**Optimal Cropping Pattern for Economic Sustainability Using Linear Programming Model**

**Abstract**

Agriculture remains the backbone of rural livelihoods, yet farmers often face challenges in maximizing income due to traditional cropping patterns and resource limitations. This study focuses on Optimal Cropping Pattern for Economic Sustainability through the lens of Profit optimization, using Piplav village in Anand district as a case study. Linear Programming (LP) Model methodology was applied to select an optimal cropping pattern that enhances farm profitability while considering constraints such as land availability, labour, and input costs. Primary data were collected through field surveys and the LP model was designed to identify the most economically viable crop combinations. Results demonstrate that by adopting the optimized cropping pattern, farmers can significantly increase their net income compared to existing practices. The study highlights the potential of mathematical programming as a practical decision-making tool for rural farmers, encouraging a shift toward more sustainable and profitable agricultural systems. These findings offer valuable insights for policymakers, extension workers, and farming communities aiming to strengthen economic resilience in the agricultural sector.

In future research, methods such as multi-objective programming and advanced computational models could be employed to address a broader range of variables, including environmental sustainability, rainfall variability, and changing market trends. Additionally, optimization techniques based on artificial intelligence will be explored to enhance the accuracy and adaptability of solutions under real-world field conditions. These approaches aim to develop more robust and practical strategies for crop planning, thereby supporting sustainable agricultural development.

**Key Words: Optimal** Cropping Pattern, Net Profit, , Linear Programming Model and Optimization

**Introduction:**

India is a predominant agrarian economy with 40% of the population involved in agriculture, either directly or indirectly. However, despite this reliance, the sector remains technologically and economically underdeveloped. Crop productivity per unit area remains significantly lower compared to global standards, largely due to traditional agricultural practices that have not evolved substantially over time (Bojang et al., 2016). Historically, fragmented landholdings and individual farmers relying on inherited methods passed down through generations have characterized Indian agriculture.(Kumar and Boraiah, 2022; Chakravorty et al, 2016)

One of the major challenges confronting smallholder farmers is the efficient allocation of limited agricultural resources (Najafabadi et al., 2019). While the primary goal remains income maximization within the constraints of available land, labour, and capital, decision-making is often guided by experiential knowledge, heuristics, and trial-and-error approaches. Although intuitive, such methods rarely lead to optimal outcomes.To address this gap, the present study employs a mathematical optimization framework designed to support rational planning in crop selection (Mardani Najafabadi & Ashktorab, 2023). The model identifies optimal cropping patterns aiming to enhance income under given constraints. The results derived from the optimization model are benchmarked against outcomes achieved through traditional decision-making approaches (Darzi-Naftchali et al., 2024). Empirical findings reveal that the model-based strategies significantly outperform conventional methods in terms of profitability, underscoring the potential of decision-support tools in resource-limited farming systems (Singh et al., 2023). This research highlights how data-driven agricultural planning can facilitate better income generation and resource efficiency in rural farming communities.

**Methodology:**

This study is based on primary data collected from small-scale farmers in Piplav village, situated in SojitraTaluka of Anand District, Gujarat.

The initial steps involved reaching out to the Sarpanch of Piplav village to facilitate the selection of farmers for the study. With the support of the Sarpanch, Piplav village a total of 30 farmers were randomly chosen using stratified random sampling method, ensuring equal representation from marginal, small, and semi-medium landholding groups 10 from each category. Following the selection, detailed information on current cropping patterns, available resources, and income levels was gathered using a structured questionnaire. The data were collectd for the year 2024. The collected data formed the basis for the development of an optimization model using Linear Programming (LP) to identify strategies for maximizing farm income under specific constraints.

The model involves decision variables that represent crop choices, which are optimized to maximize income. In its standard matrix representation, an LP Model can be expressed as:

$$Maximize C^{T}X$$

$$Subject to AX\leq =\geq B$$

Here, X is the vector of decision variables, C is the vector of objective coefficients (profit in Lakhs per unit area for each crop), A is the matrix of coefficients representing resource usage, and B is the vector representing available resources such as land, labour, or capital (; Elenchezhian et al., 2023). In this study, **Lingo 21.0.37 optimization software** was utilized to solve the formulated LP model.

The optimization model was developed for a one-year planning horizon, divided into two major agricultural seasons based on regional climatic norms: Kharif (Monsoon): June to October and Rabi (Winter): Late September to March/April.The LP model was constructed under normal agro-climatic conditions with the following considerations:

1. Onset of monsoon by mid-June.

2. Weekly rainfall ranging between 15-40 mm during the monsoon.

3. Absence of heavy rainfall from late September through October, and during February-March.

4. Uninterrupted availability of labor during critical farming operations (pre-harvest, harvest, and post-harvest).

5. Adequate access to quality seeds and fertilizers

**Objective Function for Net Profit Maximization:**

In order to maximize net profit, the central task involves optimal allocation of the total cultivable land among different crops. The goal is to determine the most profitable combination of crop areas that yields the highest net profit within the given resource constraints. Accordingly, the objective function in this linear programming model is expressed as:

$$Maximize Z=1.86847x\_{11}+0.93423x\_{12}+0.62282x\_{21}+1.12108x\_{22}$$

Here, $x\_{ij}$represents the area allocated (in hectares or relevant unit) to the $j^{th}$ crop in the $i^{th}$ season. The coefficients correspond to the net profit per unit area from each cropping option. The aim is to achieve a configuration that ensures maximum economic returns from land utilization across seasons.

**Constraint:**

**Total Crop Yield Requirement:**

To ensure a sufficient aggregate harvest, a constraint is established to guarantee that the total production across all cultivated crops meets or exceeds a specified yield threshold. This constraint is derived by calculating the product of the land area allocated to each crop and its corresponding expected yield per unit area for the given season. The cumulative result must not fall below the predefined minimum yield requirement for the farming system. Mathematically, the constraint is expressed as:

$$75x\_{11}+63x\_{12}+62x\_{21}+78x\_{22}\geq 3268.5$$

In this equation, the coefficients of$x\_{ij}$ represent the estimated yield (in quintals or tons per hectare) of each crop per season, while the variables $x\_{ij}$​ represent the allocated land area for each crop-season combination.

**Labour Availability:**

Labour is an essential input in agriculture, required at various stages throughout the cropping calendar. To ensure that labour demands do not exceed the total available workforce, a constraint is incorporated into the model. This condition ensures that the cumulative labour requirements calculated by multiplying the labour cost for each crop in a given season by the area allocated to that cropremain within the bounds of annual labour availability. The constraint is mathematically stated as:

$$0.4488x\_{11}+0.15x\_{12}+0.15x\_{21}+0.2444x\_{22}\leq 13.884$$

Here, the coefficients are represent the cost of estimated labour demand per unit area for each crop during its respective season. ( Srivastava et al., 2020; **Supriya et al. 2022**)

**Budget constraint for Pesticides and Fertilizers:**

Achieving optimal crop yield requires consistent application of fertilizers and pesticides throughout the crop cycle. However, due to the financial limitations of smallholder farmers, a constraint must be introduced to ensure that the total variable cost on these inputs does not exceed the allocated budget. This constraint is formulated by multiplying the required cost for each crop by the corresponding land area under cultivation, ensuring the total remains within the available financial limits. The expression is as follows:

$$0.23x\_{11}+0.04484x\_{12}+0.0492x\_{21}+0.12705x\_{22}\leq 6.6295$$

In this inequality, the coefficients indicate the costof pesticide and fertilizer application for each crop-season combination. (**Supriya et al., 2022**)

**Availability of Cultivable Land:**

The land area that can be utilized for cultivation during a given season is subject to a natural upper limit. To ensure sustainable planning, the combined area allocated to all selected crops must not surpass this available cultivable land. Accordingly, the model includes the following constraint to reflect this limitation

$$x\_{11}+x\_{12}+x\_{21}+x\_{22}\leq 51.5$$

Ensuring that total land usage remains within the bounds of the land resource available for agricultural activities(Upadhyaya & Roy, 2019).

**Constraints on Seed cost:**

Farmers often prioritize the quality of seeds over their associated costs, considering it a crucial investment for ensuring good yield. As a result, seed expenses are typically not a limiting factor in land allocation decisions. This behavior leads to the formulation of a constraint that ensures seed costs are accounted for but not necessarily minimized, represented as:

$$0.0872x\_{11}+0.0623x\_{12}+0.0249x\_{21}+0.07473x\_{22}\geq 0$$

which reflects the inclusion of seed expenditure in the planning model without imposing a strict upper limit.(**Supriya et al., 2022**)

**Constraints on Machine Cost:**

Agricultural operations such as ploughing, sowing, tilling, harvesting, and cultivating rely heavily on the use of machinery. These mechanized activities involve costs that need to be considered when planning crop allocations. To ensure machine-related expenses remain within the allowable limit, the following constraint is incorporated into the model:

$$0.03736x\_{11}+0.02491x\_{12}+0.02491x\_{21}+0.06228x\_{22}\leq 1.94943$$

which ensures that the total machinery cost for all crop activities does not exceed the predefined budget.( **Supriya et al., 2022; Zhang et al., 2020**)

**Constraints on Irrigation Cost:**

Water availability is a vital component for successful crop production throughout the growing season. Adequate irrigation not only influences the overall crop yield but also has a direct impact on farm profitability. To account for the expenditure on irrigation, a constraint is incorporated in the model as follows:

$$0.06228x\_{11}+0.03736x\_{12}+0.03736x\_{21}+0.03736x\_{22}\leq 2.36049$$

ensuring that total irrigation costs across all crop allocations stay within the allowable limit set for water usage expenses.

**1.4. Case Study**

This case study was undertaken in Piplav, a rural settlement situated in SojitraTaluka within the Anand district of Gujarat. Geographically, the village is located approximately 23 kilometers west of Anand town and around 90 kilometers from Gandhinagar, the capital of Gujarat. The village comprises roughly 1056 households, with a total population of about 5000 individuals 2638 males and 2362 females.(Census, 2011)

The predominant soil type in Piplav is alluvial specifically classified as Goradu or sandy loam with medium fertility. The village supports the cultivation of a variety of crops including tobacco, paddy, banana, pearl millet, wheat, potato, and a range of vegetables and fruits. Integrated farming systems that combine crop cultivation with livestock and poultry operations have been identified as potentially more profitable for local farmers.

For this study, an area of 51.5 hectares was analyzed, encompassing land used for cultivating tobacco, wheat, pearl millet, and rice. The anticipated gross returns per hectare were estimated as follows: Rs. 1.868 lakh from tobacco, Rs. 0.934 lakh from wheat, Rs. 0.622 lakh from pearl millet, and Rs. 1.121 lakh from rice. The prevailing crop allocation strategy included 17.5 hectares for tobacco, 9.5 hectares for wheat, 12.5 hectares for pearl millet, and 12 hectares for rice, resulting in a total gross income of Rs. 63.059 lakhs.

Data used in this case study were collected from 30 local farmers through structured questionnaires. This included detailed information on land use, crop yields, input costs (seeds, labor, fertilizer, machinery, irrigation), and annual cropping schedules.

**Table 1** outlines the resource utilization under the current cropping plan, while **Table 2** presents the existing cropping pattern and its associated gross income as reported by the farmers.

Table-1: Resource Utilization during the Cropping suggested by farmers plan

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Crop Name | Land (ha) | Seed Cost(Rs.) | Labour Cost (Rs.) | Fertilizer Cost (Rs.) | Machine Cost (Rs.) | Irrigation Cost (Rs.) | Yield(Quintal/Ha) | Yield(Quintal) |
| Tobacco | 17.5 | 1,52,600 | 7,85,400 | 4,02,500 | 65,396 | 1,08,994 | 75 | 1312.5 |
| Wheat | 9.5 | 59,185 | 1,42,500 | 42,598 | 23,667 | 35,501 | 63 | 598.5 |
| Pearl millet | 12.5 | 29,880 | 1,80,000 | 59,040 | 31,141 | 46,711 | 62 | 780 |
| Rice | 12 | 93,412 | 2,80,500 | 1,58,812 | 74,739 | 44,843 | 78 | 937.5 |

Table-2: Cropping pattern suggested by the farmers and gross income

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Crop Name | Tobacco (ha) | Wheat (ha) | Pearl millet (ha) | Rice (ha) |
| Crop Land | 17.5 | 9.5 | 12.5 | 12 |
| Production(Quintal) | 1312.5 | 598.5 | 780 | 937.5 |
| Total Income (Lakh) | 32.698 | 8.875 | 7.473 | 14.013 |
| Gross Income (Lakh) | 63.059 |  |  |  |

**1.5. Result and Discussion:**

The linear programming (LP) model developed for optimizing land use in Piplav village was implemented using **Lingo 21.0.37.** optimization software. The objective was to identify a crop combination that would maximize gross annual income under the constraints of available resources.

The output generated by the LP model, as detailed in **Table 3**, proposed an optimal allocation of land as follows: 17.51 hectares for tobacco, 24.18 hectares for wheat, 9.81 hectares for rice, and notably, **no land allocated to pearl millet.** This cropping combination was determined to offer the **maximum gross return of Rs. 66.30 lakhs**, indicating a potential income increase when compared to the existing farmer-suggested plan, which yielded Rs. 63.059 lakhs.

This revised plan reflects a strategic shift towards crops with relatively higher profitability per unit area and better resource efficiency, such as wheat and tobacco. The exclusion of pearl millet suggests its lower economic return or resource inefficiency under the given constraints. These results highlight the significance of optimization models in supporting data-driven agricultural decision-making, especially in regions with limited resources and diverse crop options.

**Table 3** presents the resource consumption under the optimized cropping system, while **Table 4** outlines the revised cropping pattern as recommended by the LP model.

Table-3: Cropping pattern suggested by LP Model and gross income

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Crop Name | Tobacco (ha) | Wheat (ha) | Pearl millet (ha) | Rice (ha) |
| Crop Land(ha) | **17.51** | **24.18** | **0** | **9.81** |
| Production(Quintal) | 1313.25 | 1523.34 | 0 | 766.40 |
| Total Income (Lakh) | 32.71 | 22.59 | 0 | 11.00 |
| Gross Income (Lakh) | **66.30** |  |  |  |

Table-4: Resource Utilization during the Cropping suggested by LP model

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Crop Name | Land (ha) | Seed Cost(Rs.) | Labour Cost (Rs.) | Fertilizer & Pesticide Cost (Rs.) | Machine Cost (Rs.) | Irrigation Cost (Rs.) | Yield(Quintal) |
| Tobacco | **17.51** | 1,52,687 | 7,85,848 | 4,02,730 | 65,433 | 1,09,056 | 1313.25 |
| Wheat | **24.18** | 1,50,641 | 3,62,700 | 1,08,423 | 60,238 | 90,356 | 1523.34 |
| Pearl millet | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Rice | **9.81** | 76,364 | 2,29,308 | 1,29,828 | 61,099 | 36,659 | 766.40 |



Fig.1: Solution of the LP model using Lingo 21.0.37 optimization software

Table-5: Solution of the LP model by using Excel solver 2007

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Variable |  | X11 | X12 | X21 | X22 |  |  |
| Coefficient |  | 1.86847 | 0.93423 | 0.62282 | 1.12108 |  |  |
| Solution |  | **17.51404** | **24.17872** | **0** | **9.807239** |  |  |
| Max Z |  | **66.30765** |  |  |  |  |  |
| Constraint1 | Yield | 75 | 63 | 62 | 78 | > = | 3268.5 |
| 2 | Labour | 0.4488 | 0.15 | 0.15 | 0.2444 | < = | 13.884 |
| 3 | Fertilizer | 0.23 | 0.04484 | 0.0492 | 0.12705 | < = | 6.6295 |
| 4 | Land Availability | 1 | 1 | 1 | 1 | < = | 51.5 |
| 5 | Seed | 0.0872 | 0.0623 | 0.0249 | 0.07473 | > = | 0 |
| 6 | Machinery | 0.03736 | 0.02491 | 0.02491 | 0.06228 | < = | 1.94943 |
| 7 | Irrigation | 0.06228 | 0.03736 | 0.03736 | 0.03736 | < = | 2.36049 |
|  | LHS | RHS |  |  |  |  |  |
| 1 | 3572.355 | 3268.5 |  |  |  |  |  |
| 2 | 13.884 | 13.884 |  |  |  |  |  |
| 3 | 6.358414 | 6.6295 |  |  |  |  |  |
| 4 | 51.5 | 51.5 |  |  |  |  |  |
| 5 | 3.766454 | 0 |  |  |  |  |  |
| 6 | 1.867411 | 1.94943 |  |  |  |  |  |
| 7 | 2.36049 | 2.36049 |  |  |  |  |  |

Table-6: Comparison of LP model with the farmer’s plan

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Farmers Plan** | **LP Model** | **Difference** | **Percentage** |
| **Seed Cost** | 3,35,077 | 3,76,645 | 41,568 |  |
| **Labour Cost** | 13,88,400 | 13,88,400 | 0 |  |
| **Mechanical Cost** | 1,94,943 | 1,84,741 | 10,202 |  |
| **Fertilizer/Pesticide Cost** | 6,62,950 | 6,35,841 | 27,109 |  |
| **Irrigation Cost** | 2,36,049 | 2,36,049 | 0 |  |
| **Gross Income** | 63,05,900 | 66,30,765 | 3,24,865 |  |
| **Net Profit** | **34,88,481** | **38,09,089** | **3,20,608** | **9.19%** |

The findings from this study clearly demonstrate the advantages of applying a Linear Programming (LP) model for crop planning and land allocation. When compared with the conventional cropping plan followed by farmers, the LP-based approach yielded a **net profit of Rs. 38, 09,089**, which is approximately **9.19% higher** than the **Rs. 34, 88,481** generated under the traditional plan. This improvement in profitability underscores the efficiency of optimized resource allocation.

A closer look at input cost variations reveals that the LP model resulted in a **reduction in labour expenses by 4.08%** and **irrigation costs by 4.20%**, indicating better utilization of human and water resources. However, seed expenses rose by **12.40%**, which can be attributed to the shift towards higher-yield or higher-value crops, justifying the increased investment.

The optimal cropping plan recommended by the LP model allocates land as follows: **34% to tobacco**, **47% to wheat**, **19% to rice**, and **excludes pearl millet** entirely. This configuration aligns with the economic returns per hectare and resource constraints observed in the region.

**1.6. Conclusion:**

In conclusion, the LP-based model proves to be a robust tool for improving farm profitability and resource management in Piplav village. Its adoption can support more informed and sustainable agricultural planning, especially in areas with diverse crop options and limited resources.

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