Review article

Potential of mathematical model-based decision making to promote sustainable performance of agriculture in developing countries: A review article

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ABSTRACT

In developing countries like Ethiopia, agriculture takes the leading role in the economy and enhancing the efficiency of agriculture resource decision making remains essential to eradicate extreme poverty through promoting sustainable agricultural production. Recent economic growth efforts in agriculture dependent economies are aggravating to further natural resource degradation, environmental pollution, and climate change. One of the main challenges is the use of inefficient conventional land use decision-making. Conventional land use decision making refers to the practice of traditional land use decision-making, which is inefficient to capture spatial and temporal land use decision dynamics and trade-offs. This paper reviewed existing literatures on decision-making models in agriculture targeting to document the potential of mathematical model-based decision making to enhance the sustainable performance of agriculture in developing countries compared to the existing conventional agricultural practice decision approach. From over 400 literatures collected from the Google Scholar search engine; 63 articles were selected for the synthesis. The literatures were screened through inclusion and exclusion criteria. Literatures that used any mathematical model as a decision support tool in agriculture and related sectors, included a clear description of the model type, aim of the study, the key attribute characterizing the application of the model, decision support system, and output were included in the review. The synthesis result uncovered that with varying degrees of impact, flexibility, and complexity, mathematical model-based land use decision making has greater potential to enhance sustainable performance of agriculture and resource use efficiency in developing countries.

1. Introduction

Literature shows that besides low input use, immature output markets, and inappropriate agricultural policies, agriculture, the main stay of the economy of developing countries suffers from low resource use efficiency that might be attributed to poor resource use decisions. Evidence from many studies uncovers this fact. Resource use inefficiency such as technical inefficiency, distribution inefficiency, and environmental costs are key factors that compromised the performance of agriculture over time in developing regions (Haque, 2006; Mesike et al., 2009; Mussa et al., 2011; Alabdulkader et al., 2012).

Efficiency has long been a topic of empirical research, beginning from the formal practice of Operations Research (OR) during World War II; by the British and US military to assist allocation of scarce war tools. The resulting success of these efforts promoted the use of operations research in various civilian sectors. Several interrelated and computer-aided decision support systems have been developed and used in various sectors like in transportation scheduling, land allocation, and production planning. Since the 1950s, a number of variants mathematical model based decision support tools emerged (Bjørndal et al., 2012), such as linear programming (Dantzig and Thapa, 2003), goal programming, multi-objective programming, fuzzy goal programming, and other computer aided decision support systems that significantly improved resource use efficiency. To date, these models are used in different civilian sectors worldwide, including in agriculture. Moreover, the fourth evolution of the farming technology (Agriculture 4.0) that include use of decision support systems is a topic of research worldwide that targeted to increase productivity, allocating resources efficiently, adapting to
climate change, and avoiding food waste (Zhai et al., 2020). However, smallholder farming system in most developing countries is mainly practiced by manpower and animal force using simple tools (Agriculture 1.0). Particularly, the use of mathematical model-based decision support tools is limited in developing countries.

In developing countries, rainfed mixed agriculture is the mainstay of the economy, which accounts for 40–90 % of the employment, 30–60 % of the Gross Domestic Product (GDP), and 25–95% of the foreign exchange (FAO, 2002; Hordofa et al., 2008; Federal Democratic Republic of Ethiopia, 2011; Tedia, 2012; Minot and Sawyer, 2013). Even if developing countries have significant potential for irrigation, the practice of small-scale and large-scale irrigation is immature and the existing practice itself is completely dependent on conventional decision-making of critical resources such as water, land, cropping mix and/or pattern, and other agricultural inputs (Xie et al., 2014, 2021; Nigussie et al., 2020). Supporting this fact, Belete et al. (2011) describes conventional irrigated agriculture as immature that lack both technical and input use efficiency.

In addition to the local and intrinsic challenges, the burden of climate change is significant in developing countries (Anderson et al., 2020) which calls for comprehensive adaptation and mitigation strategy and action to ensure food security and development. In this regard, a study aimed at investigating CO2 emissions’ impact on agricultural performance and household welfare in Ethiopia indicated that CO2 emission is compromising agricultural productivity and household welfare (Eshete and Gatiso, 2020).

Besides the challenges, agriculture has untapped potential for economic growth, poverty reduction, and rural development in developing countries. The International consultative conference held in Addis Ababa, Ethiopia, entitled “Advancing Agriculture in Developing Countries through Knowledge and Innovation” pronounced that advancing agricultural performance through knowledge and innovation is key for growth and poverty reduction in developing countries (Research Institute (IFPRI), 2009). However, agriculture is continuing to suffer from resource use inefficiency due to limited technology and innovation that include inefficient agricultural resource decision-making practices in addition to natural and environmental factors (Federal Democratic Republic of Ethiopia, 2011; Musa et al., 2011; Geta et al., 2013). Hence, the purpose of this paper is to review and document the significance of mathematical model-based decision making to unlock challenges associated with agricultural resource use efficiency and to promote sustainable performance of agriculture. The finding will have significant contribution for decision makers, researchers, and policy makers in the field of agriculture, particularly in developing countries.

2. Method and materials

Scoping review design was used to thoroughly examine and synthesize existing literature with the aim to understand the potential of mathematical model-based decision making to enhance the sustainable performance of agriculture. Scoping review technique was preferred from other methods of review by the fact that this technique suits to address the aim of the review study through classifying, evaluating, synthesizing, and summarizing.

2.1. Organization of the review

In this paper, a review of relevant literatures (empirical research and previous reviews) on mathematical model-based decision making in agriculture and summary of these models with possible implications for sustainable planning to enhance the performance of agriculture in the face of climate change was made. Literature search made advanced back from March 2020 on mathematical model-based decision making in agriculture were made in the Google Scholar search engine. The terms mathematical model, mathematical programming, agricultural production, agricultural resource allocation, and a combination of these with “AND” and “OR” were used to browse literatures.

The broad search passed through title and abstract screening resulted in the collection of over 400 studies including journal articles, conference papers, master’s and doctoral dissertations, and unpublished papers and reports. These literatures were then screened through inclusion and exclusion criteria. Literatures that:

1. involved one of the mathematical models as a decision support system in agriculture and related sectors,
2. included a clear description of model type, aim of the study, the key attribute characterizing the application of the model, decision support system, and possible output outlined,
3. was carried out in any country from around the world but published/ written in English language, and/or
4. is a review study of studies employing one or more of mathematical model-based decision making systems in agriculture and related sectors were included in the review.

The studies were then synthesized and summarized into mathematical model groups as linear programming, multi-objective programming, goal programming, fuzzy goal programming, and mathematical models integrated with GIS. Details of reviewed articles, author(s) name and publication year, country, model name, application area (crop, livestock, fishpond, tree lots, farm, grassland, landscape, watershed, and basin), aim of the study, key attribute, decision-making model type, and outlined output, are annexed in appendix A. Based on the screening first 50 articles were selected for the synthesis. In order to widen the search scope, an iterative technique that involved examining the reference sections of the pre-accessed articles were also used and additional 13 articles were collected for the synthesis. Including 23 literatures used to strengthen argument in the review, a total of 86 literatures are used in the review.

3. Result and discussion

The screening resulted the following categories of the literature: single objective mathematical models (Linear programming), multi-objective mathematical models (Goal programming), fuzzy goal programming (FGP), and GIS-based mathematical models. Thus, the review discussion part is subtitled based on these categories of the literature. While the detail of the articles is given in appendix A, the number of literatures per year of publication per model type is illustrated as shown in Figure 1.

The application area and the objectives of the models used in the articles reviewed are summarized per model type in Table 1 below.

3.1. Agricultural decision making using single objective mathematical models: linear programming (LP)

In this section, 27 study articles conducted in 16 countries which employed linear programming decision support tool for agricultural resource decision making were reviewed. Most of the literatures reviewed here are articles that used linear programming decision support systems for crop mix and cropping pattern (65%) while the remaining are articles that employed linear programming to promote the performance of dairy farms, crop-livestock integration, land and water resource use, arable crops and fisheries enterprises, botanical farm, and other forms of land use with the aim of maximizing net income, maximizing gross income, improving food security, and enhancing livelihood performance. Outlined results suggested that using LP as decision making tool in agriculture provides maximum annual return (Sarker et al., 1997; Hassan et al., 2005; Fallah Shamsi, 2010; Mohammad and Said, 2011; Alabdulkader et al., 2012; Felix et al., 2013; Geta et al., 2013; Andreea and Adrian, 2013; Gadge et al., 2014; Mugabe et al., 2014; Buzuzi and Buzuzi, 2018; Muhamed Jaslam et al., 2018).

To optimize the cropping pattern that result efficient allocation of scarce water resources and arable land among competing crops and to maximize the net annual return from agriculture in Saudi Arabia...
Alabdulkader et al. (2012) formulated and used linear programming mathematical model. The result disclosed that the approach was suitable to optimize the benefits of crop production through determining optimal cropping patterns and improving the utilization of scarce natural resources. Particularly, the finding of the study indicated that the use of a linear programming decision support system has the potential to create additional benefit equivalent of 2.42 billion US$ per year net return for Saudi Arabia. Besides, the finding of the study revealed that optimizing cropping patterns using linear programming has the potential to improve the efficiency of scarce natural resources. Accordingly, about 53% and 48% of water use and arable land use saving were gained respectively when linear-programming-based decision support systems were used as compared to the conventional cropping pattern decision making approach.

As income depends on expenditure, determining the optimal structure of crops that minimize expenditure and maximize income per available land size is essential. Andreea and Adrian (2013) used the LP model aiming to assess the possible effect of the optimal structure of crops to minimize expenditure and maximize profit in Romania. Accordingly, linear programming based land use decision making resulted reduction of expenditure by 81% and enhancement of profit by 143%. Buzuzi and Buzuzi (2018) in Zimbabwe also conducted a similar study aiming to analyze the agricultural efficiency using LP model on a small-scale farm. The finding disclosed that in the conventional practice, the available resources were used sub-optimally and the use of linear programming model decision support system to optimize the crop production pattern was found to have the potential to enhance the profit margin by 76%.

Common problems that most farmers encountered when thinking of maximizing profit is the selection of crop mix that is what and how much to plant. With this regard, the literature is full of evidence on the significance of the LP model to decide profit maximizing crop mix (Sarker et al., 1997; Hassan et al., 2005; Mohamad and Said, 2011; Rani and Rao, 2012; Collins et al., 2013; Felix et al., 2013; Otoo et al., 2015; Matsyapal, 2017). For instance, a study conducted by Hassan et al. (2005) aiming to maximize gross income through proper crop planning in Pakistan disclosed that the difference in gross income using the LP model was 2.91% higher when compared to the conventional crop mix decision approach. Considering the problem associated with the mismatch between the choices of the crop type appropriate for the type of land, Sarker et al. (1997) used LP model to resolve the mismatch in Bangladesh. The results of the study emphasized that crop planning using the LP model unquestionably enhances production and the socio-economic performance. A study conducted by Paramjita et al. (2018) that aimed to design an approach which enhance efficiency of water, crop, and livestock resource use using the LP also revealed that LP decision support model was helpful to enhance the utilization of water and maximization of the return from crop and livestock production.

Ahmed et al. (2011) applying LP model with objective of maximizing gross margin from the production of field crops using irrigation scheme in River Nile State (RNS), North Sudan, under the constraints of land, labor, water, and capital, concluded that the gross margin from the practice of irrigation and resource use efficiency has been significantly improved compared to the conventional decision-making practice. In addition, the study also uncovered that the use of the LP optimization model gives additional opportunity to stretch the irrigation field to a wider area by saving important resources such as water in addition to a selection of crop mix that should be cultivated to maximize gross margin. Similarly, a study in Saline track of Murtizapur Tahsil district Akola of Maharashtra in India that employed LP with the objective of maximization of net profit under the constraints of meeting expected yield, fixed labor, fixed machine-hours, cost of pesticide, seed, and fertilizer on fixed land size concluded that the model is appropriate for cropland allocation when compared to the existing conventional land use decision making (Wankhade and Lunge, 2012).

Extending the use of the LP model for cropland allocation, Igwe and Onyenweaku (2013) employed the LP optimization model to determine the possible combination of crops, monogastric farm animals, and fish enterprise in Ohafia agricultural zone Abia state, Nigeria. The study revealed that the profit without the use of the LP model of decision-making is very much low when compared to the profit obtained when using the LP model to make decision to select the proper mix of agricultural practice. Similar studies by Jayasuriya and Das (2018) and Minh et al. (2007) also confirmed that the application of the LP model enables to make optimal crop-livestock combination decisions that maximize farm income without creating excessive pressure on land resources.

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1 LP—Linear Programming, GP—Goal Programming, FGP—Fuzzy Goal Programming, GIS-MCDM—GIS-based Multicriteria Decision Making.
### Table 1. Application area and major objectives of the models per model type.

| No. | Model type | Application area | Objectives |
|-----|------------|------------------|------------|
| 1.  | LP         | Arable crops and fish, Botanical farm, Crop mix or cropping patterns, Cropland planning, Crop and livestock mix, Crop-livestock integration, Crop yields, Crop and land use planning, Dairy farm, Food and cash crops, Land and water use, Land allocation, Maize production, Water, crop, and livestock integration | Economic impact or performance, Enhancing livelihood or food security, Maximum profit level, Maximize net return or net benefit, Maximize gross margin or gross returns, Maximize net farm income, Maximize revenue, Optimize net profit or income, Optimize productivity, Enhance productivity and technical efficiency |
| 2.  | GP         | Crop production and cropping pattern, Dairy production/milk production, Livelihood enhancement, Optimal land use, Perishable products, Production, Resource allocation, Vegetable production, Water and Nutrient management | Control price, Economic and ecological performance, Productivity and environmental impact, Income maximisation, Maximize net profit, Maximization of gross margin or gross margins, Nutrient value, Nutrient management, Optimize production |
| 3.  | FGP        | Crop planning or cropping mix, Vegetable production, Cropping pattern, Crop production, Land and water use planning | Maximize income, Maximize net return, Enhance livelihood, Optimize gross margin or gross margins, Optimize production |
| 4.  | GIS-MCDM   | Crop/pineapple, Land use planning, Land use allocation, Different purpose, Aquaculture | Different values, Economic and ecological performance, Maximize economic contribution, Maximize net return, Maximize productivity, System effectiveness |

The study on cropland allocation using LP by Mohamad and Said (2011) pronounces the role of LP to promote the performance of agriculture. The study boldly disclosed that cropland allocation using the LP gives more promising output in a short planning time horizon that promotes commercialization. In addition, many studies including Glen and Tipper (2001), Val-Arreola et al. (2004), Ahmed et al. (2011), Igwe et al. (2011), study boldly disclosed that cropland allocation using the LP gives more promising output in a short planning time horizon that promotes commercialization. In addition, many studies including Glen and Tipper (2001), Val-Arreola et al. (2004), Ahmed et al. (2011), Igwe et al. (2011), and Louhichi et al. (2004) reviewed. The application areas were land allocation, dairy production, rainfed and irrigated crop production, resource allocation, water management, nutrient management, and livelihood. These studies employed multi-objective mathematical models targeting to enhance economic and ecological performance, productivity and environmental impact, maximization of gross margins, and nutrition value. Latinopoulos (2009), employing multi-objective mathematical model for efficient water and land resources allocation in irrigated agriculture in Northern Greece, has uncovered that the existing land allocation practice is in favor of farmers’ welfare at the expense of water resources quality and quantity. The model was articulated based on two classes of objectives, socio-economic objectives (maximizing farmer’s income, reducing risk on farmer’s income, getting of human labor, preserving the current cropping pattern, maintenance of the current revenues of water agencies, and maximizing total labor efficiency) and the environmental objective (maximizing water use efficiency and alignment of fertilizer utilization to the European Union legislation). The outlined results demonstrated that the current agricultural resource decision practice is skewed to the economic objectives. Thus, the multi-objective mathematical model referred as multi-criteria decision-making in the study revealed that the current irrigation water pricing approach does not meet the sustainability criteria. In conclusion, it uncovered that multi-objective mathematical model is better to be used for policy analysis to consider multiple goals of agricultural practice. Besides, the

3.2. Agricultural decision making using multi-objective mathematical models: goal programming (GP)

In this section twelve literatures from ten countries that used multi-objective mathematical models for decision making in agriculture are reviewed. The application areas were land allocation, dairy production, rainfed and irrigated crop production, resource allocation, water management, nutrient management, and livelihood. These literatures employed multi-objective mathematical model targeting to enhance economic and ecological performance, productivity and environmental impact, maximization of gross margins, and nutrition value. Latinopoulos (2009), employing multi-objective mathematical model for efficient water and land resources allocation in irrigated agriculture in Northern Greece, has uncovered that the existing land allocation practice is in favor of farmers’ welfare at the expense of water resources quality and quantity. The model was articulated based on two classes of objectives, socio-economic objectives (maximizing farmer’s income, reducing risk on farmer’s income, getting of human labor, preserving the current cropping pattern, maintenance of the current revenues of water agencies, and maximizing total labor efficiency) and the environmental objective (maximizing water use efficiency and alignment of fertilizer utilization to the European Union legislation). The outlined results demonstrated that the current agricultural resource decision practice is skewed to the economic objectives. Thus, the multi-objective mathematical model referred as multi-criteria decision-making in the study revealed that the current irrigation water pricing approach does not meet the sustainability criteria. In conclusion, it uncovered that multi-objective mathematical model is better to be used for policy analysis to consider multiple goals of agricultural practice. Besides, the
model was found to allow flexibility for decision makers (Leung and Ng, 2007).

Another study that used multi-objective linear programming was the one conducted by Walangitan et al. (2012) in the catchment of Lake Todano, Indonesia for land allocation to meet four different objectives. The objectives were generating income, creating employment opportunity, minimizing land erosion, and securing forest areas. The study uncovered that the model is essential tool for multi-objective land allocation. While it is not easy to treat multiple objectives at a time using the existing conventional land use decision practice, this study revealed that it is possible to meet all except the employment. Thus, this shows that multi-objective mathematical model is essential tool that may enhance sustainability of agriculture through considering multiple social economical and sustainability objectives. Moreover, Jeyavanan et al. (2017) used goal programming to enhance crop production for different levels of resource utilization in Sri Lanka and concluded that the use of goal programming reduces production cost by about 14%. Massoumi et al. (2016) also confirmed that GP is valuable to identify cropping pattern that enhance water utilization efficiency. The literature reviewed in this section reveals that multi-objective mathematical programming decision making is a potential decision support tool for agricultural decision making that might significantly contribute to profit or revenue optimization, ensure food security, and minimize environmental degradation. An optimum production plan with a greater gross return, fewer fertilizers use, and less irrigated water use than the existent production plan was observed using goal programming as compared to the existing practice. In addition, many literatures such as the work of Val-Arreola et al. (2006) in Mexico, Hassan et al. (2013) in Malaysia, Manos et al. (2013) in Greece, Arzamendia et al. (2015) in Paraguay, Pastori et al. (2017) in Africa, and Galan-Martin et al. (2017) in Spain pronounces the role of goal programming for multi-criteria decision-making in agriculture. Generally, literatures reviewed emphasize the role of multi-objective mathematical models for significantly improving the performance of agricultural production gross margin while preserving the environmental influence and dwindling of resources.

3.3. Agricultural decision making using fuzzy multi-objective linear programming (FMOLP) models: fuzzy goal programming (FGP)

Earlier mathematical models discussed in this paper, both single and multi-objective linear programming models, were based on deterministic model parameter estimation, which, however, does not reflect the reality predominantly in agriculture (Pal and Moitra, 2004). Besides volatile market demand and prices of the futures market predicted climate variables are subject to change in the field of agricultural practice. Therefore, the impossibility of access to perfect information in the field of agriculture implies that exact estimation of model parameters is hardly possible. Hence, a new method that reflect the level of uncertainty in model parameter estimation named fuzzy multi-objective programming or fuzzy goal programming (FGP) has evolved (Pal and Moitra, 2004; Sharma et al., 2007).

3.3.1. Fuzzy goal programming (FGP)

In this section of the review, seventeen articles that employed FGP were used. The articles were results of studies conducted in four different countries aimed to maximize farmers’ income, optimize monetary benefits, enhance the livelihood, and enhance the socio-economic and environmental performance of the agriculture in general and the land use practice in particular. Mohaddes and Mohayidin (2008) employing FGP with the objective of profit maximization, labor employment maximization, and erosion minimization for agricultural production planning in Atrak watershed, Iran concluded that the FGP model-based agricultural decision-making is “…an effective tool for generating a set of more realistic and flexible solutions in dealing with and attempting to solve the complex real world land development issues particularly in the context of sustainable agricultural production planning with consideration for the economic, social and environmental targets.”

The FGP model has been found to uplift the benefit of farmers and employment opportunities better than the current practice meeting the environmental performance objectives (Wang et al., 2006; Kakhtki et al., 2009; Garg and Singh, 2010). Pal and Moitra (2004) employing FGP as a multi-objective mathematical model decision making for long-range production in agricultural systems with five goals, meeting land utilization, productive resources use (which include workforce, water consumption, and fertilizer requirement sub-goals), production level, cash requirement, and profit goals, pronounced the significance of FGP for agricultural resource decision making to promote sustainable performance of agriculture. The result of the study indicated that the model was advantageous over other deterministic goals by the fact that it is more realistic and flexible which gives the opportunity to explore the risk level of each goal that may arise from imprecise climate information. A similar study, that employed FGP for land allocation for annual crop production confirmed the same fact that the model is able to give better results not only as compared to the conventional decision making approach but also when compared to linear programming and deterministic goal programming decision models (Sharma et al., 2007; Rezayi et al., 2017).

Most of the resources in agriculture are depletable natural resources as compared to the rate of population growth. Thus, efficient resource utilization is a concern around the globe. In this regard, literatures suggest the significance of the FGP approach for efficient utilization of agricultural resources. For instance, the work of Mohaddes and Mohayidin (2008), Safavi and Alijanian (2011), Ghaederzadeh et al. (2011), and Amini (2015) from Iran, Biswas and Pal (2005) and Lone et al. (2019) from India, and El Sayed (2012) from Egypt support the fact. The studies suggested that the use of the FGP approach is not only significant for efficient resource utilization but also to identify land allocation strategies. Moreover, many other studies also uncovered that FGP model-based decision making is a reliable decision support tool to maximize net return, to offer potential solution to the model constraints, to obtain more realistic and promising result (Regulwar and Gurav, 2011; Soltani et al., 2011; Vivekanand. & Kumar, 2016; Rezayi et al., 2017). Joolie et al. (2017) also using the FGP to determine sustainable cropping patterns in Iran considering certain economic, environmental, and social goals composed together, revealed that the FGP decision-making model provides a new perspective for analyzing multiple objectives and making precise decisions for crop planning, Wang et al. (2006) and Safavi and Alijanian (2011) also documented that FGP is a powerful tool for integrated watershed management planning that has the potential to provide a solid base for sustainable watershed management.

3.4. Agricultural decision-making using GIS based mathematical models

Although GIS and mathematical modeling are two distinct areas of research and application, combining data interpretation from both aspects can enhance analysis and problem-solving techniques. As discussed in the previous sub-sections multi-criteria mathematical models (MCDM) like GP and FGP have significant contribution in agricultural decision making. For instance, Ziadat and Al-bakri (2006) and Mazahreh et al. (2019) used GIS to solve land use problems. Ziadat and Al-bakri (2006) used GIS to compare the conventional land use and the potential land utilization in two agricultural sites of Jordan and revealed that the conventional land use in both sites has a deviation from the land use potential. Similarly, Mazahreh et al. (2019) employed GIS to assess land suitability for different land use alternatives in Jordan and discovered that the approach was suitable to identify the potential land purpose and challenges of the land use in the traditional approach. Thus, the question is what will be the significance if both GIS and MCDM approaches are combined to assist the decision-making process? Literature used in this
review demonstrated that a combination of linear programming (LP), multi-objective programming (MOP), or goal programming (GP) model with geographic information systems (GIS) to make agricultural decisions is trending topic of research in area of agriculture and land management. And the use of GIS and mathematical model-based decision-making was found useful decision support tool to promote performance of land use decision. For decision making in land use, GIS is used to analyze and assemble data for aggregate land use alternatives based on factors such as bio-physical characteristics of the land, and then the data are used in LP, MOLP, GP, or FGP models to optimize desired objectives of the land use decision using objective criteria.

In this review, five empirical study articles conducted in three countries and one systematic review that used GIS based mathematical programming are used. As in Malczewski (2006), Fallah Shamsi (2010), and Govindrao et al. (2011), the use of GIS integrated with mathematical models for land-use decisions is an important decision support tool to advance the efficiency of land use decision making.

According to Feizizadeh and Blaschke (2013) study that aimed to develop MCDM model to optimize land use pattern in Eastern Azerbaijan, Iran, used multi-criteria land allocation using the data from GIS concluded that the models offers extensive alternatives for both economic and ecological land use planning than the conventional practice. The finding also agrees with what Govindrao et al. (2011) found in India that outlined GIS integrated mathematical model provides objective criteria for multi-objective land use decision. Moreover, many literatures documented that the GIS integrated mathematical modelling-based decisions provides not only the potential land use type, but also the type of potential limitation(s) that may be faced during implementation. Furthermore, a study by Attua and Fisher (2010) in Ghana and Vafaie et al. (2015) in Iran indicated that the approach is effective in identifying and allocating appropriate land for cultivation.

The systematic review made by Malczewski (2006) on geographical information system-based multi-criteria decision analysis (GIS-MCDA) using literature published from 1990 to 2004 pronounces the use of GIS in MCDA. The review had discussed the two dimensions of the GIS-MCDA, the GIS component of the GIS-MCDA models (i.e. the geographical data models, the spatial dimension of the evaluation criteria, and the dimension of decision alternatives) and the generic element of the MCDA (i.e. the nature of evaluation criteria, the number of individuals involved in the decision making process, and the number of uncertainties). Besides, the review examined the GIS-MCDA literatures based on the level of combination in the application domain and decision seeking problems. Consequently, the review found that the application domains are environmental, transportation, urban planning, waste management, water resource, forestry, natural hazard, tourism, real estate, geology, manufacturing, and cartography. The evaluation problems include land suitability, scenario evaluation, site search and selection, resource allocation, transportation scheduling, and impact assessment. The review disclosed that the GIS-MCDA is a significant decision support tool not only in agriculture but also in other sectors such as economic, environmental management, natural resource management, and transport scheduling.

Regarding the advantage of the GIS integrated mathematical model based decision support tools, literatures revealed that the technique allows decision makers to compute values; add a value judgment and receive feedback on the overall implication of the decision. In addition, the technique provides an opportunity to make team-based decision and allows flexibility.

Literatures used for this review revealed that, regardless of the type of mathematical model used, the mathematical model-based decisions lead to achieving optimal results compared to the performance of the agricultural practice employing the conventional agricultural resource decision making. Pronouncing this result, a study by Schreinemachers and Berger (2006) that compared heuristic decision trees and optimization techniques (mathematical model-based decision making) for land use decision in developing countries pointed out that land use modeling using optimization is advantageous over heuristic decision modeling for three reasons:

1. Optimization techniques allow multiple input and output decisions, such as maximizing employment and profit (two outputs) from crop production from multiple inputs such as land, labor, and financial capital, thus relatively easily capturing the heterogeneity of agents;
2. Optimization techniques permit sensitivity analysis or economic trade-offs that can be easily evaluated to assist decision making; and
3. The results of optimization models imply clear policy recommendations identifying sources of economic inefficiencies.

Generally, the mathematical model-based decision support models such as the GIS integrated with mathematical model-based decision making and the fuzzy-logic programming are more practical for landscape/regional agricultural resource planning whereas linear programming, multi-objective programming and goal programming can be suitable for both landscape agricultural planning and agricultural enterprise planning. Landscape and/or regional mathematical model-based decision outcomes might have richer policy decision relevance. The study by Schreinemachers and Berger (2006) supports this fact.

3.5. Summary

The main aim of this review study was to document the potential of mathematical model-based decision making to enhance the sustainable performance of agriculture in developing countries. A scoping review of articles that employed different mathematical model-based decision support models that include single objective linear programming, multi-objective linear programming, goal programming, fuzzy logic programming, and GIS integrated with mathematical model programming shown in Figure 1 were made. The scoping review technique was preferred over any other review technique by the fact that the approach was found suitable to achieve the objective of the study, documenting the potential of mathematical model-based decision making to promote the sustainable performance of agriculture in developing countries. The review generally uncovered that mathematical model-based decision is an essential tool to enhance desired decision outcomes and to promote resource use efficiency in many sectors including agriculture. Moreover, it is generally comprehensive and significant decision support tool to inform policy and practice.

Although many studies reported a positive influence of using mathematical modeling in decision-making, there are also concerns on how the farmers use such tools (Collins et al., 2013). Most of the mathematical models that can be used for decision making in agriculture have varied levels of complexity and significance with regard to impact, technical capability to be used by agents, and data requirement. With regard to overall impact, multi-objective programming models goal programming, fuzzy-logic programming, and GIS integrated mathematical models can result in wider impact than single-objective linear programming models. This is by the fact that many sustainability goal/objectives either social, economic, and environmental models can be included in the multi-objective mathematical model-based decision support tool than in the single objective models and can be solved simultaneously given equal or desired weights to the objectives in the models. However, reliable time series/panel data required for mathematical model-based decision systems modelling, particularly for models that incorporate environmental risk variables is limited or costly to acquire. Hence, employing any mathematical model-based decision support model of any form might require the establishment of Geo-Databases in addition to socio-economic data centers to include environmental, social, and economic objectives into mathematical model-based decision-support mathematical models. Finally, with regard to the feasibility of application based on technical requirement and timescale, single objective and multi-objective mathematical decision support models (linear programming and goal programming) are feasible decision support tools that might be used right away at least for optimizing single time decisions outcome by any decision-making agent, farm-level, landscape level, regional level or national level. These mathematical model-based
decision support systems can be used to optimize one or a combination of economic objectives such as maximizing profit, maximizing employment, minimizing expenditure and etc. with limited technical skill employing existing socioeconomic data or primary survey data. However, employing single-objective and multi-objective mathematical model-based decision support models for dynamic decision analysis incorporating environmental outcomes require reliable data sources. Besides data and/or information requirements, fuzzy logic and GIS integrated mathematical models require extensive technical skill and expertise when compared to others.

4. Conclusion

Currently following the emphasis of sustainability and food security problems in developing countries in the face of climate change, the use of these models particularly multi-objective mathematical models such as fuzzy goal programming combined with GIS is well supported by literature being more realistic agricultural decision making models that promote systems approach of decision making. Hence, integrating mathematical model-based decision making in the current land use planning and agricultural decision making in developing countries will significantly improve the efficiency of agricultural production and contribute to achieving the goal of eradicating extreme poverty in the face of climate change. The opportunity of expansion of mobile technology and emerging cluster farming practice plays a prominent role to use mathematical model-based decision making in agriculture if supplemented with reliable national and regional agriculture, climatic, and market information. Mobile applications that make use of updated agronomic, climate, and market information from regional and national system databases can be developed and used by agricultural households that has access to mobile technology. Hence, promoting mathematical model-based decision making through accessible mobile application technology integrated with national and regional agronomy, climate and market information systems is an option to enhance the sustainable performance of agriculture in the face of climate change.

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**Appendix I**

Information about the articles included in the review (where FDP = Fuzzy Dynamic Programming, FGP = Fuzzy Goal Programming, FMOLP = Fuzzy Multi-object Linear Fractional Programming, GIS-MCDM = Geographic Information System and Multi-criterion Decision-making, GP = Goal Programming/Multi-object programing, LP = Linear Programming, IFMOP/MOP = Interval Fuzzy Multi-objective programming, LCA = Life Cycle Assessment, MCDM = Multi-criterion/Multi-object Decision Making, MOEO = Multi-objective Evolutionary Optimization, MOFLP/FLP = Multi-objective Fuzzy Linear Programming, MPMIP = Multi-period Mixed Integer Programming, NTPF = Normalized Translog Production Function.2

| Reference          | Country       | Model type | Application level | Aim                                                                 | Attribute                                    | Decision making | Result                                                                 |
|--------------------|---------------|------------|------------------|----------------------------------------------------------------------|----------------------------------------------|-----------------|------------------------------------------------------------------------|
| 1. Ahmed et al. (2011) | North Sudan  | LP         | Food and cash crops | To establish resource combination levels that maximize gross margins | Food security and maximize gross margin      | LP              | Crops that provide optimal benefit are identified                       |
| 2. Amini (2015)     | Iran          | FGP        | Crop planning    | To identify the optimal cropping pattern and land use planning under uncertainty | Maximize income                             | FGP and Comparison | Enhance utilization of resources and hence improvement of income generation |
| 3. Andreea and Adrian (2013) | Romania    | LP         | Botanical farm   | To test possible effect of LP model on spending and income           | Maximum profit level                         | LP              | Able to raise revenue by 143% and to reduce expenditure by 81%        |
| 4. Arzamendia et al. (2015) | Paraguay     | GP         | Milk production  | To design a decision-making support tool that optimize production plan | Economic performance                         | MCDM            | A GP model is suitable to plan dairy farm design of medium-sized       |

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2 A scoping review and the detail is included in the discussion part.
| Reference          | Country               | Model type      | Application level | Aim                                      | Attribute | Decision making | Result                                                                 |
|-------------------|-----------------------|-----------------|-------------------|------------------------------------------|-----------|-----------------|------------------------------------------------------------------------|
| 5. Attua and Fisher (2010) | Ghana                | GIS-MCDM       | Crop/pineapple    | To identify the most suitable land areas for pineapple cultivation | Maximize economic contribution | GIS and MCDM | The approach was effective in identifying suitable areas of land for pineapple cultivation |
| 6. Biswas and Pal (2005) | West Bengal, India   | FGP            | Crop planning     | To explore how FGP approach can be used to optimize production | Optimize production | FGP | Provided an alternative approach to analyse the diverse farm-related activities in a vague decision-making environment. |
| 7. Buzuzi and Buzuzi (2018) | Zimbabwe             | LP              | Crop mix          | To implement optimum farm resource allocation and maximize the profit margin | Optimize net profit | LP and comparison | The LP model-based decision increased the profit margin by 76% |
| 8. Collins et al. (2013) | Sri Lankan           | LP              | Crop              | To support farmers decisions about crop selection to maximize their profit | Income maximization | LP and simulation | The LP is potential tool to exercise crop diversification and rotation |
| 9. Das et al. (2015) | Eastern India        | LP              | Land and water    | To maximize net annual return | Maximize net return | LP and comparison | The approach provide alternatives that optimize income without affecting the water resource |
| 10. Delgado-Matas and Pukkala (2014) | Angola               | LP              | Land use          | To design and analyse the effect of land use alternatives | Livelihood | LP | Alternative production opportunities are observed |
| 11. El Sayed (2012) | Egypt                | FGP             | Cropping mix      | To explore optimum land allocation using FGP model | Net profit | FGP | The model is helpful to identify strategies for land allocation and hence enhance food security |
| 12. Fallah Shamsi (2010) | Tabriz County, Iran  | GIS- MCDM      | Land use          | To make land suitability analysis | Maximize productivity | GIS and MCDM | A synthesized land suitability map was generated |
| 13. Feizizadeh and Blaschke (2013) | Eastern Azerbaijan, Iran | GIS- MCDM     | Land use allocation | To develop a MCMO model to optimize land use pattern | Economic & ecological performance | GIS and MCDM | Both economic and ecological advantageous land use planning that offer extensive changes in the current pattern were identified |
| 14. Felix et al. (2013) | Zimbabwe             | LP              | Cropping patterns | To develop an optimal cropping pattern for communal farmers | Maximizes gross income | LP | The difference in gross income i.e. using the LP is 44.65% higher than the conventional |
| 15. Gadge et al. (2014) | India                | LP              | Cropping pattern  | To enhance net benefits | Maximize the net benefit | LP | Maximum net benefit possibilities are identified |
| 16. Galan-Martin et al. (2017) | Spain                | GP & LCA       | Crop Production   | Explore how to maximize the production level | Productivity and environmental impact | GP | GP technique can contribute to optimize |
| Reference | Country | Model type | Application level | Aim | Attribute | Decision making | Result |
|-----------|---------|------------|-------------------|-----|-----------|-----------------|--------|
| 17. Garg and Singh (2010) | India | FGP | Vegetable | To optimize production under uncertainty in land use planning for high economic expectations | Maximize profit | MCDM | The model-based decision is superior than the traditional |
| 18. Geta et al. (2013) | Ethiopia | LP and NTPF | Maize production | To assess the technical efficiency of maize producers and to identify its determining factors | Productivity and technical efficiency | LP and regression | The model revealed important level of technical inefficiency of smallholder farmers |
| 19. Ghaderrazadeh et al. (2011) | Iran | FMOFP | Cropping pattern | To determining a cropping pattern toward sustainable agriculture | Optimal gross income | FMOFP and comparison | The identified cropping pattern is significant for sustainability in production |
| 20. Glen and Tipper (2001) | Mexico | LP & MPMIP | Crop yields | To introduce improved farming systems in semi-subsistence agriculture | Livelihood | LP and MPMIP | Crop yield enhancement plane has been introduced and the progress is assessed at different intervals |
| 21. Govindrao et al. (2011) | India | GIS-LP | Land-use | To develop a GIS based decision-making model that deals with land use planning | Maximize net return | LP and GIS | Provided objective criteria for the different land use where different goals are being considered |
| 22. Hassan et al. (2005) | Punjab province, Pakistan | LP | Cropping pattern | To develop an optimal cropping pattern & to compare it’s effect with the existing income level | Maximize gross margin | LP and comparison | The developed cropping pattern has increased farm income by 2.91% |
| 23. Hassan et al. (2012) | Malaysia | GP | Vegetable | To deal with the nutrient management problem using LP | Nutrient management | GP | The model is found to be useful for agricultural planners |
| 24. Hassan et al. (2013) | Malaysia | GP | Vegetable | To explore the nutrient management problem of cucumber | Maximize net profit | GP | Reducing cost of production based on nutrient management was successful |
| 25. Igwe and Onyenweaku (2013) | Abia State, Nigeria | LP | Crop and livestock mix | To design optimum farm plans for farmers in terms of activities and resource utilization | Maximize gross margin | LP | Possible crop mix that yield optimum gross margin alternatives are identified |
| 26. Igwe et al. (2011) | Abia state, Nigeria | LP | Arable crops & fish | To investigate maximization of earnings from semi commercial agriculture | Maximization of the gross returns | LP | Recommended production activities to achieve an optimized |
| Reference                  | Country                  | Model type | Application level | Aim                                      | Attribute | Decision making | Result                                                                 |
|----------------------------|--------------------------|------------|-------------------|------------------------------------------|-----------|-----------------|------------------------------------------------------------------------|
| Jayasuriya and Das (2018)  | Mid hills region, Nepal  | LP         | Crop-livestock integration | To design harmonious crop- livestock mix that facilitate sustainable development | Maximize gross margin | LP               | The crop-livestock mix that maximize farm income without creating too much pressure on the land were identified |
| Jeyvanan et al. (2017)     | Sri Lanka                | GP         | Crop              | To enhance crop production for different levels of resource utilization | Optimize production | GP               | Possible to optimized production cost more than 14%                    |
| Joolaie et al. (2017)      | Iran                     | FGP        | Cropping pattern  | To design and test a sustainable cropping pattern that considers different goals in different categories. | Optimize gross margin | FGP and comparison | The FGP model has a noticeably different impact on cropping pattern performance. |
| Kakhki et al. (2009)       | Taybad, Iran             | LP & FMOLFP| Cropping pattern  | To find an optimal cropping pattern | Maximizes the net return | LP, FMOLFP & Comparison | The approach is an effective tool for optimal cropping pattern (both for economic and environmental goals) |
| Latinopoulos (2009)       | Northern Greece          | GP         | Resource allocation| To form a resource allocation decision-making model | Economic & ecological performance | MCDM            | A promising model that facilitate resource allocation to balance socio-economic development and environmental conservation |
| Leung and Ng (2007)        | Hong Kong                | GP         | Perishable products| To test possible effect of GP model on production planning for Perishable products | Control price | GP               | The model provided flexible and strong opportunity for decision makers |
| Lone et al. (2019)         | India                    | FGP        | Vegetable         | To determine the optimal cropping pattern of vegetable crops | Profit maximization | FGP              | With limited resource, maximization of profit was observed             |
| Louischei et al. (2004)    | Reunion Island           | LP         | Dairy farm        | To analyse the decision making strategy | Economic performance | Dynamic LP        | The model is a relatively good representation of the reality on the ground |
| Malczewski (2006)          | Different                | GIS- MCDA  | Different         | To survey and classify the GIS-MCDA articles published between 1990 and 2004 | Different | GIS and MCDA     | Different results were identified                                      |
| Manos et al. (2013)        | Thessaly, Greece         | MCDM       | Livelihood        | To design a model for sustainable optimization of agricultural production | Maximization of gross margin | MCDM, comparison | A model of greater gross return, less fertilizers use, and less irrigated water use were observed |
| Reference                  | Country          | Model type | Application level | Aim                                                                 | Attribute                  | Decision making | Result                                                                 |
|----------------------------|------------------|------------|-------------------|----------------------------------------------------------------------|----------------------------|------------------|------------------------------------------------------------------------|
| 37. Masoumi et al. (2016)  | Iran             | MCDM       | Cropping pattern  | To identify cropping pattern that increase income using minimum water utilization | Increase income             | MCDM             | Cropping pattern that enhance water utilization was identified         |
| 38. Matsyapal (2017)       | India            | LP         | Crop mix          | To determine the cropping pattern using LP                           | Optimize income             | LP               | The model resulted increment of income of the farmers                 |
| 39. Minh et al. (2007)     | Vietnam          | LP         | Crop-livestock interaction | To optimize the productivity of livestock - sugarcane farming system | Income maximisation         | LP               | A pattern of livestock herd (in type & size) and sugarcane cultivation area that yield maximum income were identified |
| 40. Mohaddes and Mohayidin (2008) | Atrak watershed, Iran | FMOP      | Crop planning     | To develop an optimal crop planning that minimizes soil erosion and maximizes profit and employment | Livelihood                  | FMOP and comparison | The identified pattern increased profit and employment and decreased soil erosion significantly |
| 41. Mohamad and Said (2011) | Malaysia         | LP         | Crop mix          | To plan and maximize the total returns at the end of the planning horizon | Maximise gross margin       | Multi-period LP   | The LP model enhance farm income and provide beneficial contribution |
| 42. Mugabe et al. (2014)   | Zimbabwe         | LP         | Crop and Land use planning | To develop an optimal land use plan for Long Croft farm (LCF) | Maximize net farm income    | LP               | An increase in net benefits from the land use planning/ relocation was observed |
| 43. Muhammed Jaslam et al. (2018) | Kerala, India | LP         | Crop planning     | To examine possible effect of resource allocation with the help of LP model | Maximize net return         | LP and comparison | About 22.83% of difference in net return was observed                  |
| 44. Otoo et al. (2015)     | Ghana            | LP         | Crop              | To explore possibility of crop mixing to maximize profit              | Profit maximization         | LP and comparison | The model suggests possible crop mix to maximize profit                |
| 45. Pal and Moitra (2004)  | West Bengal, India | FGP     | Crop production  | To optimize crop production by suitable allocation of the cultivable land and other resources | Maximizes income            | FGP and Comparison | FGP is better than the conventional method to achieve intended production goals |
| 46. Paramjita et al. (2018) | Odisha, India   | LP         | Water, Crop & livestock | To design an approach that enhance allocation of resources and improve net | Maximize net return         | LP and comparison | The LP model was helpful to enhance utilization of water and maximization of return |
| 47. Pastori et al. (2017)  | Africa           | MOEO       | Water and Nutrient Management | To assess the effects of potential agricultural management practices in Africa | Maximize gross margins and Nutrition value | Multi-objective analysis | It is possible to improve gross margin while preserving at the same time the environment influence |
| Reference                  | Country          | Model type | Application level | Aim                                           | Attribute                        | Decision making                  | Result                                                                 |
|----------------------------|------------------|------------|-------------------|-----------------------------------------------|----------------------------------|----------------------------------|------------------------------------------------------------------------|
| 48. Phillip et al. (2019)  | Nigeria          | LP         | Crop              | To identify optimal crop mix that maximize revenue | Maximize revenue                  | LP                               | The LP is helpful to form appropriate resource combination that enhance profit level |
| 49. Rani and Rao (2012)    | India            | LP         | Crop              | To develop cropping plan that maximize production with the limitation of available crop area | Maximize net benefits            | LP                               | The approach meaningfully enhanced the net benefits with optimal resource utilization |
| 50. Regulvar and Gurav (2011) | India         | MOFLP      | Water/Irrigation Planning | To explore an optimal cropping pattern that maximizes at once four differing objectives | Optimize monetary benefits         | MOFLP compromised solution     | A more realistic and promising decision is obtained, and hence monetary benefits are observed |
| 51. Rezayi et al. (2017)   | Iran             | FGP        | Cropping pattern  | To provide a FGP model for optimal allocation for various agricultural crops | Net profit                        | FGP                              | The FGP model offers potential solution to the model constraints        |
| 52. Safavi and Alijanian (2011) | Iran           | FDP        | Crop planning     | To develop an optimization model for crop planning and the conjunctive use of water | Optimize resource allocation       | FDP                              | The proposed model is appropriate for sustainable water management      |
| 53. Sarker et al. (1997)   | Bangladesh       | LP         | Crop mix          | To optimize production through proper crop planning | Maximize production               | LP                               | Maximized annual contribution was observed                             |
| 54. Sharma et al. (2007)   | Ghaziabad district, India | FGP   | Cropping pattern  | To present a FGP model for optimal land allocation of different crops | Optimize monetary benefits         | A tolerance based FGP technique | The developed model provided the best possible solution subject to the model constraints |
| 55. Sofi et al. (2015)     | India            | LP         | Land allocation   | To determine the optimum land allocation to major food crops | Optimize productivity             | LP                               | LP model is appropriate for finding the optimal land allocation         |
| 56. Soltani et al. (2011)  | Kerman, Iran     | FGP        | Cropping pattern  | To find the optimal cropping pattern          | Livelihood                        | FGP, GP, LP and comparison    | FGP was found to be the best and gave maximum net return               |
| 57. Vafaie et al. (2015)   | Iran             | GIS-MCDM   | Aquaculture       | To assess effectiveness of GIS-MCDM method for site selection | Effectiveness                      | GIS and MCDM                    | The method is effective to evaluate appropriate site location for plantations |
| 58. Val-Arreola et al. (2004) | Mexico   | LP         | Dairy farm        | To evaluate the economic impact of using LP model in small-scale dairy systems | Economic impact                   | LP and partial budgeting       | The model showed satisfactory performance as compared with the conventional approach |
| 59. Val-Arreola et al. (2006) | Mexico       | GP         | Dairy production  | To enhance the decision making approach in small scale dairy | Income maximisation               | GP, LP and comparison          | Applying both models helps to achieve the proposed objectives than   |
| Reference | Country  | Model type | Application level | Aim                                                                 | Attribute            | Decision making            | Result                                                                 |
|-----------|----------|------------|-------------------|---------------------------------------------------------------------|----------------------|-----------------------------|------------------------------------------------------------------------|
| 60. Vivekanand. & Kumar (2016) | India    | FLP        | Land & water      | To develop FLP model for optimization of land and water             | Maximize net return  | MOFLP                       | An increment of net profit from the sown area was obtained              |
| 61. Walangitan et al. (2012)   | Indonesia | GP, USLE model | Optimal land use | To analyze optimal allocation of land use type in order to ensure sustainable agriculture | Livelihood           | GP                          | The GP was helpful to optimal allocation of land in different priority areas and possible scenarios |
| 62. Wang et al. (2006)         | China     | MOP        | Watershed management | To create an integrated watershed plan | Socioeconomic, environmental change | IFMOP                      | The proposed model is a powerful tool and can provide a solid base for sustainable watershed management |
| 63. Wankhade and Lunge (2012)  | Maharashtra, India | LP         | Crop production   | To determine optimum land allocation to selected major crops | Maximize net profit  | LP and comparison            | Appropriate crop type and land size correlation to maximize profit are determined |

References

Ahmed, E., Sulaiman, J., Mohd, S., 2011. Agricultural resources allocation and field crops competition. Am. J. Agric. Biol. Sci. 6 (3), 384–392.
Abdullahkader, A.M., Al-Amoud, A.I., Awad, F.S., 2012. Optimization of the cropping pattern in Saudi Arabia using a mathematical programming sector model. Agric. Econ. 58 (2), 56–60.
Amini, A., 2015. Application of fuzzy multi-objective programming in optimization of crop production planning. Asian J. Agric. Res. 9 (5), 208–222.
Anderson, R., Bayer, P.E., Edwards, D., 2020. Climate change and the need for agricultural adaptation. Curr. Opin. Plant Biol. 56, 197–202.
Andrea, I.R., Adrian, J.R., 2011. Linear programming in agriculture. Int. J. Sustain. Econ. Manag. 1 (1), 51–60.
Arzamendia, S., Moreno, A., Lopez, M.M., Recalde-ramirez, J.L., Pinto-rosa, D.P., Politecnica, F., Anuncio, U. N. De, Lorenzo, S., 2015. Design of a Linear-Goal Programming Model for the Dairy Production Planning of Medium Sized Farmer. Atua, E.M., Fisher, J.B., 2010. Land suitability assessment for pineapple production in the A. k wamip criteria approach. Ghana J. Geography 2, 47–83.
Belete, Y., Kebede, H., Birru, E., Natea, S., 2011. Ethiopia Small-Scale IrrigationSituationAnalysis and Capacity Needs Assessment. Ministry of Agriculture Natural Resources Management Directorate.
Biswas, A., Pal, B.B., 2005. Application of fuzzy goal programming technique to land use planning in agricultural system. Omega 33 (5), 391–398.
Bjornstad, T., Herrero, I., Newman, A., Romero, C., Weinzraub, A., 2012. Operations research in the natural resource industry. Int. Trans. Oper. Res. 19 (1–2), 39–62.
Buzuji, G., Buzuji, A.N., 2018. A mathematical programming decision-making tool to crop mix problem on a farm in Mutasa, Manicaland Province, Zimbabwe. Int. J. Econom. Manag. Stud. 5 (11), 6–10.
Collins, A.J., Vegesana, K. Bharath, Seiler, M.J., O’Shen, P., 2013. Simulation and mathematical programming decision-making support for smallholder farming. Environ. Syst. Decisions 33 (5), 427–439.
Dansa, G.B., Thapa, M.N., 2003. Linear Programming: 2: Theory and Extensions Springer Series in Operations Research. Springer Science & Business Media, Das, B., Singh, A., Panda, S.N., Yasuda, H., 2015. Optimal land and water resources allocation policies for sustainable irrigated agriculture. Land Use Pol. 42, 527–537.
Delgado-Matas, C., Palkata, T., 2014. Optimisation of the traditional land-use system in the Angolan highlands using linear programming. Int. J. Sustain. Dev. World Econ. 21 (2), 138–148.
El Sayed, L.M., 2012. Determining an Optimum Cropping Pattern for Egypt (Issue May, 2012). The American University, Cairo.
Estete, Zerayehu Sime, Gattis, Tsegaye Gihno, 2020. The impact of CO2 emissions on agricultural productivity and household welfare in Ethiopia. A computable general equilibrium analysis. Int. J. Clim. Chang. Strateg. Manag. 12 (5), 687–704. In this issue.
Fallah Shami, S.R., 2010. Integrating linear programming and analytical hierarchical processing in raster-GIS to optimize land use patterns at watershed level. J. Appl. Sci. Environ. Manag. 14 (2), 81–85.
FAO, 2002. The role of agriculture in the development of lease developed countries and their integration into the world economy. Food Agric. Org. United Nations.
Federal Democratic Republic of Ethiopia, 2011. Ethiopia’s climate resilient green economy: green economy strategy. Report III (November), 2001.
Feizizadeh, B., Blanks, C., 2013. Land suitability analysis for Tabriz County, Iran: a multi-criteria evaluation approach using GIS. J. Environ. Plann. Manag. 56 (1), 1–23.
Felix, M., Judith, M., Jonathan, M., Munushe, S., 2013. Modeling a small farm livelihood system using linear programming in Bindura, Zimbabwe. Res. J. Manag. Sci. 2 (5), 20–25.
Gadge, S.B., Gorantiwari, S.D., Kumar, V., Kothari, M., 2014. Linear programming approach for allocation of land and water resources in canal command area under surface method of irrigation-A case study. Int. J. Innovat. Res. Sci. Eng. Technol. ISO Certified Organization 3 (4), 151–168.
Galan-Martin, A., Vaskan, P., Anton, A., Esteller, L.J., Guillon-Gosalbez, G., 2017. Multi-objective optimization applied for sustainable RainFed and irrigated crop production. A case study of wheat production in Spain SUSCAPE group: SUStainability using computer aided process engineering tools university of irvine. J. Clean. Prod. 140 (2), 816–830.
Garg, Anjali, S., 2010. Optimization under uncertainty in Agricultural production planning. Comput. Intell. Fin. Engineers 1, 1–12.
Geta, E., Bogale, A., Kanza, B., Elias, E., 2013. Productivity and efficiency analysis of smallholder maize producers in southern Ethiopia. J. Hum. Ecol. 41 (1), 67–75.
Ghaderzadeh, Hamed, Nader, Hemen, Zamani, Omid, 2011. Use of fuzzy multi-objective fractional programming model to determine the optimum cropping pattern toward sustainable agriculture: a case study sanandaji. In: 7th ASAE Conference, 1–11.
Glen, J.J., Tipper, R., 2001. A mathematical programming model for improvement planning in a semi-subsistence farm. Agric. Syst. 70 (1), 295–317.
Govindrao, S.R., Kabeer, S.J., College, M., Aurangabad, D., 2011. Linear programming planning in agricultural system using linear programming in Bindura, Zimbabwe. Res. J. Manag. Sci. 2 (5), 20–25.
Haque, T., 2006. Resource use efficiency in Indian agriculture. Indian J. Agric. Econ. 61 (1), 65–76.
Hassan, I., Ahmad, B., Akhter, M., 2005. Use of linear programming model to determine the optimum cropping pattern: a case study of Punjab. Electron. J. Environ. Agric. Food Chem. 4 (1), 841–850.
Hassan, N., Hassan, K.B., Yatim, S.S., Yusof, S.A., 2013. Optimizing fertilizer compounds and minimizing the cost of cucumber production using the goal programming approach. Am. Eurasian J. Sustain. Agric. (AEIRSA) 7 (2), 45–49.
Hassan, N., Safaii, S., Raduan, N.H.M., Ayop, Z., 2012. Goal programming formulation in nutrient management for chilli plantation in Sungai Buloh, Malaysia. Adv. Environ. Biol. 6 (12), 4008–4012.
Hordofa, T., Menkir, M., Bekele, S., Erkossa, T., 2008. Irrigation and rain-fed crop production system in Ethiopia. Impact Irrigat. Poverty Environ. Ethiopia 27–36.
Igwe, K.C., Oyenweku, C.E., 2013. A linear programming approach to food crops and livestock enterprises planning inaba agricultural zone of Abia state, Nigeria. Am. J. Exp. Agric. 3 (2), 412–431.

Igwe, K.C., Oyenweku, C.E., Nwara, J.C., 2011. Application of linear programming to semi-commercial arable and fishery enterprises in Abia state, Nigeria. Int. J. Econ. Manag. Sci. 1 (1), 75–81.

Jayasuriya, P.W., Das, Romy, 2018. Agricultural resources management through a linear programming approach: a case study on productivity optimization of crop-livestock farming integration. J. Agric. Marine Sci. [JAMS] 22 (1), 27.

Jayavananan, S., Siyambalapitiya, S.B., Jayavananan, K., 2017. Application of goal programming on yield optimization of selected agricultural crops. Int. J. Innovat. Res. Sci. Eng. Technol. 6 (7), 12474–12777.

Joolaei, R., Abedi Sarvestani, A., Taberi, F., Van Passel, S., Azadi, H., 2017. Sustainable cropping pattern in North Iran: application of fuzzy goal programming. Environ. Dev. Sustain. 19 (6), 2199–2216.

Kakhl, M.D., Sahnouhi, N., Salehi Reza Abadi, F., 2009. The determination of optimal crop pattern with aim of reduction in hazards of environmental. Am. J. Agric. Biol. Sci. 4 (4), 305–310.

Latinopoulos, D., 2009. Multi-criteria decision-making for efficient water and land resources allocation in irrigated agriculture. Environ. Dev. Sustain. 11 (2), 329–343.

Leung, S.C.H., Ng, W., Lung, 2007. A goal programming model for production planning of perishable products with postponement. Comput. Ind. Eng. 53 (3), 531–541.

Lone, M.A., Mir, S.A., Mushatq, T., 2019. Modelling and allocation of crops: mathematical programming approach. Adv. Res. 18 (6), 1–5.

Louhihti, K., Alarv, Y., Grimaud, P., 2004. A dynamic model to analyse the bio-technical and socio-economic interactions in dairy farming systems on the Reunion Island. Anim. Res. 53 (June), 363–382.

Mazahreh, S., Bsoul, M., Hamoor, D.A., 2019. GIS approach for assessment of land agriculture 4.0: survey and challenges. Comput. Electron. Agric. 170, 105256.

Mussa, E.C., Obare, G.A., Bogale, A., Simtowe, F.P., 2011. Resource use efficiency of semi-commercial arable and livestock enterprises planning in a watershed , case study of the Atrak watershed , Iran. Am.-Eurasian J. Agric. Environ. Sci. 3 (4), 636–648.

Movahed, N.H., Said, D.A., 2011. A mathematical programming approach to crop mixing problem. Afr. J. Agric. Res. 6 (1), 191–197.

Muhammed Jaslam, P.K., Joseph, B., Paul Lazarus, T., Rakhi, T., 2018. Determining optimum cropping pattern with aim of reduction in hazards of environmental. Am. J. Agric. Biol. Sci. 13 (2), 167–195.

Miot, N., Sawyer, B., 2013. Decision making in agriculture: a multi-objective approach. Adv. Res. 18 (6), 1–42.

Nugissie, E., Olwak, T., Masumba, G., Tegtegn, T., Lemmas, A., Mukuria, F., 2020. IoT-based irrigation management for smallholder farmers in rural sub-Saharan Africa. Procedia Comput. Sci. 177, 95–102.

Oto, J., Okot, J.K., Amose, F., 2015. Optimal selection of crops A case study of small scale farms in Fanteakwa district Ghana. Int. J. Technol. Sci. Res. 4 (5), 142–146.

Pal, B.B., Moitra, B.N., 2004. Using fuzzy goal programming for long range production planning in agricultural systems. Indian J. Agric. Econ. 59 (1), 75–90.

Paranjita, D., Panigrahi, B., Paul, J.C., Sahoo, N., 2018. Integrated crop and livestock planning of a minor irrigation command of Dhenkanal district by linear programming approach. Int. J. Curr. Microbiol. Appl. Sci. 7 (10), 1567–1578.

Pastori, M., Udías, A., Bourouis, F., Bigdlou, G., 2017. Multi-objective approach to evaluate the economic and environmental impacts of alternative water and nutrient management strategies in Africa. J. Environ. Informat. 29 (1), 16–28.

Phillip, D.O.A., Peter, E., Gire, A.A., 2019. Determination of optimum crop mix using linear (LP) programming among small holder farmers in agricultural zone four of Adamawa state, Nigeria. Asian J. Agric. Extension Econ. Soc. 34 (2), 1–10.

Rani, Y. Raghava, Rao, P.T., 2012. Multi objective crop planning for optimal benefits. Int. J. Eng. Res. Afr. 2 (5), 279–287.

Regulvar, D.G., Gurur, J.B., 2011. Irrigation planning under uncertainty–A multi objective fuzzy linear programming approach. Water Resour. Manag. 25 (5), 1397–1416.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sofi, N.A., Ahmed, A., Ahmad, M., Bhat, B.A., 2015. Decision making in agriculture: a linear programming approach. Int. J. Modern Math. Sci. J. 13 (2), 160–169.

Soltani, J., Karbas, A.R., Fashimlilvand, M., 2011. Determining optimum cropping pattern using Fuzzy Goal Programming (FGP) model. Afr. J. Agric. Res. 6 (14), 3305–3310.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Schrötermanners, P., Berger, T., 2006. Land use decisions in developing countries and their representation in multi-agent systems. J. Land Use Sci. 1 (1), 29–44.

Sharma, D.K., Jana, R.K., Gaur, A., 2007. Fuzzy goal programming for agricultural land allocation problems. Yugosl. J. Oper. Res. 17 (1), 31–42.

Sarker, R.A., Talukdar, S.A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.

Sarker, R.A., Talukdar, S., Haque, A., 1997. Determination of optimum crop mix for crop cultivation in Bangladesh. Appl. Math. Model. 21 (10), 621–632.