Enhancing agricultural sustainability: A decision support model approach to optimize water and fertilizer usage*

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Abstract

The aim of this research is to change land use through the implementation of a Decision Support Model. Initially, this model will focus on minimizing land fertilization and unnecessary water use while also enhancing farm economic efficiency and profitability. Through this model, producers will have the ability to customize their own production plans, setting specific limits for the inputs used to optimize production. The research addresses the problem of inefficient water and fertilizer usage in the agricultural sector. The research objective will be achieved by analyzing the outcomes of a carefully chosen set of pilot fields owned by a group of farmers located in the Central Macedonia region. To select the pilot farms, relevant data is gathered and then processed using multicriteria weighted goal programming. This process aims to develop a Decision Support Model focused on reducing water and fertilizer usage. By managing these resources more effectively, it will be possible to reduce production costs, ensure compliance with regulations, prevent water table pollution, curb soil degradation, and boost overall productivity.

Keywords

Decision Support Model, input minimization, water usage, profitability, economic performance

1. Introduction

It is undeniable that the global population is on the rise [1, 2]. This population growth naturally leads to increased food production and, consequently, greater consumption of natural resources [3]. However, the expansion of agricultural production presents numerous challenges regarding the sustainable management of natural resources. The Common Agricultural Policy (CAP) (2023-2027) addresses these challenges through a series of directives, laws, and regulations governing agricultural product trade, production, and interventions aimed at enhancing competitiveness, sustainability, and resilience while safeguarding the environment. Cross compliance is the term used to describe the legal requirements that farmers must follow with relation to the preservation of rural landscapes, public health, environmental management of natural resources, and the application of good agricultural practices [4]. Both direct single payments and linked payments are subject to these regulations, and non-compliance will result in payment reductions [5]. Nowadays, there is a great emphasis on minimizing the usage of inputs such as chemical fertilizers, pesticides, water, fuels, and other resources crucial for agricultural production [1, 2]. In this spectrum, multi-criteria

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mathematical programming (MCDM) is a useful tool that allows maximizing profit, minimizing differential inputs, and promoting rational use through land use changes, all with the aim of enhancing competitiveness. Based on MCDM, a Decision Support System (DSS) was developed, which, according to previous research, proved valuable in ensuring compliance with multiplexing regulations while optimizing economic performance [6]. The Multi-Criteria Decision Support Model was designed, adhering to the terms outlined in the new Common Agricultural Policy (CAP) for the period 2023–2027 and complying with multiple compliance regulations.

2. Materials and Methods

This paper focuses on optimizing the allocation of limited resources in agricultural production through the implementation of a Multi-Criteria Decision Analysis (MCDA) model based on the Laboratory in Agriculture’s existing infrastructure. This model is tailored to meet the producers' needs and is developed using the multicriteria weighted goal programming method after collecting relevant data [7]. The MCDA model considers economic, social, and environmental factors and has been utilized to identify beneficial changes in land use and optimize farm plans for efficiency [8]. Additionally, it is crucial to meet the objectives of the Common Agricultural Policy (CAP), which in this study will be accomplished through adherence to cross-compliance rules and standards. Given that cross-compliance rules are expected to become stricter in the coming years, it is imperative to familiarize producers with them. The model's components include variables, objectives, and constraints.

The decision variables represent the production sectors of the studied farmer group. The objectives include the minimization of variable costs, labor costs, and fertilizer use, as well as the maximization of gross profit and the minimization of water use. The constraints ensure that the total cultivated land does not exceed 100 hectares per farmer group, the total labor hours for each crop do not surpass the total available hours, and the total quantity of fertilizer allocated to each crop does not exceed the overall available fertilizer. The goal will be reached by distributing scarce financial and land resources to farmers as efficiently as possible. This will be done by having a particular farmer group in the Loudia, Thessaloniki, create a 100-acre pilot field. The Decision Support Model, which is customized to fit the unique requirements of the producers, will serve as the basis for the pilot field selection procedure. To reach their ideal production plan, each producer will create their own unique production plan, putting restrictions on inputs like fertilizer, irrigation, and other things. This will result in decreased water and fertilizer use on the land, as well as increased economic growth and profitability for the farm.

3. Results & Discussion

Following the collection of primary data, an analysis was conducted to reveal the existing crop plans along with relevant technical and economic details. Subsequently, a multi-criteria decision analysis was applied to derive the model's crop plans to be adopted. This section outlines both the current crop plans and the optimal ones for the farmer group. The Loudia ́s farmer group is located in the Thessaloniki regional unit and consists of 10 producers. They cultivate a total of 1,991 acres. 68.1% of these acres are dedicated to cotton cultivation, 18% to rice, 9.7% to maize, 1.4% to soft wheat, 0.9% to durum wheat, and the remaining 1.9% is dedicated to fallow land (Figure 1).

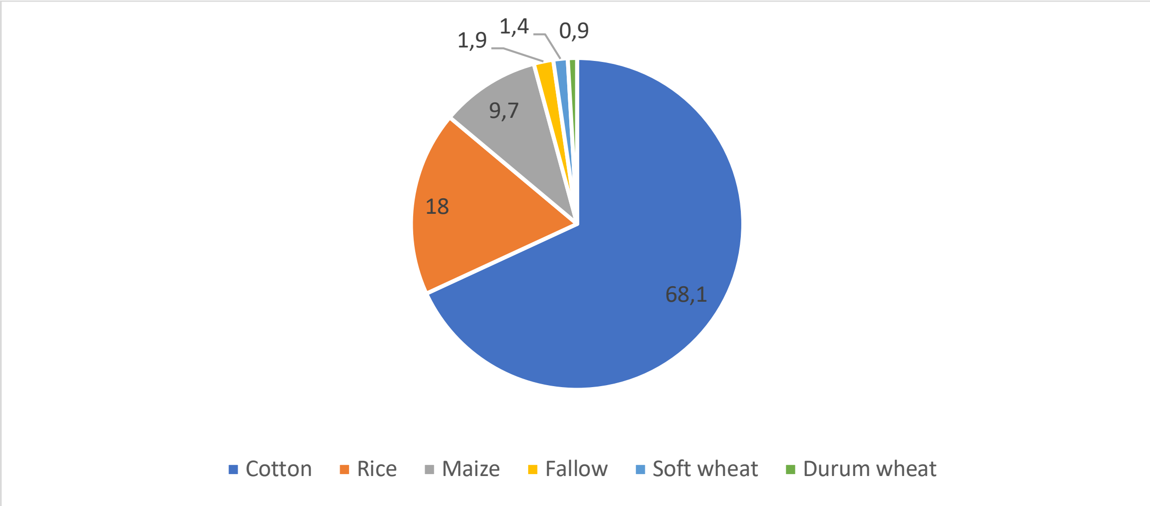

Figure 1: Existent crop plan of Loudia΄s farmer group

The implementation of the MCDA model suggests modifications to the agricultural land management of Loudia΄s farmer group, aimed at optimizing outcomes for the farmers. According to the model's recommendations for this specific farmer group, the suggested crops remain the same, but only the cultivated percentages change. Specifically, the optimal scenario proposes a 4.14% increase in cotton cultivation, while reductions are suggested for the rest of the crops (rice, maize, soft wheat, durum wheat, and fallow land). These adjustments are intended to align with the model's objectives, as mentioned in the introduction section. The optimal crop configuration is illustrated below (Figure 2).

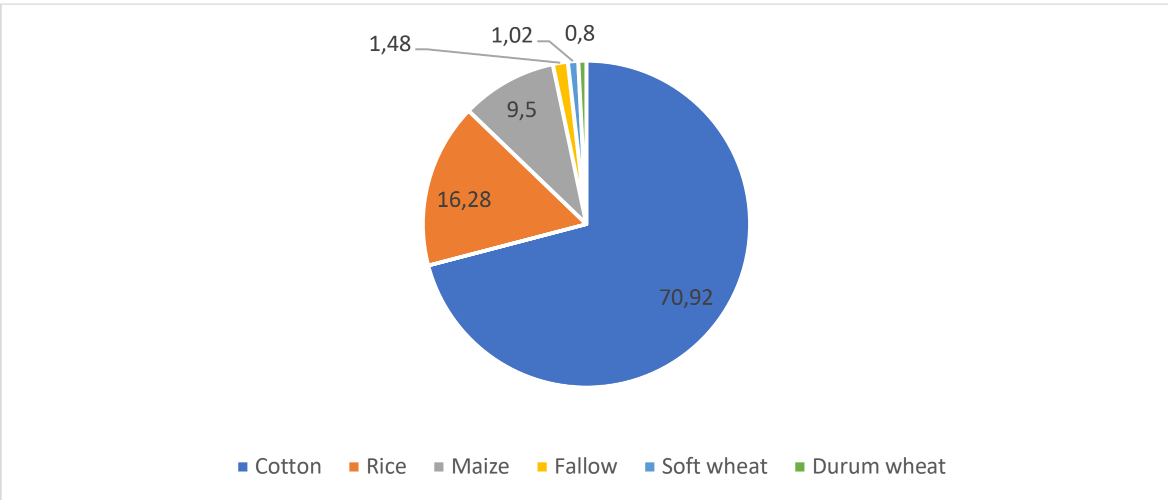

Figure 2: Optimal crop plan of Loudia's farmer group

The multi-criteria model suggests an increase in cotton cultivation, which underscores the economic viability of the crop, particularly as it already occupies 68.1% of agricultural land [9]. The reallocation of crop cultivation is balanced by a reduction in rice and maize cultivation by 9.56% and 2.06%, respectively, reflecting a nuanced approach to fertilizer savings. This finding is also supported by other studies [9, 10]. Additionally, a decrease in the cultivation of soft and durum wheat is observed, consistent with findings from other studies [10,11]. The model successfully achieves the objectives of increasing the farm's gross profit, reducing variable costs, and minimizing fertilizer use. No change is observed in labor hours. In the current crop plan, the gross profit is 22,583 euros, while in the optimized farm plan, it increases to 22,603.02 euros, indicating a 0.09% increase. Regarding costs, the current crop plan incurs 16,715 euros, whereas the optimized plan reduces this to 16,679.08

euros, marking a decrease of 0.21%. Labor hours remain consistent. Water usage is 6,494 m3 in the existing plan, whereas in the optimized plan it represents a reduction of 1.45% (Figure 3).

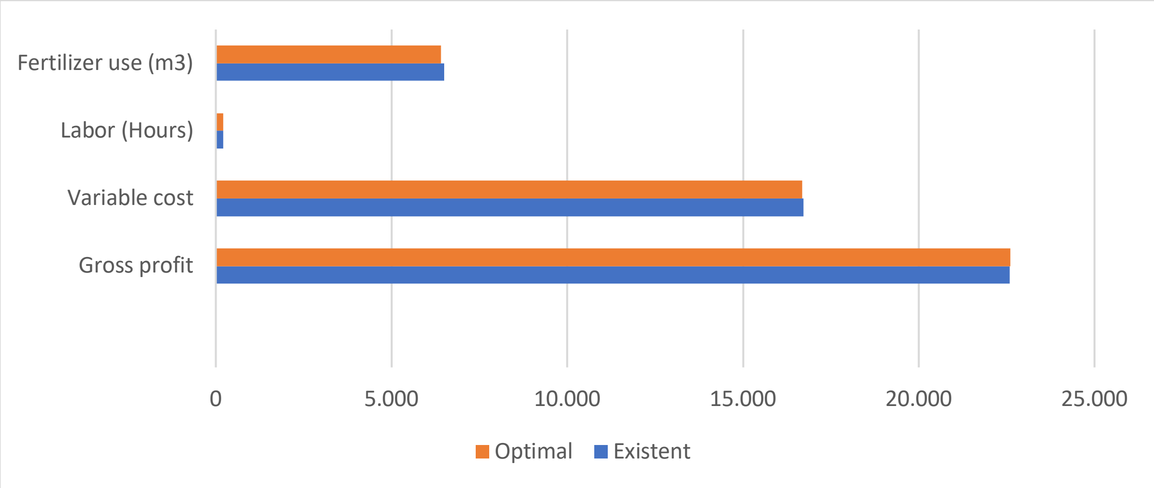

Figure 3: Changes in objectives of Loudias's farmer group

4. Conclusions

The research demonstrates that implementing a Decision Support Model (DSM) in agriculture can significantly enhance sustainability by optimizing water and fertilizer usage. By utilizing a Multi-Criteria Decision Analysis (MCDA) model, farmers can customize their production plans to reduce resource waste, increase economic efficiency, and comply with environmental regulations by investigating alternative crops with lower irrigation and fertilization demand and greater economic benefits. The study, conducted with farmers in Central Macedonia, reveals that the optimized crop plans lead to a slight increase in gross profit and a reduction in variable costs and water usage. This research marks the first large-scale implementation of its kind and could potentially extend to surrounding regions beyond Central Macedonia. The research process encourages producers to embrace more efficient crops while retaining existing ones by integrating new cross-compliance rules, thereby enhancing profitability. This approach not only supports the Common Agricultural Policy's objectives but also promotes sustainable agricultural practices, ensuring long-term farm profitability and environmental conservation.

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Declaration on Generative AI

The author(s) have not employed any Generative AI tools.

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