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# Linear programming in the planting of sunflower, sesame and sorghum at Agrícola Olivo, C.A.

## Programación lineal en la siembra de girasol, ajonjolí y de sorgo en Agrícola Olivo, C.A.

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**Abstract**

This study aimed to determine the benefits of using linear programming and post-optimal analysis to improve operational resources and maximize the economic benefit of the Olivo Agricultural Production Unit, C.A., through the efficient distribution of sunflower, sesame, and sorghum planting areas. This led to an investigation of the effects of integrating both linear programming and post-optimal analysis on resource optimization at the Olivo Agricultural Production Unit, C.A. Methodologically, yield and investment data were collected through an interview with the producer, and a mathematical maximization model was designed and implemented using WinQSB software. The results showed that the initial optimal solution requires planting 48 hectares of sunflower, 36 hectares of sesame, and 6 hectares of sorghum; this maximizes profit to Bs. 6,621,469.00 across the 90 cultivated hectares, satisfying all operational constraints. Mathematical modeling is a strategic management tool that mitigates risk and uncertainty, providing scientific certainty for decision-making in agricultural production management.

**Keywords:** Mathematical models, agricultural management, decision-making, agricultural production, resource allocation.

**Resumen**

Determinar los beneficios del uso de la programación lineal y el análisis post-optimal en la mejora de recursos operativos, además de la maximización del beneficio económico de la Unidad de Producción Agrícola Olivo, C.A., a través de la distribución eficiente de la superficie de siembra de girasol, ajonjolí y sorgo. Esto llevó a estudiar los efectos de la integración tanto de la programación lineal como del análisis post-optimal en el afinamiento de recursos en la Unidad de Producción Agrícola Olivo, C.A. Metodológicamente, se recolectaron datos de rendimiento e inversión mediante una entrevista al productor y se diseñó un modelo matemático de maximización ejecutado con el software WinQSB. Los resultados demostraron que la solución óptima inicial exige la siembra de 48 hectáreas de girasol, 36 de ajonjolí y 6 de sorgo; con ello se maximiza la ganancia a 6.621.469,00 Bs. en las 90 hectáreas cultivadas, satisfaciendo la totalidad de las restricciones operativas. La modelación matemática es una herramienta gerencial estratégica que mitiga el riesgo y la incertidumbre, proveyendo certezas científicas para la toma de decisiones en la gestión de la producción agrícola.

**Palabras clave:** Modelos matemáticos, gestión agrícola, toma de decisiones, producción agrícola, asignación de recursos.

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## Introduction

Agriculture is understood, according to the *Dictionary of the Spanish Language* (Real Academia Española, 2024), as the “set of techniques and knowledge related to the cultivation of land” (para. 2). It represents one of the most significant and impactful activities in the consolidation of humankind as a social and cultural being; its emergence is associated with the transition from nomadism to the establishment of the first human settlements and with the development of societies and culture. More recently, in 2024, the Organisation for Economic Co-operation and Development (OECD) and the Food and Agriculture Organization of the United Nations (FAO) stated that agriculture is a fundamental economic, social, and environmental activity for humankind; it provides food, clothing, housing, recreation, as well as human, economic, and social development. It is important to note that the dynamics generated by current agricultural development demand an immediate shift towards sustainability and global food security in the face of climate change, leading agricultural producers to implement precision management systems based on *big data* (Benini et al., 2025; Castillo Ortiz et al., 2025).

The inherent characteristics of agricultural production tend to directly affect its productivity, competitiveness, and profitability in the global market (OECD/FAO, 2024). Among these determining factors, seasonality is particularly significant, since planting and harvesting periods are inextricably linked to crop growth cycles and annual climatic variations (Secretaría de Agricultura y Desarrollo Rural [SADER], 2016). Although these effects can be counteracted through the use of technology, it is more profitable to take advantage of natural conditions to produce different crops suited to each cycle.

In addition, the geographical dispersion characteristic of rural areas considerably increases logistics, storage, transportation, and commercial distribution costs. Multidimensional risk must also be considered, as well as biological uncertainty—arising from pests or environmental volatility—which ultimately generates dramatic fluctuations in crop yields and quality (SADER, 2016; OECD/FAO, 2024). Recent research argues that the relationship between market price instability and extreme weather events calls for proactive approaches capable of predicting adverse scenarios before they affect the financial viability of farms (Liu & Hu, 2025; Wang et al., 2025).

Hence the importance of linear programming as a mathematical modelling technique which, in the words of Ramírez et al. (2022), seeks to “obtain a response to decision-making problems faced by entrepreneurs, considering it a key tool for organizations in reducing costs and maximizing economic profitability” (p. 3), as is the case with agriculture and agricultural production. Methodologically, linear programming seeks to guide the decision-making process regarding the distribution or allocation of, as González and García (2015) explain, “a fixed quantity of resources to satisfy several demands, in such a way that while one objective is optimized, other defined conditions are satisfied” (p. 18). Applied studies show that linear modelling outperforms decisions based on intuition or traditional heuristics, achieving profit margins more than 12% higher through a specific allocation of cultivable land per hectare (Sandmann et al., 2025).

It is important to note that post-optimal analysis and stochastic models support and strengthen the resilience of the agricultural sector under the *ceteris paribus* principle—modifying one variable at a time—giving decision-makers the opportunity to assess the sensitivity of the system to external financial or technical variations (Alvarado-Boirivant, 2013; Wang et al., 2025). The management of contemporary Agricultural Production Units (APUs) entails computational complexity, which in turn involves algorithmic matrices; this justifies the incorporation of advanced technological tools and operations research software packages such as LINGO or WinQSB (Universidad de Valencia, 2010; Sandmann et al., 2025). WinQSB (*Quantitative Systems for Business*) is “an interactive decision-support system containing highly useful tools for solving different types of problems in the field of operations research” (Universidad de Valencia, 2010, p. 1).

Alongside this scientific framework, the study provides a practical analysis of the operational optimization of the Agrícola Olivo, C.A. Agricultural Production Unit, a

90-hectare enterprise located in Turén Municipality, Portuguesa State, Venezuela. The administrative management faces the need to calculate the optimal annual allocation of land for sunflower (*Helianthus annuus*), sesame (*Sesamum indicum L.*), and sorghum (*Sorghum bicolor L.*) crops in order to maximize economic profit.

The mathematical maximization model uses the technical coefficients obtained from a field interview conducted on February 25, 2025, with producer Alfredo Aguin, a member of the Turén Rural Producers Association (ASOPRUAT) and owner and administrator of Agrícola Olivo, C.A.

- Sesame (FONUCLA variety) yields 450 kg/ha and requires an investment of Bs. 3,900.00.
- Sunflower (Charrúa variety) yields 500 kg/ha at a cost of Bs. 1,100.00.
- Sorghum (hybrid variety) yields 2,700 kg/ha and requires an investment of Bs. 1,014.00.

The operational environment is constrained by a net budget of Bs. 200,000.00 from private financing. Commercial prices regulated by ASOPRUAT—Bs. 120.00/kg for sunflower, Bs. 230.00/kg for sesame, and Bs. 12.50/kg for sorghum—and the minimum company delivery quotas of 16,000 kg to state-owned agro-industrial enterprises constitute fundamental constraints on the system, determining the feasibility of obtaining critical agricultural inputs from Agropatria.

Accordingly, the objective of this study was to determine the benefits of using linear programming and post-optimal analysis to improve the management of operational resources, as well as to maximize the economic profit of the Agrícola Olivo, C.A. Agricultural Production Unit through the efficient allocation of planting areas for sunflower, sesame, and sorghum.

## Methodology

In order to allocate resources efficiently and maximize the profit of the Agrícola Olivo, C.A. Agricultural Production Unit (APU), a Linear Programming Problem (LPP) mathematical model was developed, comprising three quantitative decision variables:

**W** = hectares (ha) to be planted with sunflower (*Helianthus annuus*).

**X** = hectares (ha) to be planted with sesame (*Sesamum indicum L.*).

**Y** = hectares (ha) to be planted with sorghum (*Sorghum bicolor L.*).

A summary of the variables is presented in Table 1.

**Table 1.** Sunflower, Sesame, and Sorghum Value.

| Variables | Yield (kg/ha) | Costs (Bs./ha) | Price (Bs./kg) |
|---|---|---|---|
| Sunflower (W) | 500 | 1,100 | 120 |
| Sesame (X) | 450 | 3,900 | 230 |
| Sorghum (Y) | 2,700 | 1,014 | 12.50 |

The coefficients of the objective function were calculated by deducting the operating production costs per hectare from the estimated gross revenue (the product of the average yield and the delivery price established by ASOPRUAT).

The objective function for maximizing profit (Z), together with its corresponding institutional, financial, and land constraints, is detailed below:

1st Equation. Profit Maximization

$$\text{Profit} = F(w,x,y)$$

$$\text{Revenue} = 120 \text{ Bs./kg} \times 500 \text{ kg/ha} \times W(\text{ha}) + 230 \text{ Bs./kg} \times 450 \text{ kg/ha} \times X(\text{ha}) + 12.50 \text{ Bs./kg} \times 2{,}700 \text{ kg/ha} \times Y(\text{ha})$$

$$\text{Expenses} = 1{,}100 \text{ Bs./ha} \times W(\text{ha}) + 3{,}900 \text{ Bs./ha} \times X(\text{ha}) + 1{,}014 \text{ Bs./ha} \times Y(\text{ha})$$

$$\text{Profit} = \text{Revenue} - \text{Expenses}$$

$$F(w,x,y) = 120 \times 500W + 230 \times 450X + 12.50 \times 2{,}700Y - 1{,}100W - 3{,}900X - 1{,}014Y$$

$$F(w,x,y) = 120 \times 500W - 1{,}100W + 230 \times 450X - 3{,}900X + 12.50 \times 2{,}700Y - 1{,}014Y$$

The coefficients of the objective function were calculated by deducting the operating production costs per hectare from the estimated gross revenue (the product of the average yield and the delivery price established by ASOPRUAT).

The objective function for maximizing profit (Z), together with its corresponding institutional, financial, and land constraints, is detailed below:

2nd Equation. Objective Function

Maximize Profit: $Z = F(w,x,y) = 58{,}900W + 99{,}600X + 32{,}736Y$ Bs.

Constraints:

| | |
|---|---|
| APU area (ha) | $W + X + Y \leq 90$ |
| Investment capital (Bs.) | $1{,}100W + 3{,}900X + 1{,}014Y \leq 200{,}000$ |
| ASOPRUAT sunflower production requirement (kg) | $500W \geq 16{,}000$ |
| ASOPRUAT sorghum production requirement (kg) | $2{,}700Y \geq 16{,}000$ |
| Non-negativity | $W; X; Y \geq 0$ |

## Results

After applying the WinQSB software package and correctly formulating the objective function, results were obtained that made it possible to precisely determine the optimal solution, as presented in Table 2.

The following solution values were obtained:

Sunflower (W) = 48 ha

Sesame (X) = 36 ha

Sorghum (Y) = 6 ha

Z = 6,621,469.00 Bs.

Data obtained directly from the WinQSB Combined Simplex Analysis Report.

The execution of the algorithm yielded an optimal Z value—representing the maximum attainable profit—of Bs. 6,621,469.00 if Agrícola Olivo, C.A. plants 48 ha of sunflower, 36 ha of sesame, and 6 ha of sorghum. The administrative management of Agrícola Olivo, C.A. estimates that this profit would meet shareholders' expectations, representing a return of 3,310.73% on the net investment of Bs. 200,000.00 required to cultivate the entire 90-ha area.

This would make it possible to cover APU maintenance expenses until the next harvest period, pay taxes, and distribute profits.

The optimal Z value is equivalent to a net profit of Bs. 6,621,469.00 from the 90 hectares planted. From the financial perspective of the administrative management, this profit fully meets shareholders' expectations, representing a return of 3,310.73% on the initial net investment capital (Bs. 200,000.00). This is supported by the sensitivity analysis presented in Table 3.

**Table 2.** Combined Simplex Analysis Report of the LPP in WinQSB.

| Variable | Crop | Optimal Solution (ha) | Unit Cost (Bs./ha) | Average Yield (kg/ha) | Selling Price (Bs./kg) | Net Contribution to Profit (Z) |
|---|---|---|---|---|---|---|
| W | Sunflower | 48 | 1,100.00 | 500 | 120 | 2,816,636.00 Bs. |
| X | Sesame | 36 | 3,900.00 | 450 | 230 | 3,610,843.00 Bs. |
| Y | Sorghum | 6 | 1,014.00 | 2,700 | 12.5 | 193,991.00 Bs. |
| Objective | Z Function | 90.00 ha | — | — | — | 6,621,469.00 Bs. |

**Table 3.** Sensitivity Analysis by Variable.

| Variable | Crop | Optimal Solution (ha) | Unit Cost or Profit | Minimum Allowable | Maximum Allowable |
|---|---|---|---|---|---|
| W | Sunflower | 48 | 58,900.00 | 34,728.00 | 99,600.00 |
| X | Sesame | 36 | 99,600.00 | 58,900.00 | 208,827.00 |
| Y | Sorghum | 6 | 32,736.00 | −M | 57,650.00 |

An analysis of the variables—hectares to be planted with sunflower (W), hectares to be planted with sesame (X), and hectares to be planted with sorghum (Y)—shows the following:

- To maintain the profit-maximization function obtained, it is necessary to consider that the variable representing hectares planted with sunflower (W), with a return of Bs. 58,900.00 per ha, can be reduced only to a minimum of Bs. 34,728.00 per ha. If it falls below this value, the maximum profit would no longer be maintained.
- With regard to the variable representing hectares planted with sesame (X), which yields a return of Bs. 99,600.00 per ha, the profit-maximization function obtained is maintained with returns ranging from a minimum of Bs. 58,900.00 per ha to a maximum of Bs. 208,827.00 per ha. Outside this range, the profit-maximization function would be compromised.

For these three variables, neither the minimization nor maximization alternatives are considered plausible because these are crops whose profit in Bs. is related to average yields in kg/ha, which cannot be reduced or increased unless affected by natural factors (rainfall, pests) or technical factors (lack of inputs, technological changes), among other factors.

Table 4 details the application of the constraints to the sensitivity analysis.

**Table 4.** Sensitivity Analysis by Constraint.

| Constraint | Shadow Price | Right-Hand Side | Minimum Allowable | Maximum Allowable |
|---|---|---|---|---|
| APU area (ha) | 42,911 | 90 | 79 | 82 |
| Investment capital (Bs.) | 15 | 20,000.00 | 98,490.00 | 244,298.00 |
| ASOPRUAT sunflower production requirement (kg) | 0 | 16,000.00 | −M | 23,910.00 |
| ASOPRUAT sorghum production requirement (kg) | −9 | 16,000.00 | 0 | 57,443.00 |
| Non-negativity | ≥ | ≥ | ≥ | ≥ |

Analysis of Constraint Compliance:

3rd Equation. Constraint 1. APU Area (ha) =

$W + X + Y \leq 90$

48 ha to be planted with sunflower (W) + 36 ha to be planted with sesame (X) + 6 ha to be planted with sorghum (Y) ≤ 90 ha

The constraint is satisfied.

4th Equation. Constraint 2. Investment Capital (Bs.) = $1{,}100W + 3{,}900X + 1{,}014Y \leq 200{,}000$

48 ha to be planted with sunflower (W) × 1,100 Bs./ha = 52,800 Bs. +

36 ha to be planted with sesame (X) × 3,900 Bs./ha = 140,400 Bs. +

6 ha to be planted with sorghum (Y) × 1,014 Bs./ha = 6,084 Bs.

52,800 Bs. + 140,400 Bs. + 6,084 Bs.

= 199,284 Bs. ≤ 200,000 Bs.

The constraint is satisfied

5th Equation. Constraint 3. ASOPRUAT Sunflower Production Requirement (kg) = $500W \geq 16{,}000$

48 ha to be planted with sunflower (W) × 500 kg/ha = 24,000 kg ≥ 16,000 kg

The constraint is satisfied.

6th Equation. Constraint 4. ASOPRUAT Sorghum Production Requirement (kg) = $2{,}700Y \geq 16{,}000$

6 ha to be planted with sorghum (Y) × 2,700 kg/ha = 16,200 kg ≥ 16,000 kg

The constraint is satisfied.

7th Equation. Constraint 5. Non-negativity =

W; X; Y ≥ 0

48 ha to be planted with sunflower (W) ≥ 0

36 ha to be planted with sesame (X) ≥ 0

6 ha to be planted with sorghum (Y) ≥ 0

The constraint is satisfied.

The mathematical verification of compliance with the constraints demonstrated the feasibility of the model:

Area constraint: All 90 available hectares were used (48 + 36 + 6 = 90), indicating that no land remained idle (slack = 0).

Capital constraint: The total consolidated investment amounted to Bs. 199,284.00 (52,800 + 140,400 + 6,084), leaving a positive budgetary slack of Bs. 716.00 relative to the Bs. 200,000.00 limit.

ASOPRUAT constraints: Sunflower production reached 24,000 kg (48 × 500), exceeding the minimum requirement of 16,000 kg by 8,000 kg (WinQSB reports an indexed technical slack of 7,910). Likewise, the sorghum harvest totaled 16,200 kg (6 × 2,700), satisfying the association's requirement of 16,000 kg.

An analysis of the constraints affecting the variables—APU area in hectares, investment capital in Bs., ASOPRUAT sunflower production requirement in kg, and ASOPRUAT sorghum production requirement in kg—shows the following. The APU area constraint establishes that 90 ha or less may be cultivated, with a theoretical minimum of 79 ha and a maximum of 182 ha without altering the result of the maximization function. However, this is not considered plausible because, in the first case, Agrícola Olivo, C.A. would not leave 11 ha uncultivated, while in the second case, cultivating an additional 92 ha would require leasing land, resulting in new costs and a greater investment requirement.

If the APU area constraint is increased from 90 ha to 182 ha while all other conditions remain unchanged, *ceteris paribus*, the contribution of the variables changes, as does the optimal solution. The area planted with sunflower increases from 48 ha to 176 ha, no hectares are allocated to sesame, and the area planted with sorghum remains unchanged at 6 ha. Maximum profit would amount to Bs. 10,269,250.00, representing Bs. 3,947,781.00 more than the initially determined optimal solution of Bs. 6,621,469.00. This constitutes another decision-making alternative to be presented to the administrative management of Agrícola Olivo, C.A.; however, it would require leasing additional land, which may be extremely costly, usually amounting to half of the harvest.

The investment capital constraint establishes that no more than Bs. 200,000.00 may be invested, with a theoretical minimum of Bs. 98,490.00 and a maximum of Bs. 244,298.00 without altering the maximization result. However, these parameters are not considered feasible because, in the first case, it would not be advantageous for Agrícola Olivo, C.A. to leave Bs. 101,510.00 uninvested, particularly when hectares are still available for planting. In the second case, the available investment capital would have to be increased by Bs. 44,298.00 above the initial Bs. 200,000.00.

If the available investment capital is increased from Bs. 200,000.00 to Bs. 244,298.00 while all other conditions remain unchanged, *ceteris paribus*, the contribution of the variables changes, as does the optimal solution. The area planted with sunflower decreases from 48 ha to 32 ha, the area planted with sesame increases from 36 ha to 52 ha, and the area planted with sorghum remains unchanged at 6 ha. Maximum profit would amount to Bs. 7,265,369.00, representing Bs. 643,390.00 more than the initially determined optimal solution of Bs. 6,621,469.00. This constitutes another decision-making alternative to be presented to the administrative management of Agrícola Olivo, C.A. and makes it an attractive scenario for decision-making.

## Discussion

The introduction of quantitative mathematical optimization models at Agrícola Olivo, C.A. empirically validates the propositions of Sandmann et al. (2025), who argue that linear modelling maximizes agricultural productivity and outperforms producers' traditional heuristic and intuitive decision-making. By precisely allocating the cultivable area (48 ha of sunflower, 36 ha of sesame, and 6 ha of sorghum), the algorithm efficiently balances the high profitability per hectare—but also the high cost—of sesame with crops requiring lower investment, thereby maximizing the return on the available financing fund of Bs. 200,000.00. This behaviour is consistent with Liu and Hu's (2025) observation that linear programming matrices discriminate among profitability coefficients in order to protect the financial structure of farms under conditions of scarce financial resources.

When the findings are compared with the contemporary literature, the balanced allocation of the planting area supports the thesis of Sandmann et al. (2025), who maintain that mathematical modelling applied to production units systematically optimizes land use and increases net productivity per cultivated hectare. In addition, the varied and diversified allocation of the agricultural portfolio mitigates the economic and environmental uncertainty described by the OECD and FAO (2024), providing operational certainty that helps balance individual investment costs against regulated delivery margins.

To evaluate the resilience of the model in the face of natural factors—such as pests and heavy rainfall—or technical and market fluctuations—such as shortages of inputs and price volatility—a post-optimal sensitivity analysis was conducted under the *ceteris paribus* assumption.

The sensitivity analysis by variable determined that the net-profit coefficients of the three basic variables have defined tolerance ranges before the optimal solution is affected:

- For sunflower, profit may range between Bs. 34,728.00 and Bs. 99,600.00.
- For sesame, it may range between Bs. 58,900.00 and Bs. 208,827.00.
- For sorghum, the model can withstand extreme reductions represented by −M, but only tolerates a maximum increase of Bs. 57,650.00.

As Wang et al. (2025) point out, determining these thresholds provides management with a vital predictive tool for mitigating the multidimensional risks associated with the rural environment.

A detailed examination of the constraints through post-optimal analysis revealed alternative decision-making scenarios with different strategic implications for administrative management:

- Land expansion scenario: The land-area constraint has a shadow price of Bs. 42,911.00 and an allowable upper limit of 182 ha. If the area is theoretically increased to 182 ha, the optimal solution is radically reconfigured: the area planted with sunflower increases to 176 ha, sesame falls to 0 ha, and sorghum remains at 6 ha, increasing profit to Bs. 10,569,250.00. However, this scenario is rejected because of its low practical feasibility, since it would require leasing an additional 92 ha, an expensive transaction commonly indexed to half of the harvest, thereby reducing actual net profitability.
- Increased financing scenario: The budget constraint has a shadow price of 15.00 and a maximum allowable value of Bs. 244,298.00. If available capital is increased to this upper limit, the allocation changes to 32 ha of sunflower, 52 ha of sesame, and 6 ha of sorghum, raising maximum profit to Bs. 7,265,369.00 (Bs. 643,390.00 above the baseline model). This alternative is highly attractive and viable for managerial decision-making if supplementary credit can be secured.

**Institutional Requirement Scenarios — ASOPRUAT**

The minimum sunflower quota has a shadow price of 0, which means that increasing the association's requirement to 23,910 kg does not alter the original profit of Bs. 6,621,469.00. By contrast, the sorghum requirement has a negative shadow price of −9.00. If this requirement is increased to its limit of 57,443 kg, the solution forces an allocation of 32 ha of sunflower, 37 ha of sesame, and 21 ha of sorghum, causing total net profit to fall to Bs. 6,239,056.00 (a loss of Bs. 385,413.00). This demonstrates that sorghum functions as a crop that helps satisfy institutional requirements but provides relatively low financial returns.

Lastly, a scenario involving the termination of institutional agreements was evaluated by assuming that 100% of the available area (90 ha) was planted exclusively with sesame. This alternative produces a theoretical profit of Bs. 8,964,000.00, requiring an additional Bs. 151,000.00 in financing (for a total cost of Bs. 351,000.00) and generating Bs. 2,342,531.00 more than the initial optimal solution. However, this scenario is considered highly risky and uncertain because failure to comply with ASOPRUAT's minimum sunflower and sorghum delivery requirements would cause the APU to lose guaranteed access to protected agricultural inputs supplied by Agropatria, exposing it to the high and unstable prices of the unregulated market. These findings support the propositions of Benini et al. (2025) and Castillo Ortiz et al. (2025), who argue that modern planning should subordinate theoretical monetary profit to resilience constraints and supply-chain partnerships in order to ensure long-term operational autonomy.

## Conclusions

Linear programming applied to the solution of agricultural production (planting) problems helps, on the one hand, to consider the many factors affecting agricultural production and profitability, planting options, crop allocation, among other elements; on the other hand, it helps reduce uncertainty margins by creating scenarios that facilitate decision-making aimed at maximizing economic benefits and making better use of the finite and uncertain resources available in agriculture. The advantages of using linear programming in agriculture have been demonstrated: it has achieved the optimal distribution of hectares to be planted with each crop and maximized profit, while the projected harvest would allow recovery of the investment and the generation of additional returns. This is confirmed by the subsequent post-optimal calculations, which indicate that this is the best decision-making scenario.

The application of linear programming determined with scientific precision that the initial optimal scenario for maximizing the profit of the Agrícola Olivo, C.A. Agricultural Production Unit consists of annually planting 48 hectares of sunflower, 36 hectares of sesame, and 6 hectares of sorghum. This combination optimizes the allocation of limited resources by using 100% of the available area (90 ha) and efficiently using Bs. 199,284.00 of the budget, generating a maximum profit of Bs. 6,621,469.00 and a return of 3,310.73%, which amply covers debts, interest, maintenance, and taxes.

The mathematical model satisfactorily met the minimum delivery quotas required by ASOPRUAT by generating 24,000 kg of sunflower and 16,200 kg of sorghum, thereby safeguarding the company's institutional access to subsidized fertilizers and agrochemicals supplied by Agropatria. The post-optimal analysis showed that alternatives based on sesame monoculture or excessive expansion of the cultivated area to 182 ha entail critical levels of operational risk and additional land-leasing costs that reduce their actual feasibility compared with the stability of the initial solution. Increasing investment capital to Bs. 244,298.00 was identified as the second most attractive scenario for the board of directors, since it expands the sesame area to 52 ha and raises net profit to Bs. 7,265,369.00.

Working with the scenarios provided by post-optimal analysis makes it possible to examine alternatives, improve decision-making, and maximize the profit available to agricultural producers. Knowledge of the variables underlying these scenarios allows them to be analyzed in greater depth. Thus, scenarios that initially appear highly profitable because of the returns they generate—such as increasing the planted area, with a projected profit of Bs. 10,569,250.00—also involve leasing agricultural land, which is often extremely costly because of rental fees and the difficulty of securing such leases. In practice, this therefore becomes a relatively unattractive option because its actual profitability may be low.

The second most attractive scenario involves planting the entire APU area with sesame, which would generate a profit of Bs. 8,964,000.00. However, this increases planting and production risks because agricultural inputs and a stable selling price would no longer be guaranteed. Although the profit is Bs. 2,342,531.00 higher than the initial Bs. 6,621,469.00, uncertainty could be extremely high, making the production process highly risky, while the established constraints and requirements would not be met. The third potentially attractive scenario involves increasing invested capital from Bs. 200,000.00 to Bs. 244,298.00. This would generate a profit of Bs. 7,265,369.00 and satisfy most of the constraints; its main disadvantage would be the need to obtain additional credit.

The fourth decision-making scenario involves expanding the APU area to 182 ha, of which 176 ha would be planted with sunflower. Maximum profit would amount to Bs. 10,269,250.00, representing Bs. 3,947,781.00 more than the initial optimal solution of Bs. 6,621,469.00. However, this scenario entails leasing land, which may be extremely costly, commonly amounting to half of the harvest. It could therefore ultimately generate very limited actual benefits. Finally, there is the scenario involving an increase in sorghum production, which generates Bs. 385,413.00 less profit than the optimal solution.

The following recommendations are made:

- Adopt the optimal-solution scenario in order to achieve the highest profitability.
- Promote the use of quantitative models incorporating new information and communication technologies in the agricultural sector in order to increase the profitability, productivity, and competitiveness of this key sector for food production in Venezuela and contribute to strengthening the country's agri-food sovereignty.
- Encourage the use of linear programming and post-optimal analysis throughout the agricultural sector, particularly within producers' associations. Both tools, especially when implemented through software, could become advisory resources offered by such associations to their members as mechanisms for reducing the risk and uncertainty inherent in agricultural production.
- Promote research into linear programming and computer programs applied to agriculture in public and private Agricultural Research Centers, Venezuelan universities, and other institutions involved in agricultural education.

## Author contributions

All authors (Amaire Mora Guerrero, Alberto Cadevilla Soto, and Adolfo Paredes Bastidas) contributed equally to the conception and design of the study, field data collection and processing, formulation and implementation of the mathematical model using WinQSB software, analysis and interpretation of the optimization and sensitivity results, as well as the drafting, critical revision, and final approval of the manuscript version submitted for publication.

## Research data availability

The primary data on investment, yields, and operating costs used to design the linear programming model were obtained from the structured interview conducted with the Agrícola Olivo, C.A. Agricultural Production Unit. Likewise, the algebraic matrices, computational runs, and detailed WinQSB software reports (Simplex Analysis and Post-optimal/Sensitivity Analysis) are available to interested readers or researchers upon formal request to the corresponding author at: amairemora@gmail.com.

## Review comments

This article underwent an anonymous peer-review process in accordance with the journal's editorial transparency policy. The reviewers, who participated anonymously in this process, consented to the publication of the comments issued during the review.

**Review Comment 1:** The manuscript requires certain adjustments detailed in the attached file. Final recommendation: Publishable with modifications.

**Review Comment 2:** Not publishable.

**Review Comment 3:** A general revision of the manuscript is recommended, including adjustment of the data presentation format, verification of the consistency of the reference list, and other points noted in the attached text. Final recommendation:

Publish once the author has made the revisions indicated in the evaluation recommendations.

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