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Research paper

Lean optimization model for managing the yield of pima cotton (gossipier Barba dense) in small- and medium-sized farms in the Peruvian coast areas

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Abstract

This study proposes a lean manufacturing-based optimization model to standardize "Pima cotton" crop yields in the Peruvian coast areas toward the north of Piura as the study area. The study also discusses how Pima cotton is grown in the Peruvian cost areas. This is represented in 2 stages: diagnosis and development of the cotton crop model. The diagnosis stage consists of 3 steps, and the development stage consists of 2 steps. The interrelation of each stage has been identified with the lean manufacturing principle for the improvement of crop yield. Results showed that to increase current crop yield in Piura to 172 bushels/ha as well as determine the quantities of resources and raw materials required considering a standardized crop production process. The limitations of the research depend on the climatic conditions in Peru. The main contribution of this research is to propose a model using which farmers may produce Pima cotton by utilizing the indicators proposed to increase the process control. In addition, the paper proposes a standardized crop production process that farmers must follow, supported by a mathematical model simulation.

Keywords: *Lean Manufacturing; Theory of Constraints; Linear Programming; Crop Yield Measurement*

1. Introduction

Cotton grown in Peru is one of the most important agro-industrial crops in the textile sector since the crop production of this raw material directly affects 20,000 farming families. The crop covers approximately 4 million wages per season, generating job opportunities in its production, clearing and processing stages. This contributes to the country's agricultural, industrial, and economic development (INIA, 2008).

The National Agrarian Innovation Institute (INIA), a Peruvian regulatory entity for the agricultural sector, has executed a strategic plan for technological innovation with the objective of obtaining competitive and comparative advantages so that cotton becomes a profitable product for farmers. The development of integrated management technologies for profitable and sustainable crop production in the north coast, central coast, and forest area is generating efficient agronomic crop management that has adapted to cotton growth requirements and patterns to reach potential yields.

For the coastal and forest areas, the optimum levels of cotton density vary and sowing times are different. Likewise, the production of Pima cotton was adapted to the northern coast area with warm climate at a temperature between 14°C and 20°C, with a flowering and ripening observed at 20°C and 30°C, respectively. The crop production period is between April and May since weather is sunny but fresh and optimal for Peruvian Pima cotton production during this period. The Peruvian Department of Ica has been the main cotton producer in Peru as of the early 20th century (INIA, 2008).

The "Agricultural Management requests are not planting cotton at the beginning of 2018 due to pests" news headline. Engineer Mario Laberry Saavedra, Regional Director of Agriculture in Piura (DRAP) suggests that during the months of January, February, and March of 2018, Pima cotton should not be planted in Piura since good results will not be obtained due to the presence of pests that may affect cotton quality (Newsroom, 2017).

Farmers refuse to grow cotton despite the stable climatic conditions because of the El Niño phenomenon and because they do not see this crop as profitable since production costs have increased and they have no incentives (García, 2016).

Earlier, the country produced 280 thousand tons of cotton fiber. This has now have been reduced by almost 50% over the past 5 years. Current cotton production amounts to only 26 thousand tons, as reported by the National Society of Industries (SNI). These changes have lowered both cotton production and profitability in Peru. Other possible factors for this decline are changes in agricultural policies affecting cotton and international competition offering different cotton quality, directly harming farmers who are still betting on cotton production (INGA, 2016).

2. State of the art

Previous research studies [6], [10], [13], [20], and [33] have proposed a methodology based on algorithms for a system of parallel machines and with dependent preparation times to determine production bottlenecks. However, this does not resolve our research

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questions given that machines are considered before conducting a more accurate assessment for the identification of possible process bottlenecks.

According to [8], [9], [14], and [24], the theory of constraints (TOC) is used to identify the operational and performance constraints through productive system simulations. While the aforementioned studies show that the application of these tools is feasible in the production stage, no solution is provided for the issues mentioned in the Introduction section.

Previous studies [4], [7], and [18] have shown that TOC supports MPS and DBR tools for the optimization of labor systems. In contrast, some studies [5], [21], and [27] have given importance to TOC to efficiently identify bottlenecks. According to the research articles on TOC, no contribution has been made to the solution of the research questions because MPS makes it difficult to identify the main constraints, which will require further analysis of the variables and the corresponding methods used.

Other studies [15], [22], and [25] reported the development of programming software to determine the optimal production batch for the productive system, thereby avoiding delays. Again, this does not contribute to the solution of the problem under study.

Much of the research focuses on lean manufacturing implementation to reduce waste in manufacturing processes reported in [11], [16], [23], and [32]. In contrast, [2] and [12] compared lean manufacturing with the mechanisms proposed in traditional studies that were specific to each company.

Considering what has been researched and unlike the previous models, we can support the need to propose an optimized production model, which, under the hypothesis of using the lean manufacturing methodology, will cover all pending implications from previous analytical studies on cotton. This model will optimize time and cost, which will in turn increase production profitability.

3. Development model proposal

A previous study [11] revealed that the quality of the product and the productivity of the production lines improve significantly with the help of the application of lean manufacturing principles. For this reason, for the Pima cotton crop production process, the model described in [12] is being adapted, which proposes production processes in levels with some existing limitations identified using TOC.

It was applied [seven] in production planning and scheduling to maximize the benefits and effectiveness that companies take into account for identifying market requirements. For this reason [27], TOC focuses on the weakest points of the productive chain since it groups them instead of considering them independent from one another. This allows us to deal with the limitations by asking [3] basic questions: what to change? What has changed and how to use the change?

Additionally, TOC can be applied in production, logistics, supply chain, distribution, project management, accounting, research and development, sales and marketing, etc. This philosophy promotes a change in the way cotton farmers think since it helps to solve the root problems.

According to [1], the main benefits of adjusted manufacturing are decreased production costs, increased production, and improved product quality safety in less production time. A considerable amount of research has focused on identifying the factors affecting production yield; thus, it is important to take these factors into account herein.

The proposed model consists of [2] stages, as described in Figure 1.

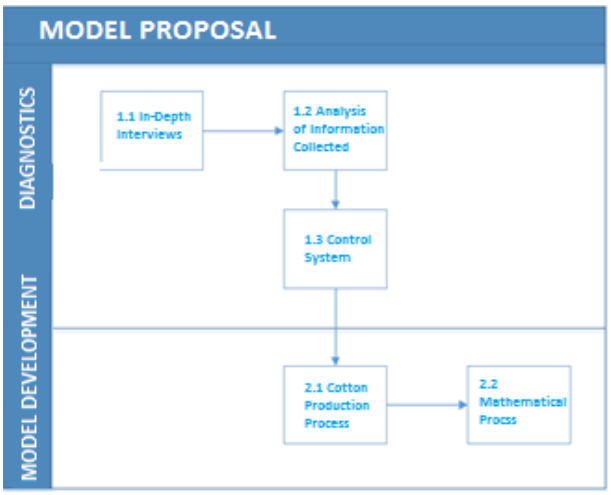


Fig. 1: Lean Optimization Model Proposed.

The diagnosis corresponds to the analysis of the current Pima cotton crop production situation and is represented by in-depth interviews and proposed production indicators. To do this, the following 3 steps are proposed for its development:

Step 1.1. Conduct In-Depth Interviews

In this step, users are identified by taking into account farmer profiles. Verification is done to ensure that they have at least 2 years of experience in the cotton industry. For this purpose, in-depth surveys taking into account the entire cotton process will be used. The interviews seek to identify the reality of the sector and determine the limitations.

Step 1.2: Analysis of Collected Information

In this step, the collected information is analyzed to determine the restrictions using TOC. Then, the optimal number of surveys is determined by performing mathematical calculations based on the population of cotton producers in Piura. The interpretation of these restrictions will aid in determining the problems with the greatest impact on production. For production processes, [16] points out that tasks are divided into 2 categories: value added (VA) and non-value added (NVA). This is based on factors that are considered essential to add value to the product or service. Likewise, waste is classified into [7] types: defects, inventory, overproduction, transportation, waiting time, excessive processing, and excessive movement.

Step 1.3: Create a Control System

In this step, the production process is continuously monitored to create alerts on how cotton is being grown. Based on the current reality of cotton producers, control indicators are implemented to track production. The results of these indicators will reflect process improvements. Likewise, the development of the model represents the structure that must be followed for cotton production in Piura, which is constituted by the standardized process and a mathematical model used to obtain cotton yield. In total, [2] steps are proposed for its development:

Step 2.1: Cotton Production Process

In this step, the process of growing cotton is standardized considering all steps as well as their individual resources. A process chart with BPMN standard methodology is created to map all steps of the process of growing cotton. Process interpretation will allow all cotton producers to follow this sequence of activities to obtain standard yields. Previous research [5] has reported the relationships between raw materials, in-process finished products, and consumables with fixed assets, such as machinery, tools, devices, equipment, and operational works, together with the capital needs of the company.

Step 2.2: Mathematical Model

The previous model allows us to find variables and quantities of resources needed for cotton production and for building a mathematical model. To improve the cotton crop yield, [5] proposed mathematical programming since there is some complexity in studies on the implementation in everyday business and decision-making. In this manner, production per hectare may be simulated using the LINGO software package. This simulation will determine the

amount of cotton (in kilograms) that will be produced in a hectare given the yield in bushels per hectare of cotton production. This model is expressed as follows:

$$Max.f(x),$$

$$s.a. \quad x \in S,$$

Where

$$f:[a_0,a_k] \subset R \to R$$

Given that

$$f(x) = \begin{cases} f_1(x) \ si \ \ a_0 < x \leq a_1 \\ f_2(x) \ si \ \ a_1 < x \leq a_2 \\ \quad . \\ \quad . \\ \quad . \\ f_k(x) \ \ si \ a_{k-1} < x \leq a_k \end{cases},$$

Where $f_j(x): R \to R$ linear $\forall_j = 1, 2, \dots \dots, k$ but with $f(x)$ not differentiable in $a_1, a_2, \dots a_k$ and with decreasing yields, i.e., if $x > y$, then $f(x) < f(y)$. If characterized by linear restrictions.

In this case, the non-linear and non-differentiable single variable problem may be transformed into a linear and differentiable problem with k variables, one for each definition section of the original objective function. The resulting approach can be expressed as follows:

$$Max.F(x_1, x_2, \dots \dots x_k) = f_1(x_1) + f_1(x_1) + \cdots + f_k(x_k) = \sum_{j=1}^{k} f_j(x_j)$$

$$s.a \qquad x_1 \epsilon \ S \qquad \forall_j = 1, 2, \dots \dots, k$$

$$a_0 \leq x_1 \leq a_1; \ 0 \leq x_2 \leq a_2 - a_1; \dots \dots, 0 \leq a_k \leq a_k - a_{k-1}$$

4. Case wherein the proposed model is applied

The case study is based on the crop production of Pima cotton in the northern coast area in the Department of Piura, which is the main producer of Pima cotton in the market. For this purpose, the proposed model consists of [2] stages. The diagnosis is implemented in [3] steps.

Step 1.1. Perform In-Depth Interviews

To validate information, an in-depth survey was taken by producers who know about cotton, the process, climatic conditions suitable for crop production, planting seasons, and other factors and have at least 2 years of experience. From these surveys, the main problems they face on a daily basis during the production process are low yields due to not using certified seeds and lack of control in cultural activities, affecting cotton harvests since the entire cotton hectare is not suitable for sale and generating losses with regard to cost and time. Likewise, INIA's specialist engineers investigate cotton crop production and its field constraints, thereby validating the problems reported by cotton producers.

Step 1.2: Analysis of Collected Information

The optimal number of in-depth surveys is determined to perform the analysis. For this purpose, the following sample size formula is used:

$$n = \frac{k^2 x \ p \ x \ q \ x \ N}{N \ x \ e^2 + k^2 x \ p \ x \ q}$$

Where n is the sample size and e is the estimation error. 10% was used since it is the maximum value allowed. Furthermore, p is the population in favor, q is the population in opposition, and k is the confidence level; 90% was used as the maximum threshold. Moreover, N is the population of cotton farmers in Piura.

$$n = \frac{1.65^2 x \ 0.5 \ x \ 0.5 \ x \ 511}{511 \ x \ 0.10^2 + \ 1.65^2 x \ 0.5 \ x \ 0.5} = 60$$

Previous studies [4] and [18] have indicated that TOC covers 3 main areas: logical thinking, performance measurement, and operation management. Within logical thinking, bottlenecks are viewed through continuous improvement. To increase the overall performance [8], [21], and [27], the main focus should be on system constraints, i.e., on any improvements beyond bottlenecks. The cycle is divided into 5 stages: (1) bottleneck identification, (2) decision on how to exploit them, (3) subordinate everything else in the system to the previous decision, (4) implement measures to raise restrictions, and (5) assess whether the bottleneck has broken and go back to the beginning.

Analysis of the number of optimal surveys and the findings of [5] fully agree with the idea of [12] about TOC determining the following restrictions:

- Capacity limitations
- Market restrictions

Step 1.3: Create a Control System

The indexes proposed by [12] have been selected according to the following criteria:

- They refer to waste that will be eliminated as part of improving the process system, so it can be used to estimate upward trends.
- Indexes refer to key processes that measure overall system performance as a constant and uninterrupted flow.

The model works within zero investment limits in capacity expansion, which is why the selection of model indexes adapted to cotton crop production in the northern area is justified:

1) Productive capacity: It indicates the amount of hectares available for cotton planting, thereby satisfying customer demands.
2) Failure production rate: The success or failure of the agricultural activity is reflected by cotton color, consistency, volume, and weight. Replacement generates loss of time and effort and increases production costs.
3) Opportunities for lost sales/delays in products: Lost sales due to bad cotton crop production hinders farmers from increasing income because of not being able to sell entire crops and losing potential customers. The attraction of new customers is both feasible and essential for reinvestment and achieving good results.
4) Industry performance: For investigating this aspect, farmer performance is assessed and the implemented improvement strategies are validated.

As a result, the priority indexes are classified. To assess the development of the production system, a separate procedure was performed for each group. Results are summarized in Table 1.

Table 1: Cotton Producer Performance Improvement Rates

N°	Index	Measurement Units	Capacity Constraints Ratio	Market Restriction Ratio
1	Production Capacity	Equivalent Units/Time Units	0.22	0.09
2	Production Failure Rate	% Returns	0.18	0.49
3	Sales Lost/Delays in Product	% Measured Against Revenue	0.30	0.25
4	Industry Performance	% Excess of a Company	0.30	0.17
Total			1.00	1.00

In addition, the proposed model development consists of 2 implementation steps.

Step 2.1: Cotton Production Process

Based on the BPMN cotton crop production process, charts are developed. With the objective of standardizing the activities to be performed considering the resources and inputs required for each activity. Farmers should consider performing soil analysis every 2 years to maintain a suitable soil for growing cotton.

1) Soil preparation is necessary since man hours are used for the entire production process and the cotton plant requires soil preparation for normal development using organic matter. Thus, the following results are obtained: aeration that favors gaseous exchanges and improves the assimilation of the nutrients in the plants, improvements on water retention capacity, decrease in plagues that attack cotton plants, and efficient control of weeds to avoid crop contamination.
2) Planting is an important stage of crop production, and certified seeds must be used to guarantee that crops stay in good condition. They can be recognized as they have 2 labels. The first label details the variety; lineage; net weight; percentage of varietal purity, germination, and humidity; analysis date; and category. The second label specifies lot number, lineage, producer, weight, analysis date, and expiration date.
3) The cultural tasks represent activities that are performed to maintain the crop healthy and profitable. Thinning is performed approximately 30 or 40 days after planting when the plant has 3-4 full leaves. Irrigation is performed 30–50 days after sowing considering the crop age. Watering is performed after thinning. In the flowering period, the plant is watered for 3–5 h with a frequency of 12–15 days, whereas in the ripening stage, plants are watered with a frequency of 16–22 days. Fertilization is performed during sowing and thinning so that nutrients may be assimilated correctly. For this purpose, 17 sacks of ammonium sulfate, [5] sacks of simple superphosphate, and [3] sacks of potassium sulfate are used.
4) Pest control inspections are conducted to rule out diseases that may affect cotton growth due to climate changes.
5) When 60% of acorns ripen, cotton is harvested early in the morning when there is no humidity or presence of rain.

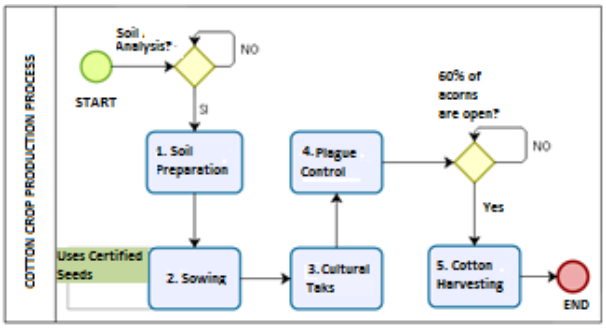


Fig. 2: Cotton Crop Production Process.

Likewise [4] and [18] reported that performance measurement covers both operational measures (performance, inventory, and operating expenses) and financial measures (net profit, return on investment, and cash flow) arising from the sole purpose of any organization, which is to make money now and in the future. Customer satisfaction is a considerably contributes to performance. Improved efficiency means a decrease in operating expenses. Thus, improving the use of capacity implies good results with regard to inventory.

Step 2.2: Mathematical Model

According to [25], for the cotton crop production process, the raw material required to produce Q of cotton must be considered from the start of the process to the stage when the finished product is obtained. A quality inspection of all batch products is performed to determine which products are optimal. Previous research [15] has proposed the use of programming problems to measure the increase of the performance.

For this case, the cost of production, the price of branch cotton per bushel, and the necessary raw materials in terms of quantity and quality (certified) are taken into account to guarantee standard cotton in terms of quality, weight, labor, and machinery necessary for [1] ha of Pima cotton crop production. In addition, cotton producers are betting each year on increasing the amount of hectares available for Pima cotton crop production given that this growth upholds cotton quality levels, increases the yield, and is beneficial to farmers.

Table 2: Available Area (Ha) for Growing Cotton in the Department of Piura

Years	Available area (ha)
2017	1.350
2018	3.000
2019	5.000

When using the LINGO software package, the following variables were proposed and determined for the case study:

The following variables were used in the model:

- X_i represents the amount of resource i based on production costs

1) = Organic matter
2) = Certified seeds
3) = Machine hours
4) = Water to be used
5) = Labor
6) = Fertilizers to be used

- Q_i is the quantity of cotton produced (i) based on income

1) = Pima cotton

5. Analysis of results

For validation, we generated this infrastructure with the LINGO software package, an application capable of solving mathematical programming models. We used version 13.0 of this software, which works with 2 kinds of documents: documents with .lg4 extension and documents with .lgr extension (wherein Lingo displays solutions). On the other hand, once LINGO creates an .lgr document with model data, it can be modified according to the restrictions in place by adding any convenient explanation, titles, and comments in the .lg4 document. Data must be correct in LINGO's language. Otherwise, an error message will be generated instead of the solution.

For the solution based on the case study, we determined the amount of Pima cotton (in kg) that will be produced per hectare and the amount of raw materials required to preserve the resulting yield.

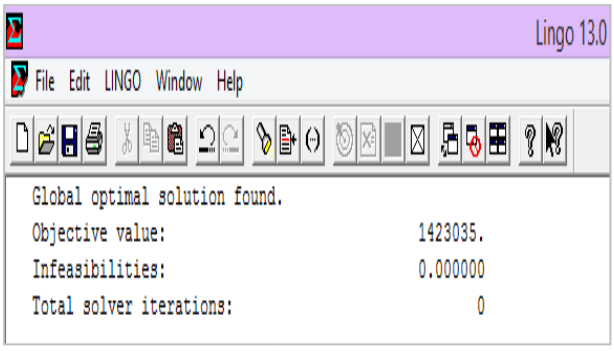
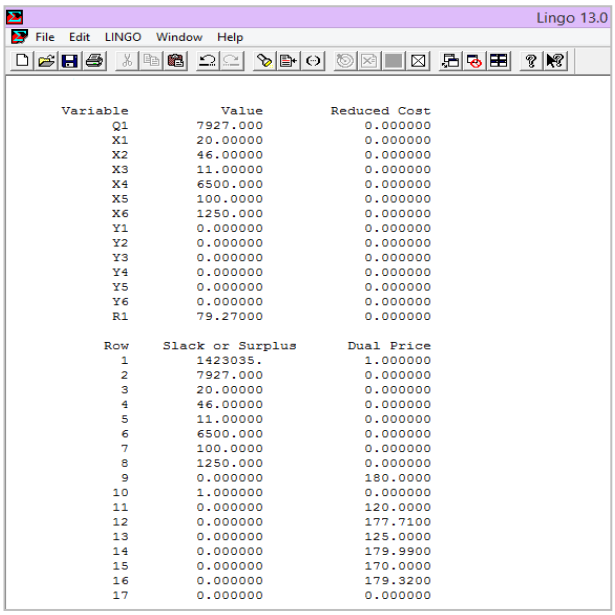


Fig. 3: Results of the Objective Function.

Figure 4 shows the amount of Pima cotton (in kg) that will be obtained in a hectare of cotton crop, which is represented by the Q1 variable. More specifically, 7,927 kg of cotton produced in 1 ha represents a yield of 172 bushels/ha (1 bushel/ha = 46 kg/ha). Likewise, the Xi variables represent the amount of resources required to obtain the standard yield per hectare.



Lingo 13.0

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Variable	Value	Reduced Cost
Q1	7927.000	0.000000
X1	20.00000	0.000000
X2	46.00000	0.000000
X3	11.00000	0.000000
X4	6500.000	0.000000
X5	100.0000	0.000000
X6	1250.000	0.000000
Y1	0.000000	0.000000
Y2	0.000000	0.000000
Y3	0.000000	0.000000
Y4	0.000000	0.000000
Y5	0.000000	0.000000
Y6	0.000000	0.000000
R1	79.27000	0.000000

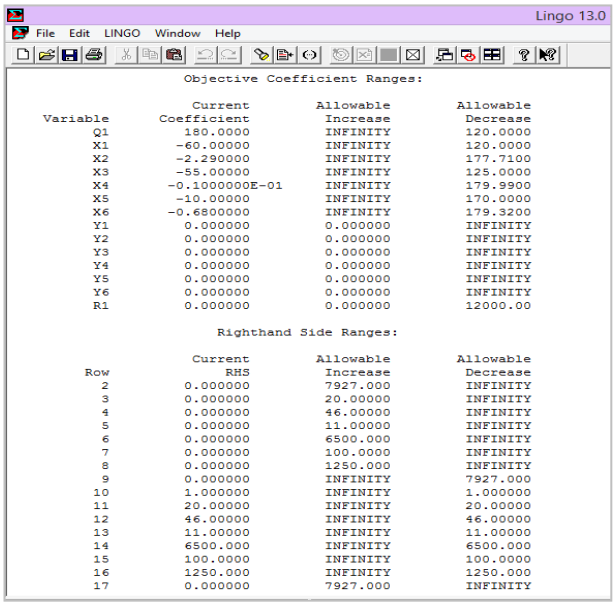
Row	Slack or Surplus	Dual Price
1	1423035.	1.000000
2	7927.000	0.000000
3	20.00000	0.000000
4	46.00000	0.000000
5	11.00000	0.000000
6	6500.000	0.000000
7	100.0000	0.000000
8	1250.000	0.000000
9	0.000000	180.0000
10	1.000000	0.000000
11	0.000000	120.0000
12	0.000000	177.7100
13	0.000000	125.0000
14	0.000000	179.9900
15	0.000000	170.0000
16	0.000000	179.3200
17	0.000000	0.000000

Fig. 4: Optimal Solution Results.

The slack or surplus section shows how close we are to satisfy a restriction as an equality. When the value is [0], it means that the restriction is satisfied as an equality. Otherwise, in the availability restriction for resource 1 (organic matter), a variable slack of 20 kg must be added. The dual price for each restriction is interpreted as an amount in which the objective would improve by the restriction constant term increased by 1 unit. In other words, the dual price 120 for the availability of resource 2 (kg), if we add one more unit of work, the objective value would improve by 120 units to a value of [1], 423155.

Figure 5 displays sensitivity results in 2 parts. In the first part, the data for objective coefficient ranges show the current coefficient value for each variable according to the objective function, i.e., to what extent can the value increase or decrease so that the optimal solution does not change. For example, if the price of resource 2 does not fall below 177.7 soles, the optimal solution will remain the same.

The second part consists of right-hand side ranges, which display the independent term for each restriction along with the maximum increasing or decreasing value so that the variables of the optimal solution remain the same. For example, the quantity of resource 2 must not increase by more than 46 kilos/ha.



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Objective Coefficient Ranges:

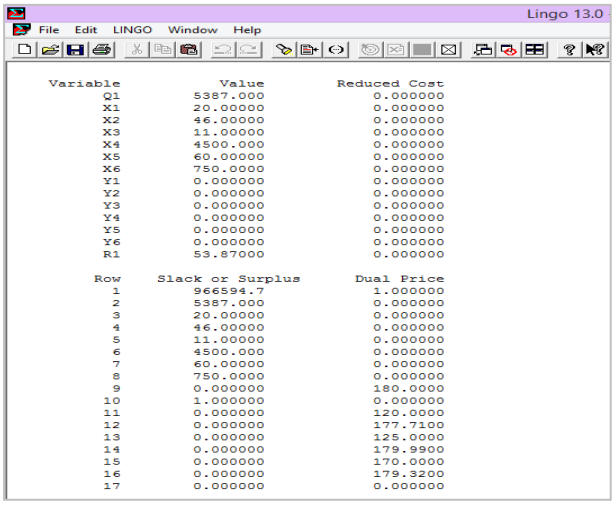
Variable	Current Coefficient	Allowable Increase	Allowable Decrease
Q1	180.0000	INFINITY	120.0000
X1	-60.00000	INFINITY	120.0000
X2	-2.290000	INFINITY	177.7100
X3	-55.00000	INFINITY	125.0000
X4	-0.1000000E-01	INFINITY	179.9900
X5	-10.00000	INFINITY	170.0000
X6	-0.6800000	INFINITY	179.3200
Y1	0.000000	0.000000	INFINITY
Y2	0.000000	0.000000	INFINITY
Y3	0.000000	0.000000	INFINITY
Y4	0.000000	0.000000	INFINITY
Y5	0.000000	0.000000	INFINITY
Y6	0.000000	0.000000	INFINITY
R1	0.000000	0.000000	12000.00

Righthand Side Ranges:

Row	Current RHS	Allowable Increase	Allowable Decrease
2	0.000000	7927.000	INFINITY
3	0.000000	20.00000	INFINITY
4	0.000000	46.00000	INFINITY
5	0.000000	11.00000	INFINITY
6	0.000000	6500.000	INFINITY
7	0.000000	100.0000	INFINITY
8	0.000000	1250.000	INFINITY
9	0.000000	INFINITY	7927.000
10	1.000000	INFINITY	1.000000
11	20.00000	INFINITY	20.00000
12	46.00000	INFINITY	46.00000
13	11.00000	INFINITY	11.00000
14	6500.000	INFINITY	6500.000
15	100.0000	INFINITY	100.0000
16	1250.000	INFINITY	1250.000
17	0.000000	7927.000	INFINITY

Fig. 5: Sensitivity Analysis Results.

Scenario 1. Consider 20 ton/ha as the maximum amount of organic matter, 4,500 m^3/ha as the minimum amount of water per crop hectare, 750 kg (15 bags) of fertilizers, and 60 man hours. With these variables, we obtain a production of 5,387 kg of cotton in 1 ha, representing a yield of 117 bushels/ha (1 bushel/ha = 46 kg/ha). With a projected demand of 53,000 metric tons, which covers 66.3% of the market.



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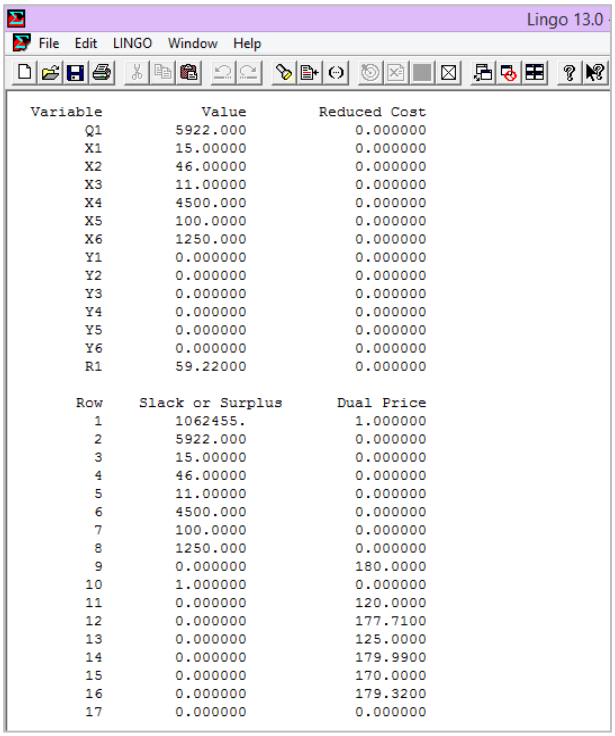
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Variable	Value	Reduced Cost
Q1	5387.000	0.000000
X1	20.00000	0.000000
X2	46.00000	0.000000
X3	11.00000	0.000000
X4	4500.000	0.000000
X5	60.00000	0.000000
X6	750.0000	0.000000
Y1	0.000000	0.000000
Y2	0.000000	0.000000
Y3	0.000000	0.000000
Y4	0.000000	0.000000
Y5	0.000000	0.000000
Y6	0.000000	0.000000
R1	53.87000	0.000000

Row	Slack or Surplus	Dual Price
1	966594.7	1.000000
2	5387.000	0.000000
3	20.00000	0.000000
4	46.00000	0.000000
5	11.00000	0.000000
6	4500.000	0.000000
7	60.00000	0.000000
8	750.0000	0.000000
9	0.000000	180.0000
10	1.000000	0.000000
11	0.000000	120.0000
12	0.000000	177.7100
13	0.000000	125.0000
14	0.000000	179.9900
15	0.000000	170.0000
16	0.000000	179.3200
17	0.000000	0.000000

Fig. 6: Optimal Solution Results for Scenario 1.

Scenario 2. Consider 15 tn/ha as the minimum amount of organic matter and 4,500 m^3/ha as the minimum amount of water per crop hectare. With these variables, we obtain a production of 5,922 kg of cotton in [1] ha, representing a yield of 128 bushels/ha (1 bushel/ha = 46 kg/ha). With a projected demand of 59,000 metric tons, which covers 73.8% of the market.



Lingo 13.0

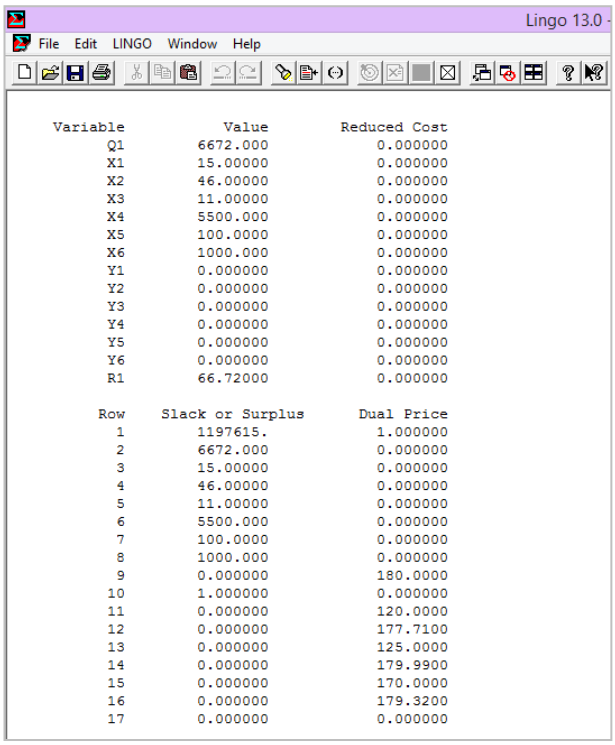
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Variable	Value	Reduced Cost
Q1	5922.000	0.000000
X1	15.00000	0.000000
X2	46.00000	0.000000
X3	11.00000	0.000000
X4	4500.000	0.000000
X5	100.0000	0.000000
X6	1250.000	0.000000
Y1	0.000000	0.000000
Y2	0.000000	0.000000
Y3	0.000000	0.000000
Y4	0.000000	0.000000
Y5	0.000000	0.000000
Y6	0.000000	0.000000
R1	59.22000	0.000000

Row	Slack or Surplus	Dual Price
1	1062455.	1.000000
2	5922.000	0.000000
3	15.00000	0.000000
4	46.00000	0.000000
5	11.00000	0.000000
6	4500.000	0.000000
7	100.0000	0.000000
8	1250.000	0.000000
9	0.000000	180.0000
10	1.000000	0.000000
11	0.000000	120.0000
12	0.000000	177.7100
13	0.000000	125.0000
14	0.000000	179.9900
15	0.000000	170.0000
16	0.000000	179.3200
17	0.000000	0.000000

Fig. 7: Optimal Solution Results for Scenario 2.

Scenario 3. Consider 15 tn/ha as the minimum amount of organic matter, 5,500 m^3/ha as the average amount of water per crop hectare, 1,000 kg (20 sacks) of fertilizers. With these variables, we obtain a production of 6,672 kg of cotton in 1 ha, representing a yield of 145 bushels/ha (1 bushel/ha = 46 kg/ha). With a projected demand of 66,000 metric tons, which covers 82.5% of the market.



Variable	Value	Reduced Cost
Q1	6672.000	0.000000
X1	15.00000	0.000000
X2	46.00000	0.000000
X3	11.00000	0.000000
X4	5500.000	0.000000
X5	100.0000	0.000000
X6	1000.000	0.000000
Y1	0.000000	0.000000
Y2	0.000000	0.000000
Y3	0.000000	0.000000
Y4	0.000000	0.000000
Y5	0.000000	0.000000
Y6	0.000000	0.000000
R1	66.72000	0.000000

Row	Slack or Surplus	Dual Price
1	1197615.	1.000000
2	6672.000	0.000000
3	15.00000	0.000000
4	46.00000	0.000000
5	11.00000	0.000000
6	5500.000	0.000000
7	100.0000	0.000000
8	1000.000	0.000000
9	0.000000	180.0000
10	1.000000	0.000000
11	0.000000	120.0000
12	0.000000	177.7100
13	0.000000	125.0000
14	0.000000	179.9900
15	0.000000	170.0000
16	0.000000	179.3200
17	0.000000	0.000000

Fig. 8: Optimal Solution Results for Scenario 3.

6. Discussion

This research depicted the current situation of cotton producers and how technology is being adapted to daily production. The study also focused on several factors related to lean manufacturing and the impact it has on operating activities.

This is shown in the case study as well as in the given scenarios since the obtained results allow for crop yields exceeding current yields currently obtained by cotton farmers as well as optimizing costs and time while reaching optimal levels of production for customers. The paper even includes the projected demand that can be supplied with the cotton yield produced in each case.

Although there are no studies related to cotton production, technologies implemented in other production sectors can be adapted to this case study.

7. Conclusions

The article presents the development of a programming model to determine cotton crop yields considering all resources necessary for its production.

The main contribution of this work is the standardization of the optimal quantities that every cotton producer may execute to grow Pima cotton in Piura. In addition, this work specifies which quantities may be changed to achieve the same yield per hectare as well as the costs for each resource used.

This study is based on the use of a lean manufacturing tool, which relies on TOC to determine production bottlenecks. For this purpose, the entire production chain was considered to determine which activities were necessary and which were not necessary.

Likewise, the limitations and restrictions of the improvement were identified using indexes for their control and monitoring. When assessing whether the proposed model was both optimal and profitable, we compared our model with the current yield obtained by cotton producers, which is 100 bushels/ha of Pima cotton. The proposed model yielded an improved result: 172 bushels/ha.

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