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Analysis of operations research applications in agricultural research: A literature review

Abasilim Chinwe Frances
chinwe.abasilim@yabatech.edu.ng
Yaba College of Technology Lagos, Nigeria

ABSTRACT

Agriculture is a productive process requiring the transformation of a set of productive inputs into output with the aim of satisfying wants. These inputs are limited and as such places a constraint in the transformational process. It therefore implies that decision making on allocation of these limited agricultural resources is a major area of concern in attaining the objectives of agricultural production. Operations research, an analytical method used in problem-solving and decision making in organizations, have been applied for over 70 decades in decision making in agriculture. A review of applications of Operations research by some researchers in agriculture problems at farm level, regional sector level, environment protection, risks and uncertainty analysis, formulating livestock rations and feedstuffs, forestry management etc., shows that its application in agriculture is extensive and its potential for development is limitless. The application is constrained by a complex interacting drivers existing in productivity, markets, the environment and the people. These drivers include accuracy of data, quantifiability of data. natural disasters, instability of prices, demand for products, changes in government subsidies and policies and dependence on an electronic computer. In conclusion, decision to implement the results from Operations research lies with the human beings and so this human element is still the most significant part of the decision-making process. The changes and adjustments in the natural and economic environment, and new improved information in the subject area, must be incorporated in the mathematical models and their parameters to account for the change.

***Keywords**: Operations Research, Agricultural Research, Decision-Making*

1. INTRODUCTION

The English word agriculture derives from the Latin words *ager* (field) and *colo* (cultivate) signifying, when combined, the Latin *agricultura*: field or land tillage (Harris and Fuller, 2014). Agricultural production is not limited to the cultivation of land but includes the raising of livestock; fisheries and recently, the activities that ensures that outputs get to the consumers in the form, where and when they are required. These have led to recent development of the fields of agricultural economics, production economics, agricultural finance, agricultural marketing and agribusiness.

Agriculture typifies the definition of the term economics by many renowned economists. According to Samuelson:
Economics is the study of how people and society choose, with or without the use of money, to employ scarce productive resources which could have alternative uses, to produce various commodities over time and distribute them for consumption now and in the future among various persons and groups of society.

Robbins defined economics as the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses.

Relating these two definitions to agriculture, agriculture is a transformational or productive process which uses sets of inputs or resources. These resources are natural resources like soil, water, plant and animal diversity etc.; human resources like labour and management and man-made resources like machineries, irrigation and agrochemical and feed concentrates. These inputs which are productive inputs. They are scarce as such it possesses a limitation in its availability and can also be used for various agricultural activities like livestock, crop, forestry etc. Within these activities many enterprises abound most of which are mutually exclusive; as such the need for decision making on allocation of these limited agricultural resources is a major area of concern in attaining the objectives of agricultural production. Agricultural activity is related to the mixture of several elements such a as land, soil chemistry, diseases, insects, water and mechanical engineering, biology, economy, administration and accounting, and as such, it is considered as the most interdisciplinary occupation with the other elements and activities (Asís, 2007).

Agriculture involves a lot of decisions that are to be taken right beginning from what is to be produce and where to produce, to selling the produce, subject to limitations imposed by the scarcity of resources. The act of effective decision making is an activity that is borne out of efficient planning. Agricultural planning is important in recent times due to the increased demand of agricultural commodity arising from population increase, thus requiring need of more production to meet the ever-increasing demand (Sophi *et al*., 2015). For any nation that successfully wants to combat the problem of food security (availability, access and utilisation), well thought out agricultural planning is a pre requisite. In planning agricultural production, there is need to understand firstly the sustainability of natural resources, take into account the complexity of growth and harvesting process; and consider the relationship between production processes and general environmental, economic and social issues (Weintraub and Romero, 2006).

2. OVERVIEW OF OPERATIONS RESEARCH IN APPLIED AGRICULTURAL RESEARCH

Operations research is an analytical method used in problem-solving and decision making in organizations and can be described as a process of using advanced techniques that help in making better decisions (Ghosh e*t al.,* 2018). Although researchers like Sophi *et al*., (2015); Weintraub and Romero, (2006) reported the application of Operations research (OR) models in agriculture to have begun in the early 1950s, Singh and Tesema (2018) reported that one of the first, interesting and challenging applications of Operations research in agriculture was by C. W. Thornthwaite (1954) on Seabrook farm, six years after Yates (1949) published a paper regarding the use of Operations research made in the field of agriculture in the United Kingdom.

Carravilla and Oliveira (2013), explained that there has been extensive application of Operations research in decision making and simulation engineering, economics, management, industry, public administration, services and, of course, in agriculture and forest management.

Operations research in agricultural research is focused on providing empirical basis for better decision for researchers especially for agricultural economists. The problems are broken down into basic components and then solved by mathematical analysis. Agrawal (1967) explained that Operations research deals with attacking the problems, faced by the decision maker, through identifying the problem or problems in question, defining the alternatives available to him and also the various states of 'nature', appraising him of the payoffs associated with each combination of the elements of these alternatives and strategies and then suggesting, to him, the best course of action obtained through the use of logic, mathematics and other sciences. Apart from solving problems confronting production and allocation of resources, GAMS modelling approach was introduced by Operations researchers for the purpose of explaining general equilibrium models for evaluating national improvement strategies, to introduce the first grain storage models to protect against shortage (Gustafson 1958 and Brooke et al. 1993).

The application of Operations research in agriculture is extensive and its potential for development is limitless because of increase in scarcity of productive resource leading to decreased resources availability for usage. Sharma (2016) explained that the relevance Operations research is more in agricultural production economics due to following reasons

- It takes into account complex system interlinkages.
- It is free from estimation problems like auto-correlation, multi-collinearity, simultaneous equation bias, etc.
- Estimation procedure is simple with the application of computer programming.
- Based upon fewer assumptions and has more realistic and practicable solutions.
- It provides scope for incorporating changes and, thus, is more flexible in methodology

3. COMPONENTS OF OPERATIONS RESEARCH

Agrawal (1967) explained the important components (steps) of an Operations research project as:

i. Identification and formulation of the problem
ii. Defining the objective function to be optimized
iii. Construction of a mathematical model satisfying the constraints on the values of the variables
iv. Obtaining the empirical estimates of the parameters
v. Solving the model and finding out the course or courses of action that would optimize the objective function.

Carravilla and Oliveira (2013) also listed the steps or phases of the OR/MS (Operations research /Management science) method when solving real-world problems as follows:

i. define the problem of interest and gather data
ii. formulate a model to represent the problem
iii. develop a procedure for deriving solutions to the problem from the model
iv. test the solution(s) and refine the model as needed
v. implement the solution(s)

4. IMPORTANT OPERATIONS RESEARCH TECHNIQUES

According to Agrawal (1967) important tools used in Operations analysis are:

1. Mathematical programming
(a) Linear programming

(b) Nonlinear programming
(c) Dynamic programming
2. Game theory
3. Probabilistic models
(a) Queuing
(b) Inventory control
(c) Monte Carlo method
4. Transportation models (special cases of linear programming)
5. Simulation techniques
6. Time-network analysis
(a) Program Evaluation and Review Technique (PERT)
(b) Critical Path Management (CPM)
7. Sequential analysis
8. Other methods
(a) Input-output analysis
(b) Capital budgeting
(c) Forecasting
(d) Theory of information
(e) Searching processes

Most of these tools have been successfully applied in the four major activities in agricultural economic activities, viz., production, consumption, exchange and distribution.

5. CASES OF APPLICATION OF OPERATIONS RESEARCH IN AGRICULTURAL RESEARCH

Application of Operations research in agriculture has been in agricultural planning problems at farm level, regional sector level, environment protection, risks and uncertainty analysis, formulating livestock rations and feedstuffs, forestry etc.

i. Applications in agricultural planning problems at farm level

Linear Programming (LP) models have been used by many researchers to assess and stimulate the economic impact of agricultural policies on production (Weintraub *et al.,*2001). Heady (1954) was the starting point of linear programming and he applied it as a decision-making situation at farm level (Andres *et al.,* 2001). Dos Santos *et al.* (2010) applied it in solving the problem of meeting the demand of some crops subject to ecologically based production constraints by using a linear program model and a column-generation approach. The two decision levels of the problem were:

- to determine the division of the available heterogeneous arable areas in plots, so that the demand is met, and
- to determine, for each plot, the appropriate crop rotation schedule, bearing in mind the ecological based constraints, such as the interdiction of certain crop successions, and the regular insertion of fallows and green manures.

Gosh *et al.,* (2018) used Assignment problem tool to assign four different crops (rice, maize, cotton and sugarcane) to four different states of India (Andhra Pradesh, Gujarat, Haryana and Madhya Pradesh) where the main occupation is farming, and through assignment problems, in order to decide which crop for minimizing land under cultivation as well as maximize the profits.

ii. **Applications in agriculture at the sector level**

When the research focus changes from the farm level to the regional sector level, the objective function of the model and the aggregation problem changes. These changes happen because the objectives pursued at farm level e.g., profit maximization, become economically unjustifiable for more economically justified objectives like maximization of social welfare measured by the sum of consumer and supplier surpluses (Samuelson, 1952; Weintraub and Olivera, 2006).

At the sector level, comparing different farms performance is important because farms are not on the same level of performance and measuring their performances, understanding the reasons for the different performances and determining what should be done to enhance their performance to benchmark units, can be achieved using Data Envelopment Analysis (Carravilla and Oliveira, 2013). The impacts of policy changes on the behaviour and reactions of the farmers may be beyond the farm level and differ among them and can be studied. Operations research is a powerful tool to model situations in which conflicting objectives arise.

Amores and Contreras (2009) conducted a sectoral study involving farm efficiency comparison in Andalusia, Spain. The aim of this study was to help government to define objective criteria to assign European Union (EU) subsidies to olive-growing farms in Andalusia. EU regulations demand objective criteria for the subsidy allocation in a sector where more than 60% of the farms would have negative returns without the EU agricultural subsidies, making it difficult to access the real efficiency of the farms. A new Farm Efficiency index was calculated by decomposing overall DEA Scores, by means of internalizing the positive and negative externalities of agricultural activity, was tested in a study carried over a sample of 3000 real farms, with data taken from the administrative subsidy database (Weintraub and Olivera, 2006).

iii. Application of Operations research model in agriculture activity at the national or regional level (macro-level application)

Asis (2007) observed the existence of an uneven allocation of the agricultural inputs, nationally and regionally, as well as an overuse of some elements. This led to weakening of the production or the agriculture sector. Linear programming was acknowledged by Hazell-Norton (1988), Moncke-Pearson (1989) as the tool used to regulate the process of agriculture planning on the national and regional levels particularly in determining the optimal posits of agriculture sources and agriculture policy in general (Asis, 2007)

iv. Application in formulating livestock rations and feedstuffs

Samuel *et al.,* (2015) proposed optimal ration formulation results produced by linear programming model in the case of the finisher ration consists of 25.09 kg maize (yellow), 24.16 kg soyabean, 39.95 kg wheat bran, 9.97 kg Oyster shell, 0.18 kg lysine, 0.04 kg methionine, 0.3 kg Salt, and 0.3 kg premix mix is the proposed optimal ration for finisher broilers according to the local feed stuffs availability.

Chagwiza *et al.,* (2016) using a mixed integer programming and Bat algorithm and Cplex solver attempt to find the optimal quantities of Moringa oleifera inclusion into the poultry feed. The results show that the farmer is likely to gain US$0.89 more if Moringa oleifera leaf meal (MOLM) is included in the feed ration at an inclusion level is found to be 5.3%.

v. Interaction between agriculture and environment

The inclusion of impact of agricultural activities on the environmental in agricultural programming is not a recent development and have been applied by researchers like Teauge *et al.,* 1995, to predict the effect of nitrates and pesticides on the environment using EPIC-PST simulation model. Tauer (1983) combined the result with a target MOTAD optimization model that minimizes the sum of the negative deviation from a prefixed income target thus the objective of the research was to evaluate the trade-offs between income and an index measuring risks associated with the use of pesticides and nitrates.

Researchers have recently developed a model known as crop-stimulator model in order to predict the environmental effects of many management practices like agrochemicals, then link it to an optimization model in order to determine the trade-off between environmental impacts and economic returns (Weintraub and Romero, 2006).

vi. Application in risks and uncertainty analysis

The Game theory provides a tool of analysing agricultural decisions under uncertainty. Melnenery (1967) introduced the use of Game theory in agriculture, while Hazel (1970) and Kawaguchi and Maruyama (1972) introduced the use of parametric games for optimizing one criterion e.g., maximizing the minimizing outcome, while considering another criterion as a parametric constraint e.g., minimizing the largest regret. Recently analysts have been using safety first models, chance-constraint programming and stochastic programming to deal with risks and uncertainties in agriculture.

Kumbhakar (2002) in dealing with specification and estimation of risk preferences, production risk, and technical inefficiency, used the Absolute Risk Aversion (AR) function to determine the risk preference functions. The main advantage of the approach is that one can use any parametric form of the AR function without worrying about the closed form solution of the underlying utility function (which may not be solved analytically). Detlefsen and Jensen (2007) used a network modelling approach to determine the optimal rotation crop for a given selection of crops on a given piece of land, with an objective of achieving sustainability goals.

vii. Applications in forest management

In forestry planning, major decisions are on land use; the forestry supply chain design, planning and operation. The forestry supply chain involves all activities concerned with the flow of fibre from the forest to the customer. Forestry supply chain management and optimization is also the goal of Carlsson and Ronnqvist (2005). Gunnarsson *et al*. (2004) propose a mixed integer linear programming model to decide when and where forest residues are to be converted into forest fuel, and how the residues are to be transported and stored in order to satisfy demand at heating plants.

6. ISSUES WITH THE APPLICATION OF OPERATIONS RESEARCH IN AGRICULTURE

Higgins *et al.,* (2010) explained that the application of Operations research in agriculture is constrained by a complex interacting drivers existing in productivity, markets, the environment and the people. These constraints include

i. **Accuracy of data**: Accurate data must be acquired for the mathematical models and parameters. However, in developing countries data collection and storage are still poorly undertaken. As such cases of missing data and discrepancies in data abound.
ii. **Quantifiability of data:** Operations research techniques can only derive solutions when all elements or decision variables are quantified. If the elements/factors of the related problem cannot be quantified, then Operations research models cannot proffer any solution.
iii. **Natural disasters:** Agriculture is dependent on the states of nature. A lot of uncertainties can lead to disasters that can adversely affect production. These calamities include drought, flood, diseases and pest outbreaks etc. Issues surrounding climate change, natural resources degradation and societal demand also greatly affect agricultural production. Operations research models cannot take into account the damage done to crops by natural calamities nor can they predict accurately the probability of occurrence of any of the disasters. Hence application of Operations research techniques can only be done under certain assumptions which can limit the finding of the perfect solution (Gosh *et al.,*2018).
iv. **Instability of prices:** Sudden hike in fuel prices increases the costs of transportation. In Operations research models where the technique is used to find the perfect transportation or to minimize the cost of transportation, the changes in fuel prices which in turn leads to increase in the cost of transportation, becomes a limiting factor (Gosh *et al.,*2018). With a nation facing persistent rise in prices of inputs, the Operations research model to minimize cost of input will be adversely compromised.
v. **Demand for products:** Operations research model assumes that there will be demand for the agricultural product, under consideration. However, it does not take into consideration the factors that can influence the demand. Agriculture is a highly volatile market which is dependent on the demand of crops and manipulation of such market is an easy task.
vi. **Changes in government subsidies and policies:** Subsidies offered to farmer and changes in policies may affect the profit of the farmers and production of crops. Operations research is dependent on the human behaviour and his decision-making process. Human behaviour is almost unpredictable and highly volatile and industrial issues and riots are the outcome of human (Gosh *et al.,*2018).

vii. **Dependence on an electronic computer:** Finding the optimal solutions in Operations research are achieved by considering the interdependence of many factors. In order to establish relationships among these many interdependent factors, huge calculations requiring iterations, are required and this can only be done using computers. As such it requires educated manpower who can program, execute and interpret the output of the model.
viii. **Money and time:** Operations research models are specific to a production and a good Operations research solution is available only the problem that it is set to solve and if there are changes in resources and the model changes.

7. CONCLUSION

Operations research is a very useful tool in agriculture in the areas of allocation, optimization, risk management, environmental protection etc. The application of operations research in devising an optimal agricultural production structure has increased agricultural productivity and reduced the risk level in the macroscopic management of agriculture (Zhao *et al.,* 1991). However, a tool, at best, is only as good as its user. The final decision therefore still lies with the human beings and so this human element is still the most significant part of the decision-making process. The optimal production structure is not cast on stone, changes and adjustments in the natural and economic environment as well as improved information in the subject area, must be incorporated in the mathematical models and their parameters to account for the change.

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