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Application of Operations Research in Agriculture

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Abstract— In our research paper, we have discussed the Applications of Operations Research to the Agriculture Industry. Agriculture is an industry involving a large number of decisions to be taken, both planned and unplanned. Since this industry is highly influenced by external factors, the farmers have to be ready to face any situation that comes their way. In Agriculture, decisions have to be taken in the present, for the future, in the presence of the aspect of uncertainty. Since uncertainty is a subjective phenomenon, parameters of a probability distribution cannot be established accurately. The Special Nature of Farming Enterprise Returns are a function of several variables, the more important being the quantity of output produced from a given set of resources, the cost of production per unit output and the price at which the output is sold.
Taking into consideration all these factors, some of the decisions we aim to analyze in our research paper are:

- Where to establish a farm? What should be the size of the farm? What type of buildings are preferred to be constructed on the farm?
- The type of farming he should have, i.e.- Grain Farming, Hog Farming, Dairy Farming, etc.
- The type of resources he should acquire and in what quantities? For example- size, quantities, models, and modifications of tractors and other machines, etc.
- Most optimum allocation of available resources.
- What, when and how much to produce?
- What level of technology should he use? The various operations to be performed, in what time period and in what manner.

Some of these decisions are taken after a lot of thought has been given to them, whereas some are spontaneous. Some might be long term in nature, such as farm expansion or buying capital assets, while some might be short-lived, like deciding whether to irrigate a crop today or the next day. We have also tried to provide feasible recommendations and conclusions that can be applied to the existing scenarios so as to improve their current state of operations and lead to the generation of higher profits with no added costs or addition of resources.

Index Terms— Agriculture, Maximization, Minimization, Operations Research

1 Introduction

Agriculture, also known as farming or husbandry, is the science of cultivating plants, animals, and other forms of food, fiber, and fuel. It encompasses industries engaged in growing crops, raising animals and fish, logging wood, dairies, hatcheries, and ranches.

The development of agriculture spans over thousands of years and has been affected by human civilization, climate change, and rapidly evolving technologies. Many people still rely on traditional methods to maintain an environment that is conducive to farming. However, farm yields have increased exponentially due to improvements in chemicals, equipment, irrigation systems and breeding of cattle. Yet, some of these developments pose a serious threat to the environment and a health risk to humans.

A breakthrough in the agriculture industry is the 'Green Revolution', which started off at the beginning of the 20th century. The revolution has helped in saving people across the globe from mass starvation via initiatives involving advanced irrigation systems, high yielding varieties of crops and better managerial strategies.

In charge of putting healthy food in consumers' plates, the agriculture industry is regulated by strict regulations. Farmers must be up to date on all legislation affecting their products and labor laws.

A hard-hitting economic slowdown and severe droughts have plagued the industry over the past decade. While employment in some sectors of this industry is set to rise, other areas are forecasted to decline. For example, opportunities are looking promising for science and research & development, prospects look bleak for farmers, ranchers, and laborers. India has the 10th largest arable land resource in the world. India has 20 Agri-climatic regions and all 15 major climates of the world exist here. India is the largest producer of spices, pulses, milk, tea, cashew and jute; and the 2nd largest producer of wheat, rice, fruits and vegetables, sugarcane, cotton, and oilseeds. In 2018-19, the Government of India has estimated food grain production of 285.2 million tonnes, and agriculture exports of India in FY19 are $38.54 million. The new Agriculture Export Policy (2018) aims to increase India's agriculture exports to $60 million by 2022.

2 The work of Dr. Thornthwaite

The first challenging and interesting application of operations research was given by Dr. C.W. Thornthwaite during 1946-50. In 1946, Seabrook farm had 7000 acres of peas to be harvested for freezing and canning process. Profits from freezing are greater than canning but if not frozen within a couple of days of their maturity, they have to be canned and thus reducing profits for farmers. The Problems faced by Seabrook farm were:

a) There was no scientific method to find the right time to harvest.
b) At the time of maturity, all used to ripe at a time and thus became impossible to keep up with the ripening peas even after using all the machine and manpower.
c) Due to large quantities at a time, freezers could not keep pace with the pickers.

Dr. Thornthwaite handled the first problem with the help of evidence that the rate of growth and development of plants depends on climatic factors. The other two problems were solved by establishing a different planting schedule so that all peas would not mature at the same time.

2 Mathematical Programming and Game Theory

Farming is different than other industries as it is greatly affected by natural factors like soil, climate, etc. The plants and animals cannot be treated the same as the output of other industries. Time lag is the major peculiarity of agriculture that differentiates it from industries, one has to wait for years before he can get returns on his investment. Due to the bulky and perishable nature of agricultural products, the problems of selling and storage are also different than industries.

All these and other peculiarities of agriculture are responsible for the difference in the nature of decision problems faced by a farmer and company executive. The objective of this study is to examine the suitability and applicability of operations research techniques to decision making in a farming process. This study is confined to the following:

1. **Mathematical Programming** – Linear fractional functioning and Programming
2. **Game Theory**

2.1 Mathematical Programming

If the objective function can be expressed in terms of the mathematical model, the desired solution can be computed by means of 'Mathematical Programming'. As the name suggests, like other mathematical tools, mathematical programming is a mathematical technique without any economic content. We will confine ourselves to the study of only following aspects of Linear Programming:

a) Characteristics of linear programming problems and the general results(theorems) of linear programming.
b) Linear Fractional Functional Programming – a brief.
c) Network Analysis

2.1.1 Linear Programming

To formulate the problem mathematically, the following notations are used

Z = The objective function to be maximized,
Xj = Input Variables
Ci = Cost coefficients of the objective function Z
bi = Maximum limit of the constraints.
Aij = Coefficients of the functional constraint equations.

It has been observed that some LP problems, the simplex algorithm takes a smaller number of iterations as compared to other algorithms. In the present study, we framed the LP model for land allocation to the four major cereal crops in agriculture. The solutions are obtained by the Simplex Algorithm.

Application of Linear Programming in Agriculture

Linear Programming has been used in agriculture since its very inception. The use of linear programming for individual farmers is referred to as 'Program Planning' and has been widely used in Europe and Japan and to a limited extent in the U.S.A. Barker conducted a study on use of linear programming in farm management decisions and came to conclusion that, "Linear programming can be of value in farm decision-making by providing quantitative estimates of returns for specified alternatives and levels of resource use" and larger the size of farm, the larger the number of alternatives and higher the chances of benefits from linear programming.

In addition to the use of Linear Programming at the micro-level i.e., cost minimization and profit maximization for an individual farm, these techniques have been applied at a macro level for solving problems of agriculture marketing and spatial analysis. Transportation models are the simplest of linear programming models applied in agriculture.

2.1.2 Linear Fractional Functional Programming

Linear Fractional Functional Programming is applicable when the objective function is a ratio. There are many situations in agriculture, the ratio needs to be optimized like returns per hour of man labor, maximizing profits per dollar of investment, etc. Given below is a simple example of an application of linear fractional functional programming in agriculture.

A farmer proposes to raise corn and wheat on 100 acres of land. Given below is the basic data for these two crops on his farm.

We assume that all costs (except for labor requirements) are identical for both crops. We further assume that whether the farmer raises any crop or not, he has to devote four hours during the crop season to the maintenance and upkeep of the equipment such as tractor, combine, etc. The farmer has 300 hours of labor available for the crop season and he is interested in maximizing returns per hour of labor.

Let X_1 be the acre under corn,
Let X_2 be the acre under wheat.

The problem is to find out as to how much area he should have under corn and how much under wheat. In other words, the decision variables are X_1 and X_2 and we have to determine their desired values.

After solving the equations, we get to the conclusion that farmers should raise corn on all 100 acres of land and not grow any wheat. The linear fractional functional programming technique holds great in its application to agriculture when the objective is to maximize returns per hour of family labor, hired labor or both, or returns per dollar of capital invested.

2.1.3 Application of Network Analysis

Network analysis has been widely used in industries for planning, scheduling, and evaluation of the projects but very applications have been made in the field of agriculture. The most detailed application of this has been done by Heiland, Jaendl, and Kastner to the problem of labor. There are many areas in agriculture where it can be used for advantage, such as if a farmer has one tractor are it can be used for plowing, bringing fertilizers, fertilizing, sowing, cultivating, irrigating and even transporting the produce. But he cannot use it for buying fertilizers from the market and plowing at the same time. There can be only one path connecting all those activities that are to be performed by the tractor. Network analysis will help us in drawing schedules for the most efficient use of the tractor.

2.2 Game Theory

This study demonstrates the use of an alternative decision models for farmer decision making under uncertainty. Partic-ular emphasis was given to game-theoretic models. These models have little empirical application to the farmer's decision problems.

Of the several models for decision making under uncertainty, only the model for maximizing expected utilities, the game-theoretic models, the naive or econometric models and various precautions for uncertainty provide an objective rule for obtaining an implicit or an explicit goal. However, this study has shown that they suggest plans which farmers in various problem settings may wish to follow. Research and extension personnel may want to use the model to derive farmer recommendations.

Uncertainty is the usual environment for agricultural decisions. Uncertainty is introduced by technical and technological changes, price variation and unpredictable human action. Game-theoretic techniques may have considerable use in the whole farm planning. Usually, input-output coefficients used in linear programming or budgeting are averages. They are subject to variations. This variation may affect the profitableness of the whole farm planning. Some farmers want to be sure that income levels will not fall below some minimum or feasible level. Thus, a whole farm plan based on average input-output coefficients is not acceptable. However, farmers might accept a plan which assures maximum minimum levels each year. Such a plan may be based on the input-output coefficient derived from a game against nature by application of the Wald criterion. The solution for a crop enterprise problem would suggest a plan which assures a minimum return. The minimum return may be regarded as the output coefficient. The input coefficient is given by the combination of variety, fertilizers and cultural practices required for the crop plan which is selected. The particular crop is an activity to be included in linear programming analysis designed to plan the whole farm operation.

Operations Research (OR) can be described as the discipline of applying advanced analytical methods to help to make better decisions and has been around in the agricultural management sector since the 50s, approaching decision problems that range from more strategic level planning to farm operation issues and integrated supply chain. The presence of OR in Agriculture Management applications is already extensive but the potential for development is huge in times where resources are becoming increasingly scarce and more has to be done with less, in a sustainable way.

3 New Planning tools for optimal climate change adaption strategies in irrigation

To maintain productive, well-irrigated agriculture with scarce water resources requires very high water usage efficiency. This can be done by the precise scheduling of deficit irrigation systems while considering the crops' behavior to 'water stress' at the various stages of plant growth. An optimal solution is of paramount importance, taking into the effect of climate change and a rapidly increasing population. A complex multidimensional and non-linear optimization problem was developed by Niels Schütze and Gerd H. Schmitz, M.ASCE, to find the ideal schedule for maximizing crop yield with a given water volume, and developing alternate patterns of crop yield by factoring in various factors of uncertainty viz a viz, climate, soil conditions, and management.

The developed solution aims at optimal climate change adaptation strategies in irrigation facilities. It consists of: A weather generator to simulate the geographical impacts of climate change, an optimization algorithm to set optimal irrigation levels with limited water supply, and a number of models to simulate water transport and crop growth. The results, namely 'Stochastic Crop-Water Production Functions', helps us determine the impact of climate variability on crop yield and thus helps us to calculate the minimum water level requirements for various locations. The model was applied on the Maize crop and was successfully tested in Southern France, the results proving that there is a huge variation in the crop yield for maize, due to difference in global radiation and local irrigation facilities in France.

4 Application of operations research in the optimization of agricultural production

In recent years, people in agricultural planning have come to realize the importance of increased regulation in developing agricultural countries and since computers have become more available, increased agricultural production regulations have become possible in China. As a result, the question to be solved with the help of the research paper was If various resources and technological equipment are fixed can the production profit increase through scientific regulation and planning? There was a) Qualitative and b) Quantitative Analysis to find the answer which consisted of :

Modeling:

A. **Variables:** Let Xij denote the portion of the jth arable land to be used to cultivate the ith crop combination And Let Yij denote the amount of livestock to be raised on the jth land.

B. **Objective function:** The net income as the objective function. The coefficient of variable Xij in the objective function is equal to the net income (the output value per mu - --0.16 acre - minus the cost of a mu when the ith crop combination is grown on the jth land) per year. Similarly the coefficient of Yij equal to the net income from livestock per year.

C. **Constraints:** Constraints come from social demand, state purchase quotas, peasants' capacity of storing grain, the quantity for the market, ability to process factories, productive capacity, inherent law in the agricultural activities mainly.

D. **Sensitivity analysis:** To understand the influence of market prices on the structure of fanning and stock raising, application of sensitivity analysis to the coefficients of the objective function in the model established for the Changqing county. After the analysis, we found that the fluctuation of prices is sensitive to some crop combinations and almost unresponsive to others. This result is important when revising the production structure according to the change of market prices.

Results of the application and its evaluation:
The strategies stated above were worked out on a UNIVAC-1100 computers. They were first applied in the Changqing county. According to the strategy, the planting area of wheat, millet, and soybean is now more expanded than the original one. In stock-raising, it increased the number of herbivorous animals such as cows, sheep, and rabbits as there are plenty of grass resources available in the area. Accordingly, the local peasants need to change their traditional habit of having pigs as their main livestock. The output in 1985 has doubled in comparison with that of 1981 when the traditional cultivation was used and the weather was similar to that in 1985. After deducting costs of fertilizers, seeds, and management, the net output value increased by nearly 30%. The corresponding net income in the Weifang county was even higher.

At present, knowledge of O.R has been popularized in approximately 30 counties in the province of Shandong and in eleven counties of other provinces such as Qinghai. Its effect on agriculture Industry has been gradually acknowledged by the population. However, the factors involved in agricultural production are numerous, many of them uncertain. There are problems awaiting further.

5 Optimal cropping pattern in Egypt

Rapid increase of population in Egypt, limited usable water resources, improper maintenance, and poor irrigation systems have led to a serious burden on Egyptian natural water resources. For Egypt, land and water resources management is considered to be a top strategic priority. For the analysis, the authors (Sara Osama, Mohamed Elkholy, Ravya M. Kansoh), have made a linear optimization model with the purpose of maximizing the net annual return, on a sample of 28 crops for a period of 5 years (2008 to 2012). The main objective of this case is to find the most apt cropping pattern for the various parts of Egypt, and give maximum earnings to the farmers, assuming there is no water deficit. The constraints taken into account are socio-economic in nature, with an objective of achieving food security, effective use of water resources, keeping available arable land as high as possible for strategic crops, and self-sufficiency. Briefly, we see that the allocated areas for crops like onion, garlic, barley and flax (non-strategic crops) have decreased, and the allocated areas for strategic crops like wheat, maize, rice, and sugarcane have remained almost similar to satisfy the country's food requirements. On the other hand, crops with high net returns, such as tomatoes, have increased substantially. However, the net returns are seen to be following a declining trend and are expected to touch the lowest figures in 2017.

The results of the analysis portray that it is impossible increase the net benefits by limiting the allocated areas for the non-strategic crops and increasing the land available for tomatoes while keeping the allocations same for the strategic crops.

6 Optimal cropping pattern in Iran

It is difficult to grow crops with deficit water resources. So, In Southern part of Iran operations research was applied to reduce water consumption and determine an optimal cropping pattern as the constraints of water. The technique that was used is multi-objective programming approach.

Given specific amount of money and reduced water consumption, multi-objective programming approach was applied to cover all the objectives. The objectives that were taken into consideration while finding an optimum solution are gross margin, water use and risk in terms of gross margins variance, Several solutions obtained instead of a unique solution which implicates trades offs between objectives. The approaches that were applied to the farmers in the study area are Target MOTAD and Min Variance risky. For the study farmers of Jahrom district were divided into two groups based on their average activity scale of 11 and 15 hectares, separately and average gross margin of the groups are 1545 and 1380 $ per hectare.

Based on optimal pattern, selected farmers' income can be raised by 14% and water consumption can be reduced by 14.7%. The results showed that there was trade-offs among reduced water usage, reduced risk, and gross margin. At high level of risk, wheat tends to increase. The crop combination of the risk-minimized patterns were so close to the current cultivation pattern of farmers, showing that farmers are risk-averse.

7 Two-layer optimization of lower Indus basin

This study conducted on the Indus Basin Irrigation System aims at the development of a model to schedule the sowing dates of crops in such a manner that the peak water requirements of different crops are more uniformly distributed over different months and hence, more area can be irrigated for a given canal and tube well capacities. For this purpose, a two-level optimization model for optimal use of groundwater and surface water has been developed. In the first level, the model gives monthly water withdrawals from canal and tube well for a given set of sowing dates to maximize the net economic returns and optimal cropping patterns. At second level, the optimized sowing dates are obtained using an integer programming model and sowing dates are varied within the allowable limits.

The sowing dates at the first level are then taken as the sowing dates obtained from the second level. The sensitivity analysis for some of the parameters is also done. This model is applied to Dadu canal command of Lower Indus Basin. After study, results show an overall increase of 40% in the crop intensities and 38% in the benefits over the existing ones by using the two-level optimization model.

Now, this increase is obtained mainly by optimizing the crop sowing dates and without making any change in the infrastructure. So, an additional 5.4% increase in area and 4.2% increase in benefits is obtained by just dividing the crop area in four zones having different sowing dates which can also be managed within the existing infrastructure. An increase of 56.4% in crop intensities from existing ones is being obtained by increasing the tube well capacities to 76%. The irrigation efficiencies taken in the study are the same. Further improvement in the cropping intensities can be obtained by improving the current efficiencies. The two-level optimization model is quite general and can be applied to other irrigation systems.

8 Optimal use of irrigation water and crop selection in Saudi Arabia

This portion talks about the water crisis problem in the Kingdom of Saudi regarding the quality and quantity of water. Cropping pattern and Irrigation planning are the prime focus of this paper. Every year the growers are confronted with the problem which crops the harvest given the limited supply of water. It is very important for the authorities to assess the value of water in irrigation. This will help in strategic decision making such as pricing water and deciding its availability in different regions. He presented the review of the state of the art of mathematical model developed for reservoir management and operations up to the year 1982. The optimization model surveyed include Deterministic and stochastic linear programs, deterministic and stochastic dynamic programs, nonlinear program, stimulation, and their combinations. A mixed-integer programming model is developed using various inputs (as explained in the Appendix). The model uses several sets of constraints, namely water and land availability constraints, market constraints, time constraints, and mass balance constraints.

The inputs of the model can be characterized in the following:

1.Land inputs which cover:
• Current crops that are previously grown over the land of interest.
2.Irrigation season inputs:
• Available amount of water for each irrigation season.
3.Candidate crops inputs:
• Earliest cropping date.
• Latest cropping date.
• Growth period in days.
• Harvesting period in days.
• Selling price per ton (maximum, minimum, and average)
• Cost per hectare (maximum, minimum, and average).
• Market constraints (minimum and maximum requirements).

<u>The output of the Model are:</u>

1. **<u>General Output</u>**
Total water to be consumed in each irrigation season.
• Total expected yield.
• Total expected profit.

2. **<u>Detailed outputs</u>**
For each selected crop, the model will determine:
• Allocated area
• Immediate predecessor.
• Specific piece of land (identified by the existing crops at the start of the cropping plan).
• Cropping date.
• End of growth date.
• End of harvesting date.
• Water to be consumed.
• Selected irrigation level for each growth period.

In this study, a decision support system (DSS) has been developed in order to help agriculture companies make the optimal water and land exploitation for a given year. The DSS is a user-friendly package and does not require much training to be efficiently operated by non-sophisticated users. Its options and screens are considered of professional quality as witnessed by the several highly ranked personnel of the companies to whom the DSS was exposed. The DSS in its present form was also considered as a valuable tool for solving companies' problems of water use, farm exploitations, and future plan preparations.

9 Evaluating alternate strategic options for agricultural value chains

Changing an agricultural process can be difficult as it includes complex logistics and biophysical interactions. This paper revolves around maximizing the co-generation of electricity (which in turn helped increase profitability and sustainability) with the help of cane leaves and stalk at three sugar mills by of applying an agent-based, value chain modeling framework. A comparative analysis was done for the three mills which clearly depicted that usefulness of cogeneration must be considered on a case by case basis because Mill 1 suffered a loss due to higher implementation costs and logistical requirements while Mill 2 and 3 just reached the break-even point.

An in-depth study of their supply chain helped increase knowledge of whole-crop harvesting to managers across the chain and thus increased their capacity to evaluate innovative business models involving the co-generation of electricity. Thus such a method could be an effective way of exploring change.

10 Linear Programming model for optimal

CROPPING PATTERNS FOR ECONOMIC BENEFITS OF MRBC

Limited availability of Resources and Irrigation methods have led to a water crisis in Nadiad canal region of Gujrat, India. In this case, we develop an Irrigation model using Surface and Ground Variables, We Calculate the fixed cost for the cultivation process by keeping cost of seeds and equipment on one side and the cost for irrigation on the other side as Variable cost, we can then find out the optimality for irrigation process. The net benefits are obtained by:

Net profit = market value product - cost1 – cost 2.

Cost-1 = the expenditure on seeds, pesticides, fertilizers, and labor.

Cost-2= irrigation cost = net annual capital cost.

Here we are concerned about the cost 2 from the department of agriculture: the amount for cost 1 for each crop was obtained and deducted from the market value product. We then take 4 different cases to find out the net benefit due to the regulated water flow through the canals:

CASE-I. Existing and suggested cropping pattern for rabi season with different intensities for actual release of canal water.

CASE-II. Allow 25% variation in cultivating area under each crop for existing and suggested cropping pattern for rabi season with different Intensities for actual release of canal water.

CASE-III. Suggested cropping pattern for rabi season with different intensities for different release of canal water.

CASE-IV. Allow 25% variation in cultivating area under each crop for existing and suggested cropping pattern for rabi season with different intensities for different release of canal water.

The comparison of case –I and case-II for actual release policy and existing cropping pattern shows that the net return in case-II was higher as compared to case–I for same intensity of irrigation. This showed the existing cropping pattern was not optimal.

Comparison of results of case-III and case-IV showed that the for different release policies under same intensity of irrigation the change in benefits is nominal. Hence the average of four release policies could be considered as the best scope of surface water and groundwater utilization.

11 Case Study: China

Rural industry in China is a system with multilevel and multifarious aspect. It includes farming, forestry, stock-raising, supplementary production, fishery, in the "first industry", rural enterprises and building in the "second industry", and rural transportation and commerce in the "third industry". They rely on each other but the problem is that laborers in the country are very numerous. The agricultural economy is self-supported or half self-supported. The data which are needed for directing agricultural production and for developing agricultural economy are not as comprehensive, systematic as in developed countries. In the past, experimental and quantitative methods were often adopted for management of agriculture. The development of agriculture was limited, as management science in China is still in the beginning stage and the structure of agricultural production has to be rationalized.

One of the important problems in the development of agriculture is that we should arrange our agricultural production in a rather scientific scheme. Through the analysis of present conditions, we thought that our rural industry should be founded on farming, forestry, stock-raising, and fishery.

Attention should be paid to other industries so that we can change the present single-product economy, farming, to a complex of agricultural production industry and trade units, and our self-supported or half self-supported economy to a more developed commodity economy. After identifying the actual conditions, find a rational structure for our rural industry so that we can give a scientific and feasible basis for agricultural decision making.

Conclusion

Operations Research plays a major role in the agriculture industry, especially when it comes to aspects of decision making. As we have stated in our literature review, agriculture plays a golden role in the economies of many countries and is now facing a lot of risk from factors such as climate change, scarcity of resources, changes in soil composition, etc. We have seen many positive results of the tests conducted in various areas, and these measures, if put in practice on a large scale, can lead to massive improvement in the field of agriculture. This, in turn, will lead to better utilization of resources and minimal wastages, thereby increasing process efficiency and profitability.

If we keep using our resources at this rate, there will be hardly anything left for the future generations. Sustainable Development is the key to a successful future, and Operations Research can help us get there. New innovations, better techniques, and improved facilities can be developed and applied in farming so as to increase growth, use lesser inputs and increase the quality of the produce.

We urge the people to put these practices to use, as soon as possible, to ensure a bright outcome for us and our future generations to come.

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