the entire piece of land to wheat cultivation, as provided in Situation 2? If there is ample supply of wheat in the market, the law of demand and supply will come into force and a higher supply of wheat than the demand will pull down the prices and the farmer will lose on his profits. Thus the farmer mix-and-match his production.

6 Conclusion and Direction for Future Research

This paper illustrates an example of reality differing from theoretical model building. We take an example from land allotment for agriculture in a setting where a land produces four crops at the same time. We illustrate that while a linear programming model allots all land to one or two crops, in reality all crops are produced. This is done to take care of the vagaries of nature that might harm a crop or to take care of profit objective.

Future research can expand the horizon of the model by increasing the number of constraints and application of the model in other parts of the country.

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