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Article

The Theoretical and Methodological Foundations for Optimizing The Use of Resources in Agriculture

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Abstract: Humanity's growing population and a global hunger for food, especially in relation to agriculture, efficient resource use must become a key focus. The continued growth in food consumption will continue to create stressors on effective land and resource management, and fortunately, there are ways to balance cost-effective practices while being environmentally friendly. The optimization agriculture land resources and cattle farming using linear programming and stochastic models the optimization agriculture land resources and cattle farming using linear programming and stochastic models. This allows to reduce production costs and increase revenue through optimum land use and feed rationing. While there have been studies aggregate using optimization methods, natural and climatic changes are seldom incorporated into existent models, thus making the model agricultural yield dependent. At the same time, the present study synergistically combines these aspects in the optimization process that is a more realistic model of agricultural production problems. This research focuses on the development and application of optimization models that aim to improve land resource use in agriculture specifically livestock production so as to increase the sustainability of farming systems in terms of the farm profitability and environmental impact. This research shows that in order to get more efficient and sustainable agriculture outcomes, eased by applying linear programming and stochastic variables, is achievable in terms of economic benefits and sustainable growth of Thai agriculture outputs. In this work, we propose a linear stochastic programming model that explicitly accommodates climate impacts, which is an important missing component in traditional optimization frameworks. These results offer an applied methodology to tailor development of land use and livestock production efficiencies that can effectively contribute to sustainable food production systems under a range of climatic conditions.

Keywords: optimization model, linear programming, coefficients, cost, income, minimization, maximization, agricultural products, land resources.

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1. Introduction

In the current era, which has reached the highest level of resource scarcity, the issue of meeting the growing needs of the population by using the available natural resources has become critically important. In particular, the rapid population growth observed today has made the problem of producing more food to meet people's primary needs a pressing issue. As a result, efficient use of resources in agriculture has become more relevant than ever. Naturally, one of the most effective methods for solving such problems is to determine the optimal solution using the linear programming method. By applying this method, it becomes possible to identify ways of producing more agricultural products with fewer resources, thereby contributing to the resolution of the issue described above.

In solving optimization problems in agriculture, linear programming methods are widely used by various researchers to address different issues. However, in many cases, the problems most frequently encountered relate to optimizing the use of land resources, which are considered a key factor in agricultural production. Taking this into account, the study focuses on optimizing land resource utilization in agriculture specifically,

determining in what proportions land resources should be used in order to achieve maximum income. To this end, a linear programming problem was formulated and examined.

Literature Review. The theory and practice of livestock development, feed base strengthening, and pasture utilization in foreign countries have been extensively studied by numerous scholars. In this field, Dahal Subash conducted a comprehensive analysis of sustainability issues in pasture-based livestock production systems. The study demonstrated the relationships between efficient pasture utilization, ecological balance, and economic efficiency [1]. McIntire J and Grace D examined the impact of the livestock sector's global development in the scientific research of the International Livestock Research Institute, as well as issues of implementing research results into practice [2].

Kulikova N.I, Eremenko O.N and Malakhova A.O presented theoretical and practical aspects of livestock production in an educational-methodological manual on livestock fundamentals [3]. Nasiev B.N, Makanova G.N and Rzaev N investigated factors of forage land degradation in semi-desert zones. The study analyzed the causes of pasture deterioration and measures for their restoration [4]. Shevtsov V.V demonstrated ways to improve the efficiency of pasture livestock farming through the use of modern technologies in research on the intensification of pasture livestock farming [5].

Gulyamov S.S., Abdullaev A.M and Olimjonov A.U developed a methodology for statistical analysis of time series and forecasting seasonal fluctuations. This methodology is widely applied in analyzing agricultural indicators, including livestock indicators [6]. Abdullayev Yo.A presented the methodology for analyzing agricultural statistics, including livestock indicators, in a textbook on statistics theory [7]. Narbaev Sh.K conducted in-depth research on improving the organizational and economic foundations of forming a pasture utilization system based on materials from the Republic of Karakalpakstan. The study developed pasture management mechanisms for regional conditions [8].

2. Materials and Methods

This research examines the optimization of land resource utilization in agriculture, taking into account its specific characteristics, namely the variability of crop productivity and production costs, considering two scenarios: minimizing production costs or maximizing income. Additionally, the study presents linear programming problems widely used in minimizing agricultural production costs. However, given the current situation where the impact of natural and climate changes on agricultural production is intensifying, these factors are also taken into account, utilizing linear stochastic programming problems as an optimization model for this issue. The formulation of the problem of livestock feeding with minimal costs and the issue of selecting optimal livestock composition to maximize pasture utilization are of significant importance [9].

3. Results and Discussion

When optimizing the use of land resources in agriculture, it is important to take into account their specific characteristics, since both the productivity of crop cultivation and the amount of expenses incurred depend on the composition of the soil. As a result, two different approaches can be considered: either minimizing the costs of production or maximizing the income. In this section, we examine the theoretical formulation of such a problem.

The objective function of the model is aimed at minimizing costs:

$$f = \sum_{k \in K} \sum_{j \in J} \sum_{i \in I} c_{ijk} x_{ijk} \rightarrow min \qquad (1)$$

Here:

c_{ijk} – the unit cost (in conditional units/kg) of producing product j on land plot k in region i;

x_{ijk} – the quantity (in tons) of product j obtained from land plot k in region i.

In agricultural production, several constraints must be considered, including land area, the minimum required production level for each type of product, the amount of

labor needed, the required quantity of fertilizers, and the allowable production costs. These constraints can be represented in the following form:

$$\begin{gathered}\sum_{k\in K}\sum_{i\in I}\frac{x_{ijk}}{y_{ijk}} \le S_j \\ \sum_{k\in K}\sum_{i\in I} x_{ijk} \ge V_j \\ \sum_{k\in K}\sum_{i\in I} k_{ijk}x_{ijk} \le K_j \\ \sum_{k\in K}\sum_{j\in J} w_{mijk}x_{ijk} \le W_{mi} \\ \sum_{k\in K}\sum_{j\in J}\sum_{i\in I} d_{ijk}x_{ijk} \le D \\ x_{ijk} \ge 0\end{gathered} \quad (2)$$

Here:

y_{ijk} – yield of agricultural crop j on land plot k in region i (tons/hectare);

S_j – available cultivated area for agricultural crop j (hectares);

V_j – minimum required production volume for agricultural crop j (tons);

k_{ijk} – labor input required to cultivate one unit of agricultural crop j on land plot k in region i (man-hours/ton);

K_j – production cost constraint for agricultural crop j (million UZS);

wm_{ijk} – amount of fertilizer type m required to cultivate one unit of crop j in region i (tons/hectare);

W_{mi} – fertilizer limit of type m allocated for region i (tons);

d_{ijk} – cost of producing agricultural crop j on land plot k in region i (million UZS/ton);

D – total allowable production cost (million UZS).

The above-mentioned linear programming problem is widely used to minimize agricultural production costs. However, under current conditions, where the impact of natural and climatic changes on agricultural production is increasing, it is necessary to take these factors into account as well. This is because such factors directly affect the yield of cultivated crops. In order to consider this aspect, if we use their probable (expected) values [10], the problem should be formulated as a linear stochastic programming model in the following form:

$$\begin{gathered}f = \sum_{k\in K}\sum_{j\in J}\sum_{i\in I}(c_{ijk} + c'_{ijk})x_{ijk} \to min \\ \sum_{k\in K}\sum_{i\in I}\frac{x_{ijk}}{(y_{ijk} - y^p_{ijk})} \le S_j \\ \sum_{k\in K}\sum_{i\in I} x_{ijk} \ge V_j - V_j^p \\ \sum_{k\in K}\sum_{i\in I}(k_{ijk} + k^p_{ijk})x_{ijk} \le K_j \\ \sum_{k\in K}\sum_{j\in J}(w_{mijk} + w^p_{mijk})x_{ijk} \le W_{mi} \\ \sum_{k\in K}\sum_{j\in J}\sum_{i\in I}(d_{ijk} + d^p_{ijk})x_{ijk} \le D \\ x_{ijk} \ge 0\end{gathered} \quad (3)$$

In this model:

c'_{ijk} – additional costs incurred due to yield losses caused by natural and climatic changes;

$y_{ijk}{}^p$ – yield reduction coefficient for agricultural crop j on land plot k in region i under scenario p of natural and climatic changes;

$V_j{}^p$ – loss in the production volume of agricultural crop j under scenario p of natural and climatic changes;

k_{ijk}^{p} – additional labor resources required for technological operations in cultivating crop j on land plot k in region i under scenario p of natural and climatic changes;

w_{ijk}^{p} – additional costs for fertilizers and plant protection products needed to cultivate crop j on land plot k in region i under scenario p of natural and climatic changes;

d_{ijk}^{p} – additional production costs for cultivating crop j on land plot k in region i under scenario p of natural and climatic changes.

Optimization models of the type described above are widely applied in practice. This is because such models are among the most powerful tools for understanding complex processes and finding effective solutions to them. Nevertheless, in real-world situations, the use of this method is complicated by challenges related to constructing an appropriate model and selecting the correct set of constraints to reflect the actual problem accurately [10].

To properly formulate an optimization problem and obtain a feasible solution, it is first necessary to define the objective function clearly. After that, the constraints for each variable must be determined, and the normative values of the production factors required for each variable must be accurately selected. In this context, the variables represent controllable conditions within the model, while the objective function measures the decision-maker's goal as a function of these variables. The primary role of constraints is to serve as a mathematical expression of the upper bounds of the unknown variables. Next, we turn to the application of the optimization problem in the field of livestock farming. Linear programming can be used for various purposes in livestock production, such as selecting the composition of livestock that ensures maximum income from the available land area, or minimizing costs in the feeding process. One of the most frequently applied optimization problems is selecting a high-quality, cost-effective feed ration. In what follows, we will examine the formulation of the problem of feeding livestock at minimal cost, see Figure 1.

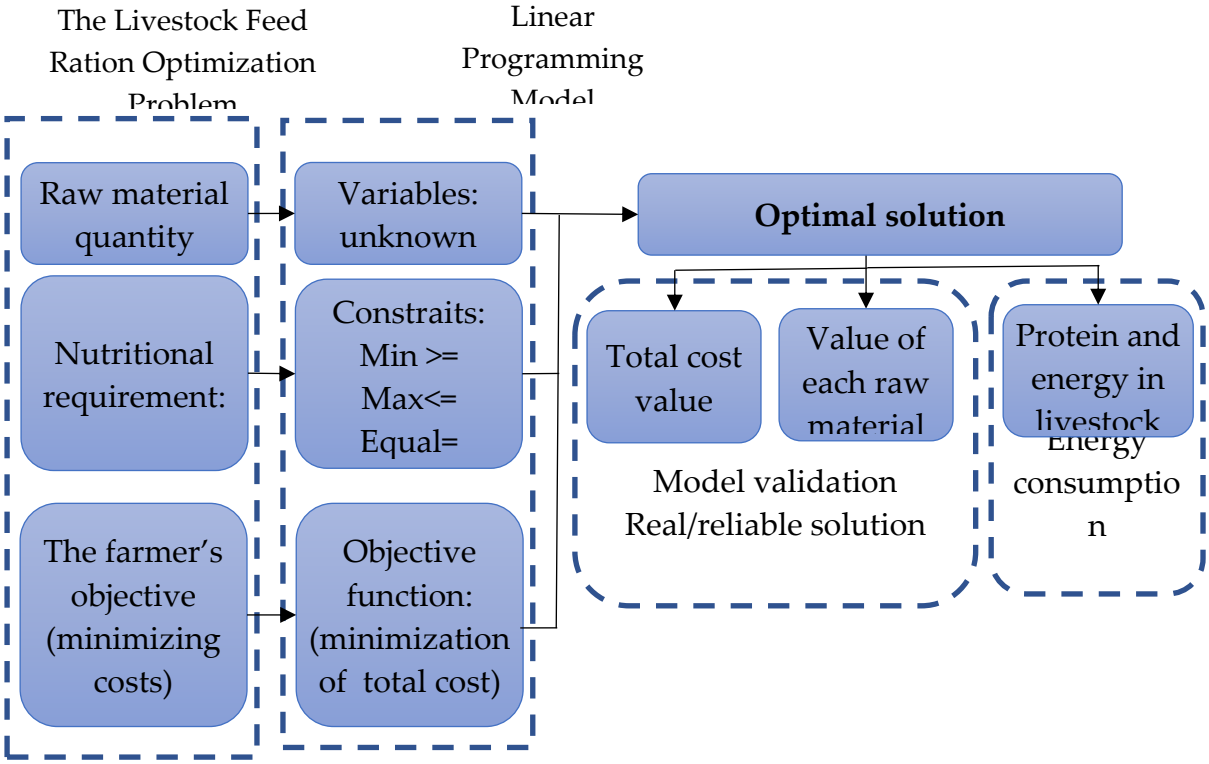


Figure 1. The Livestock Feeding Problem: Linear Programming Model and Energy Consumption [11].

First, it is necessary to identify a number of indicators related to the feeding problem specifically, the quantity of raw materials and the required nutritional demand must be determined and matched accordingly. The primary objective of a farming enterprise in this context is to minimize the cost needed to meet these nutritional requirements.

Based on the identified quantities, linear programming is applied, where the raw materials used in forming the ration are selected as variables. Nutritional requirements serve as constraints in the optimization problem, while the farmer's goal forms the basis of the objective function. The solution to this problem is considered optimal, as it enables the provision of the required nutrients and energy to livestock at minimal cost.

The theoretical and mathematical formulation of this problem has been addressed in numerous studies. We now consider a linear programming problem aimed at formulating the least-cost feed ration. To achieve this, several assumptions must be made, taking into account the dataset, constraints, and the target values to be fulfilled:

First, all components of the ration must be divisible without restriction (i.e., they can be split into any quantity);

Second, all coefficients must be known and well-justified;

Third, the total outcome of the activity should be considered as the sum of individual activities.

Minimization Problem:

$$Z = \sum_{j=1}^{n} C_j x_j \tag{4}$$

Constraits:

$$\sum_{j=1}^{n} a_{ij} x_j \leq (\geq, =) b_i \tag{5}$$

Here, Z represents the total cost of the feed ration..

$$\sum_{j=1}^{n} x_j = q \qquad x_j \geq 0 \tag{6}$$

C_j= cost of the j-th component in the feed ration;

x_j – amount of the j-th component in the ration;

a_{ij} – amount of nutrient i in component j of the ration;

b_i – required amount of nutrient i in the ration;

q – weight coefficient.

The type of constraint (equality or inequality) depends on the balance of nutrients or nutritional components required in the ration. This is because, even if a certain nutrient is expensive, it would be incorrect to minimize costs by setting its required amount to zero. The minimum required level of such a nutrient must be maintained.

On the other hand, for cheaper nutrients, it is necessary to set an upper limit and ensure the proper balance of components. If we denote the lower and upper bounds of nutrient i in one unit of feed by l′ and u′, respectively, then the constraint can be written as follows:

$$l_i' q \leq \sum_{j=1}^{n} a_{ij} x_j \leq u_i' q \tag{7}$$

Based on this, the constraint can be expressed in the following form:

$$l_1' q \leq a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \leq u_1' q$$
$$l_2' q \leq a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \leq u_2' q$$
.
.
$$l_m' q \leq a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \leq u_m' q \tag{8}$$
$$0 \leq x_1 \leq u_1$$
$$0 \leq x_2 \leq u_2$$
.
.
$$0 \leq x_n \leq u_n$$

Under conditions of symmetric distribution, forming a ration based on average nutritional values means meeting approximately 50% of the nutritional needs over time and across necessary requirements. In this case, it is essential to consider the variability of nutrient composition in the feed and fluctuations in the demand for those nutrients.

When the demand for nutrients and the composition of feed components are treated as random variables, their inclusion in the model necessitates the use of mathematical expectation.

The mathematical expectation of the amount of nutrients in the ration is expressed as follows:

$$E(R_i) = \sum E(A_{ij})X_j = \sum \mu_{ij} x_j \quad (9)$$

The variance is expressed in the following form:

$$V(R_i) = \sum_{j=1}^{n} v_{ij} x_j^2 + \sum_{j=1}^{n} \sum_{j'=1}^{n} c v_{ij.j'} x_j x_{j'} \quad (10)$$

$j \neq j'$

Here:

R_i – daily requirement of nutrient i;

$\mu_{ij} = A_{ij}$ – expected value of nutrient i in component j;

x_j – the amount of component j in the ration;

v_{ij} – variance of A_{ij};

V() – denotes the expected value of the squared deviation from the mean.

Since this is a case of independent random variables, the second term in the variance equation drops out, as the covariance equals zero. Thus, the expression takes the following form [12]:

$$V(R_i) = \sum_{j=1}^{n} v_{ij} x_j^2 \quad (11)$$

If our goal is to ensure that the amount of nutrients R_i meets or exceeds the required level b_i within a specified time a_i, then we require that:

$\text{prob}(R_i \geq b_i) \geq \alpha_i$, where
$1 > \alpha_i > 0$.

In this case, we convert R_i into a normally distributed variable.

If R is considered a normally distributed variable, then the new standardized variable is given by:

$\phi = (R - E(R)) / \sqrt{(V(R))}$,

which has a mean of zero and a variance of one.

This means that,

$$prob\left[\left(\frac{R_i - E(R_i)}{\sqrt{V(R_i)}}\right) \geq \left(\frac{b_i - E(R_i)}{\sqrt{V(R_i)}}\right)\right] \geq \alpha_i \quad (12)$$

If we replace the first part with a standard normal variable,

$$prob\left[\emptyset \geq \left(\frac{b_i - E(R_i)}{\sqrt{V(R_i)}}\right)\right] \geq \alpha_i \quad (13)$$

This can be written as a deterministic term as follows:

$$\sum \mu_{ij} x_i \geq b_i + \emptyset \sqrt{\sum v_{ij} x_j^2} \quad (14)$$

If we express this inequality in deterministic form, it will be as follows:

$$\sum \mu_{ij} x_j \geq b_i + \emptyset \sqrt{\sum v_{ij} x_j^2} \quad (15)$$

The right-hand side of this inequality, which represents the variance of the nutrient unit in the ration, is considered as a factor, and ϕ denotes the standard deviation, whose value is determined using the probability of positive outcomes α_i.

If we take into account the variability in nutrient content, we arrive at a nonlinear expression involving the mean and standard deviation. A nonlinear programming algorithm provides effective results for solving this problem. However, to simplify the

solution, the nonlinear inequality is transformed into a linear form using mathematical methods.

This transformation into a linear form was implemented by Rahman and Bender [13], namely:

$$\sqrt{\sum v_{ij} x_j^2} \quad \text{with} \quad \sqrt{\sum \delta_{ij} x_j}$$

However, this form of simplification has been criticized by a number of researchers, as it assumes that when a and b are positive numbers, the expression √a + √b is equal to √(a + b), which is mathematically incorrect [14]. Nevertheless, the proposed simplification is widely used in practice and is scientifically accepted, since its application ensures that the actual probability of meeting the requirement does not fall below the specified value. In such cases, if the demand exceeds expectations or if the requirement is not met due to losses, it becomes necessary to consider the probability of achieving a positive outcome, taking into account the forfeited profit.

According to our research findings, the theoretical and methodological foundations of optimization problems have been developed to address issues related to the efficient use of land, which is a key production factor in agriculture, and particularly to minimizing costs in livestock farming that is, creating a low-cost yet effective ration [15]. Using the methods discussed above, we now consider the optimization of resource use in pasture management. The problem can be formulated in the following form, see Figure 2:

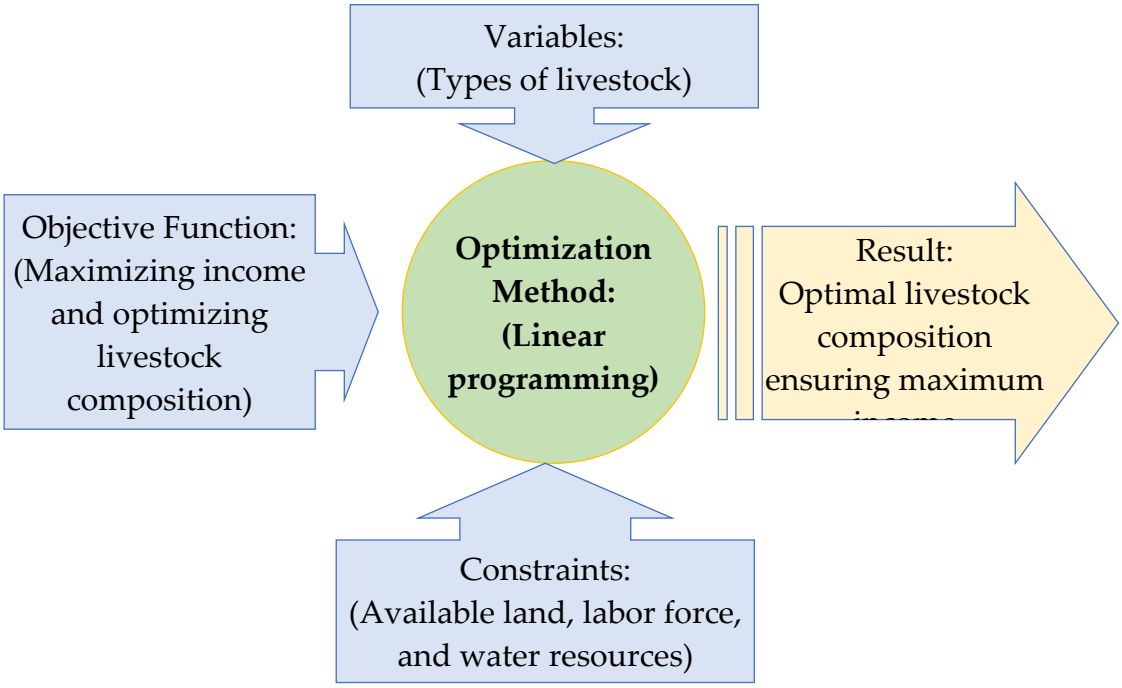


Figure 2. The problem of selecting the optimal livestock composition for maximizing pasture utilization.

The main objective here is to determine the optimal livestock composition that would maximize the income of farming households engaged in animal husbandry on pasturelands, taking into account existing resources and constraints.

The primary constraints include:

1. The available land area (with necessary biomass derived from established norms),
2. The amount of labor required for managing livestock, and
3. The availability of water resources, given that the pastures are located in arid regions.

Formulating and solving this problem using linear programming enables the identification of optimal solutions that help increase the income of farmers in the target

region and provide greater opportunities to meet the population's demand for livestock products.

4. Conclusion

In our view, by applying the above-mentioned methods and tailoring them to the specific conditions of each region, it becomes possible to determine optimal production levels in agriculture. This, in turn, allows for increasing income and minimizing costs, which is one of the key strategies for addressing the global challenge of food security today. However, it is essential to simplify the application of these methods so that every actor in the agricultural sector can use them effectively. In this context, the use of "smart" technologies is seen as a promising direction.

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