Design of an Annual Harvest and Inventory Plan for Fruits and Vegetables Using an Optimization Model

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1. Abstract
In Paraguay the agriculture is considered important for the economic development of families. Fruit and vegetable production represents 32% of the value of national production in monetary terms, and is developed by family farmers, to which 83% of national production farms belong. This research is focused on a plan for harvesting and storage design for a group of producers in Aveiro Company of Ita city, by designing a mathematical model based on Linear Programming (LP). On the studied farms are not performed proper planning of harvesting crops, making it difficult for producers to determine accurately the financial resources and materials to be used in agricultural activities. To satisfy demands, decisions regarding the allocation of greenhouses for continuous production and in seasons with unfavorable climate for the development of crop production are necessary. The interest of the study on the optimization of the harvest and management of resources for fruit and vegetable production, mainly because the country is still using traditional production systems, which do not account for planning short and medium preserved term agricultural operations and product availability for timely commercialization. The main variables of an annual optimal plan are related to the amounts and periods of harvest of various items produced - tomato, pepper, melon and cucumber - as well as a purchasing plan and resources used for conditioning inventory. Alternative greenhouses installation for the associated production and temporary storage of products was taken into account to achieve the levels of demand satisfaction. The restrictions deemed essential for operational activities were the product levels in plot for each period, the harvest capacity in each farm crop and greenhouse, proportionality in the associated sale according to each individual production capacity, and purchase and storage capacity of products and resources.

2. Keywords: Production Planning, Linear Programming, Fruits and Vegetables Production

3. Introduction
According to the last National Census of Agriculture [1], in Paraguay about 83% of the farms have between 1 and 20 hectares (ha), i.e., they belong to small producers that supply the national market mainly with fruits and vegetables, grown so temporary or permanent, and generating about 32% of the value of agricultural production in monetary terms [2]. At the national level, the total area devoted to agricultural activities, 3.365.203 ha are arable land for temporary and permanent crops, of which 7.539 ha are located in the Central Department [3], where there are approximately 6.000 farms characterized by being producing large volumes of strawberry, tomato, pepper and cucumber. These farms are sources of income for approximately 2.500 fruit-vegetable producers supplying the markets of Central Department and Asuncion [4].

Ita city, located in the Central Department, has 1.813 farms of small producers with sources of income based on the production of fruit and vegetables individually and / or associated [1]. Overall, the Paraguayan family farming is characterized by highly fragmented, run by families with low capitalization on the farm, low adoption of technology, low educational background, a different culture of the commercial producers, and a low level of associativity, which leads to problems of competitiveness [2].

4. Justification
Poor management of agricultural operations makes difficult to determine workers number, material and financial resources to use, meet customer demand, and make decisions regarding the provision of additional infrastructure for continuous production in seasons with unfavorable climates for crop development.

Ita city has certain advantages, such as its next supply centers of Central Department and Asuncion, the access to two main roads, availability of land for cultivation and immediately location of workers. Therefore, we want to generate a harvest plan and buy/storage resources plan, for a group of producers of the town of Ita, by designing a mathematical model based on Linear Programming.

5. Literature Review
5.1. Theoretical framework
Linear Programming (LP) was used in this research as mathematical programming technique. This is based on the efficient allocation of limited resources to known activities, while meeting the established restrictions. The values of the decision variables can be continuous, integers, mixed or binary; these names are also used to classify models LP [5].
5.2. Fruit and vegetable production
Horticulture or fruit and vegetable production includes farming: vegetables, fruit and ornamental plants. The horticultural adjective refers to this large group of plants that are generally labor intensive [7].

The items considered in this work, for testing the mathematical model, are three vegetables: tomato, cucumber, pepper; and one fruit: melon.

5.3. Applications of mathematical models for production planning, crop and inventory of agricultural products
Applications of mathematical models have provided enough information for decision-making within the agricultural area, and specifically for production planning, crop and inventory of agricultural products.

At work "Using an LP model that determines the maximum number of people to feed with an area of land given and distribution of selected crops" [9], the model balanced between the needs of people and the contribution of food, reporting the amount of land that is necessary to plant each crop to ensure food for most people. Some variables were the amount of land to plant a certain type of crop, demand and supply of each nutrient, people to feed and the number of hectares to cultivate [9].

Another proposal is a Mixed Integer Linear Programming (MILP) model [11], to support planning decisions in seeking to improve crop productivity and quality of the fruit produced in a region. The authors want to minimize the amount of resources used in harvest activities, ensuring obtaining a good quality fruit for export. Moreover, to support decision making in the context of the Paraguayan family agriculture [12], a mathematician based on LP model representing agricultural activities for vegetables harvesting, storage and inventory planning, minimizing the total costs of these activities. In a more recent work was mentioned some methods for planning of planting, harvesting, and distribution of fresh vegetables and fruits [13]; for this purpose refer to the way of using mathematical models of specific optimization and planning methods to show the functionality and importance of planning tools for food from de farming supply chains.

This research contributes through a mathematical model to generate a plan to harvest fruit and vegetable products and to purchase/storage resources in monthly periods for a year, with the particularity of inclusion in planning decisions pepper harvest in a greenhouse, one of the products with higher national demand. Options like purchasing of resource and use inventory deposits in associated manner are also included.

6. Methodological design
A mathematical model based on Linear Programming (LP) was designed; for that effect, we defines parameters, decision variables, objective function and constraints that limit the problem. The general guidelines established for the implementation of an operations research model [6] were followed: Defining the problem, model building, solution and validation. According to the extent of this investigation, the final implementation of the solution will not take place immediately, because we want to make only a proposal generated.

The model was solved using the software IBM ® ILOG CPLEX Optimization Studio Version 12.6, with academic license, on a laptop with Intel Core i3® processor 2.20 GHz with 4 GB RAM.

Two possible scenarios were considered to obtain annual plans. In the first scenario, the parameter of product availability in the plots is considered, according to the amounts that producers produce and harvest in 2015 months. In the second scenario parameter, product availability for harvest is modified in plots, according to harvest periods recommended by the Ministry of Agriculture and Livestock (MAG), and technical materials for the Central Department in the early, middle and late seasons.

7. Problem formulation
For the mathematical model, the following items are considered: products \((i)\) and producers \((p)\). Products cultivated by producers are showed in Table 1.

<table>
<thead>
<tr>
<th>Products</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pepper</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cucumber</td>
<td></td>
<td>√</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melon</td>
<td></td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tomatoes</td>
<td></td>
<td></td>
<td></td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>

This work considers that harvesting activities in two ways. The first one \((m = 1)\) refers to the harvesting and individual sale of producers in their own plots, and the second one \((m = 2)\), refers to individual harvest for subsequent shipment of the product to a deposit, so to make an associated sale with the other producers, while buy resources, also in partnership. Currently, farmers work in the first way \((m=1)\).
For storage the crop, wooden boxes are used as resources \((k = 1)\), and adhesive labels to identify the boxes \((k = 2)\), acquired from suppliers for each of the producers individually. By solving the model, results are obtained to four aspects of a tactical or medium-term planning at the lowest possible cost:

- Resources: purchasing and inventory of resources individually and associated way.
- Harvest: harvest of products individually and associated way, considering the two scenarios presented.
- Use Greenhouse and associative deposit: the use of a greenhouse for further availability of pepper was raised, in the months of unsatisfied demand that is possible to cover, and the possibility of rent a deposit for storage of resources (wooden boxes) and for temporary storage of harvested products for sale to customers in associated way.
- Labor or workers: The amount of labor required to harvest periods and work days needed to carry it out.

7.1. Mathematical model design

Subscripts

\(i\): type of product available on plot, \(i = 1, \ldots, 4\)

\(j\): type of product available in greenhouse, \(j = 1\)

\(p\): producer, \(p = 1, \ldots, 7\)

\(k\): resource type, \(k = 1, 2\)

\(t\): time (months), \(t = 1, \ldots, 12\)

\(m\): harvesting mode, \(m = 1, 2\)

Decision Variables

\(YC\text{OM}_i^p_t\): binary variable that takes value 1 if the producer \(p\) buys the resource \(k\) in period \(t\), and takes 0 otherwise

\(COMR_i^p_t\): amount of resources \(k\) that should buy the producer \(p\) in period \(t\)

\(INV_{R,k}^p_t\): amount of resources \(k\) stored by the producer \(p\) during the period \(t\)

\(YCOMRA_{k,m}^t\): binary variable that takes value 1 if producers purchase the resource \(k\) in period \(t\) in associated manner, and takes 0 otherwise

\(COMRA_{k,m}^t\): amount of resources \(k\) they should buy producers in associated manner in the period \(t\)

\(INVA_{k,m}^t\): amount of resources \(k\) to store in associated manner in period \(t\)

\(YO\text{COSE}_{p,m}^t\): binary variable that takes value 1 if the producer \(p\) harvesting a product in period \(t\) with mode \(m\), and takes 0 otherwise

\(CO\text{SE}_{i,p,m}^t\): amount of boxes of product to be harvested for the producer \(p\) in period \(t\), in the mode \(m\)

\(INVP_{i,p}^t\): amount of boxes of product \(i\) that the producer \(p\) left in the land after the harvest period \(t\)

\(YC\text{VEN}_{i,p}^t\): binary variable that takes value 1 if products are sent in associated manner to customers in period \(t\), and takes 0 otherwise

\(VIN\text{VER}_{i,p}^t\): binary variable that takes 1 if the producers decide to build a greenhouse in period \(t\), and takes 0 otherwise

\(YO\text{COSE}_{j}^t\): binary variable that takes value 1 if the product \(j\) is harvested in the greenhouse in period \(t\), and takes 0 otherwise

\(CO\text{SE}_{j,t}^t\): amount of boxes of product \(j\) to be harvested in the greenhouse in period \(t\)

\(INV_{j,t}^t\): amount of boxes of product remaining in the greenhouse after the harvest period \(t\)

\(NTRAB_{p,i}^t\): Number of workers to employ for the producer \(p\) for harvesting of product \(i\) in each plot in period \(t\)

\(NTRAB_{j,t}^t\): Number of workers to employ for harvesting in the greenhouse in period \(t\)

Parameters

\(cosd_{k}\): Cost of ordering the purchase of resource \(k\)

\(coscom_{k}\): Cost of buying a unit of resource \(k\)

\(cosinv_{k}\): Cost of inventory a unit of resource \(k\)

\(cosordas_{k}\): Cost of ordering the purchase of resource \(k\) in associated manner

\(coscomas_{k}\): Cost of buying a unit of resource \(k\) in associated manner

\(cosinvas_{k}\): Cost of inventory a unit of resource \(k\) in associated manner

\(costr\): wage by the labor used to harvest or maintenance the products

\(cos\text{par}\): cost of maintaining a product unit on the plot for a period

\(cos\text{constr}\): Cost of building a greenhouse obtaining an agricultural credit

\(cosf\): fixed cost of harvesting a product unit in the greenhouse for a period

\(cos\text{inver}\): Cost of maintaining a product unit in the greenhouse for a period

\(cos\text{dep}\): Cost of renting the associative deposit in each period
Minimize Total Cost \[ Z = \]

\[
\sum_{p=1}^{7} \sum_{k=1}^{2} \sum_{t=1}^{12} \left( \text{COMR}_{pkt} \times \text{coscom}_k + \text{YCOMR}_{pkt} \times \text{cosord}_k + \text{INVR}_{pkt} \times \text{cosinv}_k \right) + \\
\sum_{k=1}^{2} \sum_{t=1}^{12} \left( \text{COMRA}_k + \text{YCOMRA}_k \times \text{cosordao}_k + \text{INVR}_k \times \text{cosinvaso}_k \right) + \\
\sum_{i=1}^{4} \sum_{p=1}^{7} \sum_{t=1}^{12} \text{INVP}_{ipt} \times \text{cospar} + \sum_{j=1}^{12} \left( \text{YINVER}_j \times \text{consconstr} + \text{YCOSEL}_j \times \text{cosf}_i \right) + \sum_{j=1}^{12} \text{INV}_{jit} \times \text{cosinver} + \\
\sum_{t=1}^{12} \text{YCNV}_t \times \text{cosdep} + \sum_{i=1}^{4} \sum_{p=1}^{7} \sum_{t=1}^{12} \left( \text{NTRAP}_{ipt} \times \text{costrab} \times \text{dmes}_t \right) + \sum_{t=1}^{12} \left( \text{NTRABI}_t \times \text{costrab} \times \text{dmes}_t \right)
\]

Subject to

1. Balance equation of each inventoried resource for each product and each period

\[ \text{INVR}_{pkt-1} + \text{COMR}_{pkt} = \sum_{i=1}^{4} \text{COSE}_{ipt} \times \text{usor}_{ik} + \text{INVR}_{pkt} \quad \forall p, \forall k, \forall t, m = 1 \]

2. Balance of each inventoried resource of associated producers for each period

\[ \text{INVRA}_{kt-1} + \text{COMRA}_k = \sum_{j=1}^{12} \text{COSEL}_j \times \text{usor}_{2jk} + \sum_{t=1}^{12} \sum_{t=1}^{7} \text{COSE}_{ipt} \times \text{usor}_{ik} \times \text{INVR}_{k} \quad \forall k, \forall t, m = 2 \]

3. and 4. Activation of binary variables to decide resource purchasing in individually and associated way
\[ \text{COMR}_{p,k,t} \leq \text{capalm}_{p,k} \cdot \text{YCOMR}_{p,k,t} \quad \forall \ p, \forall \ t, \forall \ k \]
\[ \text{COMRA}_{k,t} \leq \text{capalm}_{a,k} \cdot \text{YCOMRA}_{k,t} \quad \forall \ t, \forall \ k \]

(5) and (6) Do not exceed the maximum storage capacity for individual and associated resources
\[ \text{INV}_{p,k,t} \leq \text{capalm}_{p,k} \quad \forall \ p, \forall \ t, \forall \ k \]
\[ \text{INV}_{RA}_{k,t} \leq \text{capalm}_{a,k} \quad \forall \ t, \forall \ k \]

(7) Just build a greenhouse for the associated production of pepper \((j = 1)\)
\[ \sum_{t=1}^{T} \text{YINVER}_{t} \leq 1 \]

(8) and (9) Satisfy the products demands
\[ \sum_{p=1}^{P} \sum_{m=1}^{M} \text{COSE}_{iptm} + \text{COSEI}_{jt} \geq \text{demand}_{i,t} \quad \forall \ t, i = 1, j = 1 \]
\[ \sum_{p=1}^{P} \sum_{m=1}^{M} \text{COSE}_{iptm} \geq \text{demand}_{i,t} \quad \forall \ i > 1, \forall \ t, \]

(10) and (11) Activation of the harvest on plots and in greenhouse
\[ \sum_{i=1}^{I} \text{COSE}_{iptm} \leq M \cdot \text{YCOSE}_{iptm} \quad \forall \ p, \forall \ t, \forall \ m \]
\[ \text{COSEI}_{jt} \leq \text{prod}_{j} \cdot \text{YCOSEI}_{jt} \quad \forall \ j, \forall \ t \]

(12) Balance equation for inventoried products (boxes) in associated way
\[ \text{COSEI}_{jt} + \sum_{i=1}^{I} \sum_{p=1}^{P} \text{COSE}_{iptm} = \text{CENV}_{t} \quad \forall \ t, m = 2 \]

(13) Activation of the products shipping to the associative deposit, and maximum capacity of the deposit
\[ \text{CENV}_{t} \leq \text{capdep} \cdot \text{YCENV}_{t} \quad \forall \ t \]

(14) Amount of each product left unharvest (boxes) in each period, on each producer plot
\[ \text{INV}_{ipt} = \text{prod}_{ipt} + \text{INV}_{ipt-1} - \sum_{m=1}^{M} \text{COSE}_{iptm} \quad \forall \ p, \forall \ i, \forall \ t, i = 1 \]

(15) Amount of each product left unharvest in the greenhouse, in each period
\[ \text{INV}_{i,t} = \text{prod}_{j} \cdot \text{YINVER}_{i,t} - \text{COSEI}_{jt} \quad \forall \ j, 3 < t < 8 \]
\[ \text{INV}_{i,t} = \text{prod}_{j} \cdot \text{YINVER}_{i,t} + \text{prod}_{j} \cdot \text{YINVER}_{i,t-2} + \text{INV}_{i,t-1} - \text{COSEI}_{jt} \quad \forall \ j, 7 < t < 12 \]
\[ \text{INV}_{i,t} = \text{prod}_{j} \cdot \text{YINVER}_{i,t} + \text{prod}_{j} \cdot \text{YINVER}_{i,t-2} + \text{prod}_{j} \cdot \text{YINVER}_{i,t-11} + \text{INV}_{i,t-1} - \text{COSEI}_{jt} \quad \forall \ j, t = 12 \]

(16) and (17) Have sufficient workforce to harvest in the plots and on greenhouse
\[ \text{NTRABP}_{ipt} \geq \left( \sum_{m=1}^{M} \text{COSE}_{iptm} / \text{capose}_{it} \right) \quad \forall \ i, \forall \ p, \forall \ t \]
\[ \text{NTRABI}_{jt} \geq \left( \text{COSEI}_{jt} / \text{capose}_{2jt} \right) \quad \forall \ t, j = 1 \]

(18) Send to associative deposit a minimum and maximum fraction of harvest products
\[ \text{fpmn} \leq \frac{\text{CENV}_{t}}{\text{CENV}_{t} + \sum_{p=1}^{P} \text{COSE}_{iptm}} \leq \text{fpmx}, \quad \forall \ i, \forall \ t, m = 1 \]
(19) Integrality restrictions
\[ COMR_{pt}, INVR_{p}, COMRA_{kt}, INVR_{kt}, COSE_{ipt}, INVP_{ipt}, CENV_{t}, COSEI_{jt}, INV_{jt}, NTRABP_{ipt}, NTRABI_{t} \geq 0; \]
\[ YCOMR_{pt}, YCOMRA_{kt}, YCOSE_{pt}, YCENV_{t}, YINVER_{t}, YCOSEI_{jt} \in \{0,1\}; \quad \forall t,p,k,m \]

Explanation of the sets of constraints

(1) Balance equation of each inventoried resource for each product and each period:
In each period \( t \) input resources \( k \) must equal the output of resources for each producer \( p \) buying individually.
Input: amount of resources stored in the previous period and amount of resources to buy in the current period individually.
Output: amount of resources used and amount of resources to inventory in the current period.

(2) Balance of each inventoried resource of associated producers for each period:
For harvesting in the greenhouse and on plots in mode 2, and its subsequent delivery to an associative deposit, buying \( k \) resources is done in partnership or in associated way.
Input: amount of resources stored in the previous period and amount of resources to buy in the current period.
Output: amount of resources to use for harvest in the greenhouse and harvest in mode 2, and amount of resources to inventory in the current period.

(3) and (4) Activation of binary variables for resource purchasing decisions individually and associated way:
The purchase of a certain amount of resources \( k \), individually and associated way, will only be possible if it was decided to make the purchase in a period \( t \).

(5) and (6) Do not exceed the maximum storage capacity for individual and associated resources

(7) Just build a greenhouse for the associated production of the product \( j \):
Producers may decide to build a greenhouse for the production of associated way between periods 1 and 9 \((1 \leq t \leq 9)\); If a greenhouse is built outside this range, the product is no longer available for harvest within the planning period.

(8) Satisfaction of the demand for pepper:
To satisfy the demand for pepper should be harvested product \( i = 1 \) in each plot, with the possibility of harvesting product \( j = 1 \) in the greenhouse, in each period \( t \) enabled.

(9) Satisfaction of the demand of cucumber, melon and tomato:
To satisfy the demand of cucumber, melon and tomato should be harvested each product \( i > 1 \) in each producer \( p \) plot to sale the products to the customers in individually or in association way.

(10) Activation of the harvest in plots:
Each producer may harvest products, in each mode \( m \) and period \( t \), only if they decided to harvest in that period.

(11) Activation of the harvest in greenhouse:
It can be made harvest certain amount of pepper in the greenhouse in each period \( t \), only if it was decided to harvest.

(12) Balance equation for inventoried products (boxes) in associated way:
The amount of products \( j \) harvested in the greenhouse and the amount of product \( i \) harvested by producers in the mode \( m = 2 \), should be equal to the amount to be sent to the associative deposit to deliver it to the customers.

(13) Activation shipping products in associated way in the deposit, and maximum capacity of the deposit:
It can be made to shipment of products to the associative deposit in each period \( t \), only if it was decided to send to. Also in each period \( t \) the quantity shipped must not exceed the maximum capacity of the deposit.

(14) Amount of each product left unharvest (boxes) in each period, on each producer plot:
In each producer \( p \) plot, a certain amount of each product \( i \) remaining in inventory at each period \( t \).
Also in certain periods $t$ must be added the availability of products for harvesting according to product $i$ availability in the producer $p$ plot.

(15) **Quantity of each product left unharvest in the greenhouse, in each period**
Just as in the plots, in greenhouse, at the end of a period $t$, they left inventoried products $j$ for later harvest. Depending on the period in which they decided to build the greenhouse products will be available for harvest.

(16) **Have sufficient labor to harvest in the plots:**
The number of workers to be used for the harvest of the product $i$ by the producer $p$ in period $t$, must be greater than or equal to the total amount must be harvested divided monthly capacity harvest of each worker.

(17) **Have sufficient labor to harvest in the greenhouse:**
The number of workers to be used for the harvest of the product $j$ in period $t$, must be greater than or equal to the total amount must be harvested divided monthly capacity harvest of each worker.

(18) **Send to associative deposit a minimum and maximum fraction of the total amount of product $i$ sent, in each period:**
This restriction allows counted as fraction parameters a minimum and maximum for sending products to associative deposit for sale in partnership.

(19) **Integrity restrictions:** They indicate that the variables are not negative or binary as appropriate.

7.2. Results of the resolution of the mathematical model
In Table 2, the overall results for the four aspects considered are presented.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resources</td>
<td>88% of wooden boxes and labels must be acquired in associated way from April to December. Only buy individual boxes the producers 2 and 3. Should be inventoried boxes for two months of the year for later use.</td>
<td>90% of wooden boxes and labels must be acquired in associated way all the year. Only buy individual boxes the producers 2 and 5 should be inventoried for three months of the year for later use.</td>
</tr>
<tr>
<td>Harvest</td>
<td>Most products must be harvested associated manner to satisfy demand. Only 12% of the crop must be harvested for individual sale</td>
<td>90% of the products must be harvested associated manner to satisfy demand.</td>
</tr>
<tr>
<td></td>
<td>In both scenarios, the results specify the amounts and periods of harvest, and quantities to be harvested in later months.</td>
<td></td>
</tr>
<tr>
<td>Use of greenhouse</td>
<td>Will be used for pepper production in the months of less satisfaction, according to the real availability. The greenhouse should be built in January to have pepper in April, August and December</td>
<td>Partial satisfaction of demand in the months that no product availability (May and September) was raised. The greenhouse should be built in February; to have the first harvest in May and the second in September.</td>
</tr>
<tr>
<td>Workforce</td>
<td>Through the results could be determined the amount of workforce necessary to harvest products, and days of work per product and per producer. The product that will require more workforce is tomato.</td>
<td></td>
</tr>
</tbody>
</table>

In Table 3, the minimum total costs obtained for each scenario and the percentage of satisfaction of demand for each type of product requiring by potential customers are showed. As for the distribution of total costs for both scenarios, costs higher value are purchasing, order and inventory of resources (53% and 58% for stage 1 and 2 respectively), workforce (22% and 19%) and maintenance of the products on a plot at harvest (14% and 15%).
Table 3. Summary of minimum percentage of total costs and demand satisfaction for both scenarios.

<table>
<thead>
<tr>
<th>Products</th>
<th>( \text{Scenario 1} )</th>
<th>( \text{Scenario 2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pepper</td>
<td>33.721 USD</td>
<td>47.455 USD</td>
</tr>
<tr>
<td>Cucumber</td>
<td>15%</td>
<td>38%</td>
</tr>
<tr>
<td>Melon</td>
<td>56%</td>
<td>155%</td>
</tr>
<tr>
<td>Tomate</td>
<td>36%</td>
<td>73%</td>
</tr>
<tr>
<td>Tomate</td>
<td>91%</td>
<td>101%</td>
</tr>
</tbody>
</table>

With respect to the purchase and inventory of resources, the Figure 1 shows as an example in the case of scenario 2. As you may notice is appropriate, according to the results, that producers work in associated way to incur in less costs to purchase and use resources, in this case wooden boxes and labels, will be purchased in the exact amounts needed and in certain cases the resources will be stored for later use as seen in January and October.

![Figure 1. Example of the monthly wooden boxes buying, individually and associated way, in the case of scenario 2.](image)

Figure 1. Example of the monthly wooden boxes buying, individually and associated way, in the case of scenario 2.

Furthermore, the Figure 2 shows an example of the tomato harvest, for the producer 2, which would have available tomatoes in his plot, equivalent to 7,000 boxes in January and August. By restricting the balance it would ensure that the products will decrease as plot to be harvested monthly to satisfy demand.

In general for all products was obtained a plan with amounts and periods to harvest by each producer, as well as the mode, which is mostly in partnership. In Table 4, an example of harvest plan is shown, and workforce use and resources buying suggested for the producer 2.
8. Conclusions

Regarding the purpose of this research, the following goals were achieved:

- Describe the agricultural operations fruit production process.
- Identify production volumes and resources used on farms.
- Develop a Linear Programming Model, which describes the annual harvest and process purchase/storage of necessary resources.
- Testing the model for two possible scenarios, with information provided by producers and technical parameters of fruit and vegetable production.
- Obtained plans allow to determine that mathematical models can be used to support decision-making and specifically in the planning of farm operations.
9. Recommendations
Suggestions for future works:
• Develop annual-plan production by some of the techniques of PL, to complement the harvest plan done.
• Develop a plan to satisfy the demand of each customer.
• Restrict the period of time that each product can remain in the plots.
• Considering the above case, propose to the producers to plan the production to dispose of the products in other months of the year or in case of over-marketed to other customers.
• Determine the amount of greenhouses needed to meet all potential demand, periods of construction and economic feasibility of having such infrastructures.

10. References