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Research Article

Application of Linear Programming for Efficient Resource Allocation in Agriculture: A Case Study of Tiruchirappalli District

Arivudai Nambi Jenifer Christinal[1], Dhasaiyan Surjith Jiji[2, *]

[1]Department of Mathematics, Bishop Heber College (Autonomous), Bharathidasan University, Trichy, India
[2]Department of Mathematics, K. Ramakrishnan College of Technology (Autonomous), Trichy, India

Abstract

In the complex domain of real-world farm planning, agricultural decision-makers are continually confronted with a myriad of interconnected challenges, particularly in water management, crop selection, the determination of optimal crop combinations, and the effective implementation of advanced agricultural techniques to boost production and ensure sustainability. These operational hurdles are not faced in isolation; they are deeply intertwined with broader concerns of socio-economic development, such as farmer livelihoods and regional food security, and are often intensified by significant resource scarcity, especially in arid and semi-arid regions. To address these critical issues, the robust mathematical framework of linear programming (LP) offers a powerful solution, providing a systematic methodology to optimize farm returns by ensuring the most efficient allocation of available, limited resources. The primary objective of this study is to develop a linear programming model tailored to the specific agricultural context of Tiruchirappalli District, Tamil Nadu. This model is designed to identify the optimal crop combination from a set of feasible alternatives and to determine precisely how critical resources—such as land and water—can be allocated to enhance overall productivity for the farming community. The comprehensive analysis was carried out using Linear Optimization Techniques, and the resultant model was formulated and solved using the specialized LINGO software to derive a practical, actionable, and data-driven solution for the district's agricultural stakeholders. The analysis reveals that the optimal resource allocation strategy can yield a maximum achievable productivity of 786,151,300 kg for the major crops in the district.

Keywords

Linear Programming Problem, Agriculture, Optimal Solution, Decision-Making

1. Introduction

The agricultural sector, a cornerstone of global food security and socio-economic development, is increasingly under pressure from challenges such as acute water scarcity, land constraints, and the imperative to boost production for a growing population. Effective farm-level planning has become a critical determinant of success, as decision-makers must navigate these complex variables to ensure both profitability and sustainability. The efficient allocation of limited

*Corresponding author: jijisurjithds@gmail.com (Dhasaiyan Surjith Jiji)

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resources is no longer just a best practice but a fundamental necessity for survival and growth, particularly in regions heavily reliant on agriculture for their economic stability and the livelihood of their communities.

In the specific context of Indian agriculture, regions like the Tiruchirappalli District in Tamil Nadu exemplify these challenges. This area faces significant hurdles in resource management, compelling local decision-makers to grapple with complex choices regarding crop selection, viable crop combinations, and the implementation of agricultural techniques that can maximize output. These farm-level decisions are inextricably linked to the socio-economic fabric of the district, where inefficient resource allocation can stifle development, jeopardize farmer incomes, and exacerbate regional resource scarcity. Therefore, there is an urgent and clear need for a data-driven, systematic approach to optimize farm planning specifically tailored to the local agro-ecological constraints of Tiruchirappalli.

To address these multifaceted agricultural planning issues, mathematical optimization, particularly Linear Programming (LP), has emerged as a highly effective and widely accepted tool. LP provides a robust framework for determining the optimal solution for allocating resources subject to various real-world constraints. This study harnesses the power of this technique to develop a bespoke model aimed at optimizing farm returns within the Tiruchirappalli District.

The central objective of this research is to identify the optimal crop combination and resource allocation strategy that enhances production. By applying the Linear Optimization Technique and utilizing LINGO software for analysis, this paper aims to deliver a practical, efficient, and actionable solution to the region's pressing agricultural challenges.

2. Research Objectives

The primary purposes of studying Linear Programming Problem applications in agriculture includes:

Optimal Resource Allocation: LPP helps farmers allocate limited resources such as land, water, labor, and capital in the most efficient way. By optimizing the use of these resources, farmers can maximize yields or minimize costs.

Crop Planning and Selection: LPP assists in determining the optimal combination of crops to be cultivated, taking into account factors like land availability, input costs, expected profits, and environmental conditions.

Maximizing Profit or Yield: LPP helps farmers maximize their profitability or yield by developing optimal cropping patterns based on market prices, input costs, and other economic considerations.

Minimizing Environmental Impact: LPP can be used to minimize the environmental impacts of agriculture, such as reducing water usage, chemical inputs, or land degradation, while maintaining high productivity.

3. Review of Literature

This review of literature synthesizes studies related to agricultural productivity in India, the application of optimization techniques in production, and the foundational methodologies of linear programming.

The challenges and policies surrounding agricultural productivity in India have been a subject of research for decades. Chand [4] provided a comprehensive study on the relationship between development policies and agricultural productivity in India, establishing the long-standing importance of optimizing the agricultural sector for national development. This need for continuous analysis is reinforced by the ongoing publication of data by the Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, which provides the essential area, production, and yield reports that form the basis for contemporary optimization models.

Linear programming (LP) itself is a well-established and robust management tool. The foundational work of Charnes and Cooper detailed the management models and industrial applications of linear programming, cementing it as a primary method for solving resource allocation problems. This versatility is demonstrated by Akpan and Iwok, who applied LP for the optimal use of raw materials in a bakery. Their study, while not agricultural, reinforces the core principle of LP: maximizing output (or profit) from a set of limited inputs (or "raw materials"), a problem structure identical to that faced in farm planning [1, 5].

In the specific domain of agriculture, the Agricultural Economics Research Review highlights the wide-ranging applications of linear programming in agricultural production, confirming its relevance and acceptance as a standard tool for analysis in the field. However, LP is not the only optimization method available. Mariappan et al., for instance, used a different approach—Data Envelopment Analysis (DEA)—to assess the production efficiency of principal crops in India. Similarly, Maragatham et al. explored the use of Fuzzy Optimization Techniques within the production industry, demonstrating an alternative approach for handling uncertainty [6, 11-13].

These practical applications are built upon a foundation of continuous mathematical and computational refinement. For example, Ammar and Emsimir [2] contributed to the technical advancement of the field by proposing a specific mathematical model for solving integer linear programming problems, a variant of LP often required when decision variables must be whole numbers (e.g., number of machines or projects). Collectively, the literature establishes a clear precedent: optimization models are critical for production, LP is a central and historically validated tool for this purpose, and its application to Indian agriculture is a necessary and ongoing field of study.

The challenge of optimizing agricultural production is a critical area of research, particularly in resource-constrained, semi-arid regions. The literature provides a clear foundation for this study, establishing the problem's context, the importance of resource analysis, and the validity of Linear Programming (LP) as the chosen methodology. The core problem of this study is rooted in the specific challenges of semi-arid agriculture. Mkonda & He directly address this by analyzing the yields of major food crops and their implications for food security in Tanzania's semi-arid agro-ecological zone. Their work establishes the high stakes of optimizing production in such regions, linking crop yield directly to policy and regional sustainability. This focus on resource-scarce environments is further detailed by Singh et al., who investigate crop water productivity in a semi-arid region. Their study underscores the critical importance of efficient resource management—especially water—in determining productivity, a challenge central to the Tiruchirappalli district [8, 15].

To build an effective optimization model, one must first analyze the inputs required for cultivation. Owoeye et al. [11] provide a clear precedent for this, conducting an analysis of the productive resources for maize crops among farming households in Nigeria. Their research highlights the necessity of understanding the specific resource demands (such as land, labor, and capital) for each crop, which is a foundational step for any model seeking to optimize the allocation of those resources.

With the problem context and resource inputs defined, Linear Programming (LP) emerges as a robust and widely-applied methodology for optimization. Its utility in production systems is demonstrated by Oladimeji et al., who successfully applied LP for decision-making in a beverage company to optimize their production. Although in a different industry, their study validates LP as a powerful tool for achieving a maximum objective (like profit or production) from limited resources. Furthermore, the methodological soundness of LP is supported by Shek Ahmed et al. Their work explores the technical aspects of LP in decision-making models, confirming its reliability and rigor as a scientific approach for solving complex allocation problems [10, 14].

The methodology's foundation is built upon the robust mathematical framework of LP, as detailed by Taha in Operations Research: An Introduction, which provides the systematic methodology for the efficient allocation of limited resources, directly supporting the study's objective. This application is strongly validated by the work of Bhatia and Rana, who specifically utilized an LP model to successfully optimize crop allocation, a task central to the current research. Furthermore, the study aligns with contemporary trends emphasizing sustainability, referencing Guerra Rosa et al. who apply analytical approaches to optimize sustainable farm operations through linear reformulation, ensuring the resulting solution is both practical and relevant to the specific context, while also acknowledging potential implementation challenges reviewed by Molin et al. regarding the integration of digital solutions in crop production [3, 7, 9, 16].

Finally, the practical and region-specific nature of the research necessitates grounding the LP model's constraints and objective function in high-fidelity, local data, which is sourced directly from the Tiruchirappalli District Agricultural Reports for the year 2023 [17].

4. Mathematical Model

Linear Programming (LP) is a powerful mathematical method used for optimization, which means finding the best possible outcome from a given set of options. The linear part of its name refers to the fact that all relationships in the model are represented as straight-line equations or inequalities. This technique is widely used in fields like business, agriculture, and engineering to solve complex problems where the goal is to maximize a certain value, such as profit or production, or to minimize another, like cost or resource consumption. It works by taking a single, clear goal and figuring out the best way to achieve it while operating within a specific set of rules or limitations.

The general model is built on a few key components. First is the objective function, which is the mathematical expression of the primary goal (e.g., total profit) that is to be maximized or minimized. Second are the decision variables, which represent the choices that can be made (e.g., how many acres of each crop to plant). Finally, there are the constraints, which are the real-world limitations and rules (e.g., limited water, land, or budget) that restrict the decision variables. The solution to a linear programming problem is the set of values for the decision variables that satisfies all the constraints while providing the very best value for the objective function.

$$\left.Maximize\middle/_{Minimize}\right. \; Z = a_1\,x_1 + a_2\,x_2 + \cdots + a_n\,x_n \quad (1)$$

Subject to the constraints

$$b_{11}\,x_1 + b_{12}\,x_2 + \cdots + b_{1r}\,x_r + \cdots + b_{1n}\,x_n \,\{\le, =, \ge\} c_1 \quad (2)$$

$$b_{21}\,x_1 + b_{22}\,x_2 + \cdots + b_{2r}\,x_r + \cdots + b_{2n}\,x_n \,\{\le, =, \ge\} c_2 \quad (3)$$

$$b_{m1}\,x_1 + b_{m2}\,x_2 + \cdots + b_{mr}\,x_r + \cdots + b_{mn}\,x_n \,\{\le, =, \ge\} c_m \quad (4)$$

$$x_1, x_2 \ldots x_n \ge 0$$

The above model can be expressed using mathematical symbol as follows:

$$\left.Maximize\middle/_{Minimize}\right. \; Z = \sum_{j=1}^{n} a_j\,x_j \quad (5)$$

Subject to

$$\sum_{j=1}^{n} b_{ij}\,x_j \;\{\le, =, \ge\} c_i \quad (6)$$

$$x_j \ge 0 \; (for\; j = 1, 2, \ldots n)$$

5. Data Collection

This study utilizes secondary data sourced from the official 2023 reports of the Directorate of Economics and Statistics, Government of India. The dataset encompasses key agricultural metrics for the Tiruchirappalli district, including the total area, production volumes, and productivity levels for the major crops cultivated in the region. The agricultural landscape of the district is characterized by a net sown area of approximately 200,000 hectares. The analysis focuses on the primary crops—paddy, maize, groundnut, pulses, and sugarcane—which are the mainstay for the 95,800 farmers involved in their cultivation within the district.

Decision Variables

The decision variables for this linear programming model, denoted as x_1, x_2, x_3, x_4, and x_5 represent the total area of land (in hectares) allocated for the cultivation of each of the five major crops: Paddy, Maize, Groundnut, Sugarcane, and Pulses, respectively.

x_1 =Area Planted with paddy (ha)
x_2 =Area Planted with Maize (ha)
x_3 =Area Planted with Groundnut (ha)
x_4 =Area Planted with Sugarcane (ha)
x_5 =Area Planted with pulses (ha)

***Table 1**. Data for the Major Crops Cultivated in Tiruchirappalli District for the Year 2023.*

Decision Variable	**Crop**	**Area (ha)**	**Production (kg)**	**Productivity (kg/ha)**
x_1	Paddy	48,300	20,98,63,500	4,345
x_2	Maize	19,000	8,50,06,000	4,474
x_3	Groundnut	13,600	3,14,84,000	2,315
x_4	Sugarcane	6,500	44,99,95,000	69,230
x_5	Pulses	8,400	98,02,800	1,167

6. Problem Formation

The main focus of this work is maximizing the profit of the major crops with the constraints such as Land and Labor. The analysis was carried out using linear programming techniques.

***Table 2**. Data for Objective Function.*

Decision Variable	**Crop**	**Productivity**
x_1	Paddy	4,345
x_2	Maize	4,474
x_3	Groundnut	2,315
x_4	Sugarcane	69,230
x_5	Pulses	1,167

***Table 3**. Data Crop Area Constraints.*

Decision Variable	**Crop**	**Maximum Area**
x_1	Paddy	48,300
x_2	Maize	19,000
x_3	Groundnut	13,600
x_4	Sugarcane	6,500
x_5	Pulses	8,400

All the information provided in Tables 2 and 3 was used to form the linear programming model of the maximization type for the data as stated below.

Objective Function:

$$\max Z = 4345\, x_1 + 4474\, x_2 + 2315\, x_3 + 69230\, x_4 + 1167\, x_5$$

Land Availability Constraint:

$$x_1 + x_2 + x_3 + x_4 + x_5 \leq 2{,}00{,}000$$

Crop Area Constraints:

$$x_1 \leq 48300$$
$$x_2 \leq 1900$$
$$x_3 \leq 13600$$
$$x_4 \leq 6500$$
$$x_5 \leq 8400$$

Labor:

$$x_1 + x_2 + x_3 + x_4 + x_5 \leq 95800$$

Non- negativity Constraints:

$$x_1, x_2, x_3, x_4, x_5 \geq 0$$

The goal is to maximize the total productivity of the crops while adhering to the land constraints and ensuring that the areas for each crop do not exceed the cultivated amounts. This model helps in decision-making regarding crop selection and land use.

7. Result Analysis

To obtain the optimal solution for maximizing productivity in the Tiruchirappalli district, the formulated linear programming problem was solved using LINGO software. LINGO is a comprehensive and powerful tool designed specifically for building and solving complex mathematical optimization models. Furthermore, LINGO is equipped with a suite of fast, built-in solvers capable of handling a wide variety of problem types, including linear, nonlinear, and integer programming. By employing this specialized software, the model was efficiently processed to determine the precise allocation of resources that yields the maximum possible productivity.

Optimal Crop Allocation:
Paddy: 48,300 ha
Maize: 19,000 ha
Groundnut: 13,600 ha
Sugarcane: 6,500 ha
Pulses: 8,400 ha
Total Productivity:
The maximum achievable productivity is 786,151,300 kg.

8. Conclusions

This study developed a linear programming model to identify the optimal land allocation for maximizing agricultural productivity in the Tiruchirappalli district. The analysis, solved using LINGO software, reveals that the maximum achievable productivity from the five major crops is 786,151,300 kg.

An important finding is that this optimal solution is achieved when the land allocation for each crop (e.g., dy≤ 48,300ha) is at its maximum, meaning the individual crop area constraints are the binding constraints. This indicates that within the specific, land-based constraints of this model, no further improvements can be made by simply reallocating land between these crops.

However, it is critical to interpret this finding within the model's limitations. This LP model is a normative benchmark based on a single objective (maximizing physical productivity in kg) and does not account for the numerous complex factor's farmers face. Real-world decisions are rightly influenced by considerations such as market price volatility, input costs, risk preferences, crop rotation needs, and institutional constraints, which were outside the scope of this model. Therefore, the conclusion that the current allocation is "optimal" is limited to the narrow context of this specific model, and it does not represent a broad judgment on farmer efficiency.

Future research should build on this foundation. A valuable next step would be to develop a more complex, multi-objective model. Such a model could incorporate economic factors (to maximize profit, not just kg) and additional resource constraints (like water or labor) to further enhance our understanding of true sustainability and profitability in the region.

Abbreviations

LP	Linear Programming
LPP	Linear Programming Problem
DEA	Data Envelopment Analysis

Author Contributions

Arivudai Nambi Jenifer Christinal: Conceptualization, Methodology, Project administration, Supervision, Writing – review & editing

Dhasaiyan Surjith Jiji: Investigation, Software, Resources, Validation, Writing – original draft

Conflicts of Interest

The authors declare no conflicts of interest.

Appendix

Lingo Optimization software output:
LINGO/WIN64 21.0.38 (22 Apr 2025), LINDO API 15.0.6099.233

Licensee info:	Eval Use Only
License expires:	16 MAY 2026
Global optimal solution found.	
Objective value:	0.7861513E+09
Infeasibilities:	0.000000
Total solver iterations:	0
Elapsed runtime seconds:	1.95
Model Class:	LP
Total variables:	5
Nonlinear variables:	0

Integer variables:	0
Total constraints:	7
Nonlinear constraints:	0
Total nonzeros:	15
Nonlinear nonzeros:	0

Variable	Value	Reduced Cost
X1	48300.00	0.000000
X2	19000.00	0.000000
X3	13600.00	0.000000
X4	6500.000	0.000000
X5	8400.000	0.000000

Row	Slack or Surplus	Dual Price
1	0.7861513E+09	1.000000
2	0.000000	4345.000
3	0.000000	4474.000
4	0.000000	2315.000
5	0.000000	69230.00
6	0.000000	1167.000
7	0.000000	0.000000

References

[1] Akpan, N. P. and Iwok, I. A. (2016), “Application of linear programming for optimal use of raw materials in bakery.” International Journal of Mathematics and Statistics Invention, 4(8), 2321-4759.

[2] Ammar E. E. and Emsimir, A. A. (2020), “A mathematical model for solving integer linear programming problem.” African Journal of Mathematics and Computer Science Research, 13(1), 39-50. https://doi.org/10.5897/AJMCSR2019.0804

[3] Artur Guerra Rosa, Pedro Henrique Ferreira Azevedo, Victor Rafael Rezende Celestino, Silvia Araújo dos Reis, An analytical approach to optimizing sustainable farm operations through linear reformulation, Decision Analytics Journal, Volume 17, 2025, 100632, https://doi.org/10.1016/j.dajour.2025.100632

[4] Chand, R. (2012). Development Policies and Agricultural Markets. Economic and Political Weekly, 47(52), 53-63. http://www.jstor.org/stable/41720551

[5] Charnes, A. and Cooper, W. W. (1961). “Management Models and Industrial Applications of Linear Programming”. John Wiley and Sons New York.

[6] M. Maragatham, D. Surjith Jiji, P. Mariappan, Fuzzy Optimization Technique in Production Industry, Advances and Applications in Mathematical Sciences, Mili Publications, India, Volume 21, Issue 6, April 2022, Pages 3401-3406, 2022

[7] Mahak Bhatia, Anil Rana, A Mathematical Approach to Optimize Crop Allocation - A Linear Programming Model, International Journal of Design & Nature and Ecodynamics, Vol. 15, No. 2, April, 2020, pp. 245-252. https://doi.org/10.18280/ijdne.150215

[8] Mkonda, M. Y., & He, X. (2017). Yields of the Major Food Crops: Implications to Food Security and Policy in Tanzania’s Semi-Arid Agro-Ecological Zone. Sustainability, 9(8), 1490. https://doi.org/10.3390/su9081490

[9] Molin, J. P., Wei, M. C. F., & da Silva, E. R. O. (2024). Challenges of Digital Solutions in Sugarcane Crop Production: A Review. AgriEngineering, 6(2), 925-946. https://doi.org/10.3390/agriengineering6020053

[10] Oladimeji Olanrewaju Adedipupo, Lasisi Taiwo Abideen, Ogunbanwo Tolulope Samson, Fadare Ayodeji, Oluborode Kayode Oladipupo. (2022). Application of Linear Programming for Decision Making to Business in Whao Beverages Nig. Ltd. American Journal of Applied Mathematics, 10(3), 86-92. https://doi.org/10.11648/j.ajam.20221003.11

[11] Owoeye R. S., Adetule F. S., Ajayi G. T. (2017). Analysis of Productive Resources of Maize Crop Among Farming Households in Ekiti State, Nigeria. International Journal of Agricultural Economics, 2(5), 142-148. https://doi.org/10.11648/j.ijae.20170205.11

[12] P. Mariappan, A. Jenifer Christinal and Dinesh S. Dave, Assessing production efficiency of principal Crops in India: A DEA approach, Our Heritage. Vol 68, Issue 4, Jan 2020.

[13] S M Rahaman, B K Bera, Subhadip Pal, A K Nandi, & Surajit Haldar. (2023). Countering vulnerability and enhancing resilience: coastal agriculture in West Bengal, India. Agricultural Economics Research Review, 34(2), 179-191.

[14] Shek AhmedDepartment of Mathematics, University of Barishal, Barishal, Jakia Sultana, Tanzila Yeasmin Nilu, et al. (2021). Sensitivity Analysis of Linear Programming in Decision Making Model. International Journal of Theoretical and Applied Mathematics, 7(3), 53-56. https://doi.org/10.11648/j.ijtam.20210703.12

[15] Singh, P., Sehgal, V. K., Dhakar, R., Neale, C. M. U., Goncalves, I. Z., Rani, A., Jha, P. K., Das, D. K., Mukherjee, J., Khanna, M., & Dubey, S. K. (2024). Estimation of ET and Crop Water Productivity in a Semi-Arid Region Using a Large Aperture Scintillometer and Remote Sensing-Based SETMI Model. Water, 16(3), 422. https://doi.org/10.3390/w16030422

[16] Taha, H. A. (2017). Operations Research: An Introduction (10th ed.). Pearson Education.

[17] Tiruchirappalli District Agricultural Reports. (2023). Data on crop cultivation, area, production, and productivity for the year 2023. Directorate of Economics and Statistics, Tamil Nadu.

Research Field

Arivudai Nambi Jenifer Christinal: Differential Calculus, Mathematical Modeling, Operations Research, Decision-Making, Optimization Techniques.

Dhasaiyan Surjith Jiji: Fuzzy Mathematics, Fuzzy Set Theory, Mathematical Modeling, Operations Research, Fuzzy Modeling.