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PROFITABILITY AND RISK OF THE MULCH-DRIP IRRIGATION SYSTEM ONION PRODUCTION, COSTA RICA

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Abstract:

The profitability and risk of onion cultivation in Costa Rica in a conventional production system and an alternative system with drip irrigation and mulch were compared. Production costs for both systems and real agricultural prices were estimated, which were important factors in the simulation of profitability scenarios. The results suggest that profitability improves in the alternative production system and risk decreases significantly, which allows mitigating the adverse conditions that the farmer usually faces. Despite the alternative production, onion growers are still exposed to high market risk due to price volatility.
Keywords: *Mulch, agricultural, cost, onion, crop, alternative, production, Monte Carlo Simulation, risk analysis.*
JEL Codes: *G17, Q12, Q15, Q16.*

1. Introduction

The onion is part of the basic food basket of the country, generates 20 thousand jobs a year and is a source of income for approximately 400 farmers. It is sown at marked times of the year, so onion prices fall when there is a high supply of production. Farmers seek to produce in times of low supply and for this they use technology and varieties appropriate to each area in order to achieve market windows (CIMS, 2010).

In recent years, onion production in Costa Rica exceeds 33,000 tons, onion imports represent 3% of national production, prices during the year fluctuate by supply and demand, the wholesale modal price is 0.83 $ USD and the international onion market price remains below the dollar per kilogram (Serrano & Morales, 2017). The annual per capita consumption of onion in Costa Rica is 5-7 kg, which translates into a total domestic consumption of 26,000 tons with a gross production value of 7 million dollars (MAG, 2012).

In Costa Rica, the Ministry of Agriculture and Livestock (MAG) divides the onion producing areas into three geographic areas: Central Valley (Llano Grande, Cot and Potrero

Cerrado de Cartago), Middle Zone (Santa Ana, Escazú, La Guacima and Belén) and Chorotega Region (Cañas, Bagaces, Fortuna and Carillo); being the Central Valley where the largest proportion of the productive area is concentrated. Through the “Tierra Blanca Agricultural Extension Agency”, MAG promotes the development of precision agriculture and added value (MAG, 2007).

Cartago is one of the provinces with the greatest potential for agricultural production in Costa Rica. In 2017, 55% of the cultivated area of Costa Rica belonged to this province and onion was one of the fastest growing products. The largest onion areas are in the north of Cartago, but intensive cultivation has generated phytosanitary problems such as resistance to pathogens and pests, and failing that, reduced profits (MAG, 2007).

Cartago produced 74% of the national volume of onion in approximately 1 000 hectares (CNP, 2015). The main towns with onion production are Llano Grande, Tierra Blanca and Pacayas, with an annual rainfall of 1 400 to 2 600 mm, winter occurs between January and May and between October-December there is the highest rainfall, contrary to January -April; This behavior limits onion production due to the availability of water (MAG, 2012).

Onion production costs under a conventional system are around $ 15,000 per hectare, significant expenses are generated in the application of herbicides and labor in manual weeding in conventional production systems, while the yield is around 30 tons per hectare (CIMS, 2010). Other estimates indicate that the average onion yield in Costa Rica is 25 tons per hectare, low in relation to other countries such as the United States, where the best onion yield is obtained with 56 tons (Serrano & Morales, 2017).

The farmers of Cartago have low yields in relation to the genetic potential of the varieties used and one of the reasons is because they do not have the necessary water availability throughout the year to maintain adequate yields, reducing the level of production and profitability of the crop (Chinchilla, 2018).

The mulch used in onion cultivation, known as "onion mulch", is a soil cover that consists of the use of black plastic inside, to improve weed control since it reduces germination and color. silver on the outside to reflect sunlight, enhancing the photosynthesis process. This improvement in productive efficiency allows generating higher yields (Ucles, 2011).

In onion cultivation, the use of mulch has been of interest to MAG (2007) since it allows increasing yield, reducing the use of agricultural inputs and achieving efficient water use (El Mundo CR, 2020).

Climate change has affected the availability of water for agricultural use and has forced the authorities of the Costa Rican agri-food sector to seek and adopt solutions such as mulch (Montonya, 2020). The efficient use of water resources is important to provide more food to a growing population, under a world scenario of less availability (Mata, et al., 2011).

Conventional production with reduced negative impacts is possible with the incorporation of techniques such as fertigation and mulch, which could lead to an increase in yields from 25 to 33 tons per hectare (Serrano & Morales, 2017). However, the cost of using onion mulch is not known, so it is important to demonstrate whether the investment provides better economic benefits than producing in a conventional system.

In the world, it has been shown that through the use of irrigation systems and mulch covers in the soil, economic yields can be increased by 100%, by reducing production costs, while the use of water is reduced by 50 % between fertigation and sprinkling. (Montoya, 2020).

In studies carried out that use drip tape systems, compared to a conventional onion system, better efficiency indicators were determined, producers in the north of Cartago have the best technical indicators of efficiency in onion supply costs, in hand of work, seed and fertilizers used in the productive cycle (CIMS, 2010).

Onion irrigation techniques have shown positive results in Costa Rica. One of the strengths of the use of drip irrigation in onion is the efficiency of the water resource, and among the opportunities is the use of the irrigation system for nutrition through the implementation of fertigation; as part of the weaknesses is the high investment cost and the longer investment recovery time (CIMS, 2010).

Among the weaknesses of the use of this technique in onion cultivation, is the little knowledge of the technology and among the threats, the fear of change due to the economic risk that is assumed in the learning curve when incorporating productive technology (CIMS, 2010).

Under a conventional system, Cartago producers must schedule planting between April and May with harvest periods in August and September (4 months later). In view of this, the seedbed should be scheduled one month before transplantation to the field. This implies that the majority of producers who do not have irrigation are exposed to the risk that their crops will be put on the market at the time of greatest supply and lowest prices. With the mulch system it is possible to program production continuously, since there is plastic coverage and drip irrigation, so production would be available at all times and the producer would have the opportunity to compensate moments of low prices with moments of high prices.

The question arises: What is the profitability of establishing a mulch system in a conventional onion crop in the north of Cartago under multiple probability scenarios?

The results can be considered as preliminary findings that serve as the basis for future research

2. Reference Framework

2.1 Onion Crop in Cartago

The largest areas in the northern area of Cartago are sown in April to harvest in August, taking advantage of the time of greatest availability of rainwater. The second sowing season is between August and September to harvest in December or January (MAG, 2007). The third sowing season depends on the availability of water for irrigation, and takes place between January and March, to harvest in May or June; at this time 50% of the cycle depends on irrigation (MAG, 2007).

The moisture available in the root system of the plant is usually provided by rain. Due to the different rainfall conditions that exist in a conventional system, plants can suffer water stress due to not having the necessary resources for their correct development. By using a drip irrigation system, the producer can distribute the necessary irrigation applications in a crop to obtain high yields (Mata, et al., 2011). Hence the importance of conducting profitability analysis in agricultural systems to guide investment decision-making (FAO, 2016).

Weed control determines the yield of the onion crop, since the plants are not competitive due to the planting density used; weeds compete for water, light, nutrients and are sources of pathogens and insects (Lardizábal, 2007). The herbicides used in onion (commonly with oxyfluorfen as an active ingredient) are not selective for cultivation, which implies counterproductive effects such as plant stress (Lardizábal, 2007).

2.2 Plastic Mulch System

Around 70% of the water consumed in the world is used in production systems; Due to the increase in world population and the negative effects of climate change, availability will be less and less, so cultivation technologies must be adapted to improve water use (World Bank, 2021).

There are different types of ground covers, including plastic mulch, which consists of black plastic on the inside and silver on the outside to reflect sunlight. It is used to improve weed control (black color reduces weed germination) and decrease the erosion process, which leads to higher crop yields (Ucls, 2011).

When mulch is used, the use of water resources is improved, since evaporation and the loss of nutrients from the soil are reduced by maintaining humidity and temperature inside the plastic, the growing cycle is shorter and the maintenance costs (Uclés, 2011). Covers are used, the damage caused by pathogens within the crop is reduced because splashing of the soil is minimized when it rains and pathogens are reduced with favorable conditions of high humidity and lower temperatures, so fewer phytosanitary products are used for the control in the growing cycle (Namesny, 2020).

Reflection of sunlight is enhanced with silver mulches. This process strengthens the photosynthesis process of plants and consequently yields, in addition to reducing nitrogen loss due to reduced evaporation (Namesny, 2020). In mulched systems, the use of drip tapes for fertigation is recommended, improving the applications of agrochemicals, nutrients and water directed to the soil and the root system (Jiménez & Rodríguez, 2021).

The investment of mulching and irrigation system could be recovered in the first harvest, and the use of these systems is for three consecutive cycles of onion production, something that is not done in conventional production (Fonseca, J, personal communication, 2020).

The benefits of an investment are sales minus expenses. Among the expenses are fixed costs, which are maintained over time, and variable costs, which depend on the level of production or demand for the good or service (Mayorga, 2019).

3. Methodology

A case study research was conducted through qualitative / quantitative processes. Semi-structured interviews on production costs were applied to three onion producers in the northern zone of Cartago, with good agricultural management and high yields in conventional production systems. These farmers diversify their production throughout the year by rotating potato, onion and carrot crops.

A farmer who has implemented the mulch system in onion cultivation for six consecutive years was also interviewed. This farmer has received constant technical assistance, improving his learning curve.

The production costs in the conventional production systems were averaged to structure a model of cumulative monthly cost comparable to the mulch production system, generating cost standards for the management control of the production systems.

In both cases, an area of 7000 square meters (0.7 hectares), known in Costa Rica as "apple" (mz), was determined as the costing unit. The cost model considered expenditures on labor, agricultural inputs, seeds or seedlings, and other indirect costs (fuel, maintenance, and equipment depreciation).

3.1 The Proposed Model for Static Conditions

In Costa Rica there is a single wholesale market (CENADA), which is responsible for publishing the prices of agricultural products that serve as a reference to establish prices throughout the marketing chain. The basic model proposed in this research is based on the fact that the farmer is a price taker and assumes the farm gate price (common condition), which is a fraction of the closing price in the wholesale market and is represented by the following equation:

$$FP = (1 - k)WP \tag{1}$$

where *FP* is farm gate price; *WP* is wholesale price; k is chain margin between the wholesaler and the farmer ranging from 0 to < 1.

The *k* parameter is not observed in the local market because there are no official statistics. In this research k=0.30[1] was used because farmers accept it as a reasonable level, but it is important in future research to estimate its value by surveying a representative sample of farmers.

The following is a basic equation to calculate the economic utilities of the agricultural production systems in an area of 7000 m^2:

$$\pi = (FP)Q_i - (c_{Si}S_i + c_{Li}L_i + c_{Ii}I_i) \quad (2)$$

where Q_i is yield of the onion crop in the i-esim production system; c_{si} is unit seed cost; S_i is seed requirement; c_{Li} is unit labor cost; L_i is labor requirement; c_{Ii} is unit input cost; I_i is input requirement (the proportion of mulching investment is included here); i is 1 for conventional system and 2 for mulching system.

3.2 Incorporating Risk into the Model

Onion growers' expectations indicate that low prices are more prevalent in the market than high prices. To simulate the behavior of the real price of onion in the Costa Rican market, three probability distributions with particular asymmetry and kurtosis were used: Normal, Inverse Gaussian and Lognormal. The results of the Inverse Gaussian and Lognormal distributions were contrasted with the results of the Normal distribution as a reference in the empirical analysis.

The inverse Gaussian distribution represents the first step for Brownian motion, has several properties analogous to a Gaussian distribution, and includes two parameters: the mean and lambda λ (Folks & Chhikara, 1978; Tweedie, 1956).

The lognormal distribution is obtained when the logarithms of a continuous variable are described by a normal distribution, that is, the logarithm of this random variable is normally distributed. A variable can be modeled as Lognormal if it can be viewed as a multiplicative product of many small independent factors (Holgate, 1989).

The normal distribution is one of the most used in empirical study, since it has the ability to represent the behavior of many natural and economic phenomena. Simple visual exploration of the data can suggest the shape of its distribution; however, this distribution implies that the data cluster symmetrically around a mean where the skewness is zero and the kurtosis is 3 (Bryc, 1995).

Risk variables other than the actual onion price are modeled using the triangular distribution, which is very useful in cases where the best estimates are based on expert judgment (Evans, Hastings, Peacock & Forbes, 2011).

[1] This implies that the chain's margin from the producer to the wholesale price is 30%, so the farmer receives 70% of the wholesale price.

Table 1. Mathematical Definitions of the Probability Distributions Fitted

Item	Inverse Gaussian distribution	Lognormal distribution	Normal distribution	Triangular distribution
PDF	$\sqrt{\frac{\lambda}{2\pi x^3}}\, e^{\left[-\frac{\lambda(x-\mu)^2}{2\mu^2 x}\right]}$ (3)	$\frac{1}{x\sigma\sqrt{2\pi}} e^{\left(-\frac{lnx-\mu}{2\sigma^2}\right)}$ (10)	$\frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(-\frac{x-\mu}{\sigma}\right)^2}$ (18)	$\begin{cases} 0 \quad for \quad x < a, b < x \\ \frac{2(x-a)}{(b-a)(c-a)} \quad for \ a \le x < c \\ \frac{2}{b-a} \quad for \ x = c \\ \frac{2(b-x)}{(b-a)(b-c)} \quad for \ b < x \end{cases}$ (24)
CDF	$\Phi\left[\sqrt{\frac{\lambda}{x}}\left(\frac{x}{\mu}+1\right)\right] + e^{\frac{2\lambda}{\mu}}\Phi\left[-\sqrt{\frac{\lambda}{x}}\left(\frac{x}{\mu}+1\right)\right]$ (4*)	$\int_0^x \frac{1}{x\sigma\sqrt{2\pi}} e^{\left(-\frac{lnx-\mu}{2\sigma^2}\right)} dx$ (11)	$\int_0^x \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(-\frac{x-\mu}{\sigma}\right)^2} dx$ (19)	$\begin{cases} 0 \quad for \quad x \le a \\ 1 + \frac{(x-a)^2}{(b-a)(c-a)} \quad for \ a < x \le c \\ 1 - \frac{(b-x)^2}{(b-a)(b-c)} \quad for \ c < x < b \\ 1 \ for \ b \le x \end{cases}$ (25)
Mean	μ (5)	$e^{\left(\mu+\frac{\sigma^2}{2}\right)}$ (12)	μ (20)	$\frac{a+b+c}{3}$ (26)
Mode	$\mu\left[\left(1+\frac{9\mu^2}{4\lambda^2}\right)^{1/2} - \frac{3\mu}{2\lambda}\right]$ (6)	$e^{(\mu-\sigma^2)}$ (13)	μ *(21)*	c

Median	No closed form analytic equation is known, but is evaluated as quantile (0.5)	e^{μ} (14)	μ (22)	$\begin{cases} a+\sqrt{\frac{(b-a)(c-a)}{2}} & for\ c \geq \frac{a+b}{2} \\ b-\sqrt{\frac{(b-a)(c-a)}{2}} & for\ c \leq \frac{a+b}{2} \end{cases}$ (27)
Standard deviation	$\sqrt{\frac{\mu^3}{\lambda}}$ (7)	$\sqrt{(e^{\sigma^2}-1)e^{(2\mu+\sigma^2)}}$ (15)	σ (23)	$\sqrt{\frac{a^2+b^2+c^2-ab-ac-bc}{18}}$ (28)
Skewness	$3\left(\frac{\mu}{\lambda}\right)^{1/2}$ (8)	$(e^{\sigma^2}+2)\sqrt{e^{\sigma^2}-1}$ (16)	0	$\frac{\sqrt{2}(a+b-2c)(2a-b-c)(a-2b+c)}{5(a^2+b^2+c^2-ab-ac-bc)^{3/2}}$ (29)
Kurtosis	$3+\frac{15\mu}{\lambda}$ (9)	$3+e^{4\sigma^2}+2e^{3\sigma^2}+3e^{2\sigma^2}-6$ (17)	3	$3-\frac{3}{5}$

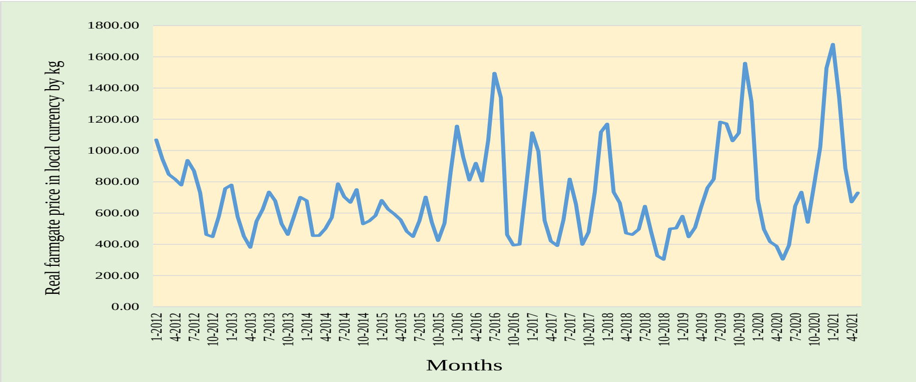
Source: Adapted from Folks & Chhikara (1978); Holgate (1989); Bryc (1995).

*/ Φ=cumulative frequency normaldistribution

4. Results and Discussion

4.1 Modeling the Main Risk Variables

The historical trend of the onion price paid to the producer (calculated with equation 1) indicates that in recent years the price fluctuated more strongly at the beginning of each decade (Figure 1). However, the observations present in each decade, although they exert greater variability, allow the establishment and visualization of a broader analysis scenario for the visualization of the price in the long term.



Source: Prepared based on statistics from PIMA-CENADA.
Note:[*/] USD exchange rate is 600 units of local currency (colones).

Figure 1. Historical Trend of the Real Monthly Price[*] of Onion at the Farm Gate (2012-2021)

The prices paid to the producer do not follow the typical behavior of a normal distribution. On the contrary, these prices behave as an asymmetric distribution with a high concentration of values (Table 2). According to the Akaike information criterion (AIC), the normal distribution presents the least desirable value (lower values are expected), compared to the inverse Gaussian and lognormal distributions. Indeed, the historical trend indicates that there is a high concentration of cases around the mean, causing an excess of kurtosis with respect to the value 3, which corresponds to a normal distribution.

Table 2. Results of Probability Distributions Parameters Fitted for Farmgate Real Price

Parameter	Input[*]	Inverse Gaussian Distribution	Lognormal Distribution	Normal Distribution
Minimum	211.65	116.22	132.12	−∞
Maximum	1176.25	+∞	+∞	+∞
Mean	498.45	382.22	367.17	498.45
Mode	≈514.28	365.27	369.63	498.45
Median	460.79	450.20	449.66	498.45
Std Dev	203.19	207.38	213.13	203.19
Skewness	1.21	1.63	1.92	0
Kurtosis	4.22	7.42	10.34	3
AIC		1488.57	1489.07	1524.78
Lambda		1298.40		

Note:[*/] Time series data.

The cases of low prices have a high concentration, which translates into high probabilities of occurrence around $ 0.5 USD / kg. While the upper extreme value is around $ 1.67 USD but it has a low probability of occurrence. The data is visualized in Figure 2 and supports the producers' expectations regarding the price of onion.

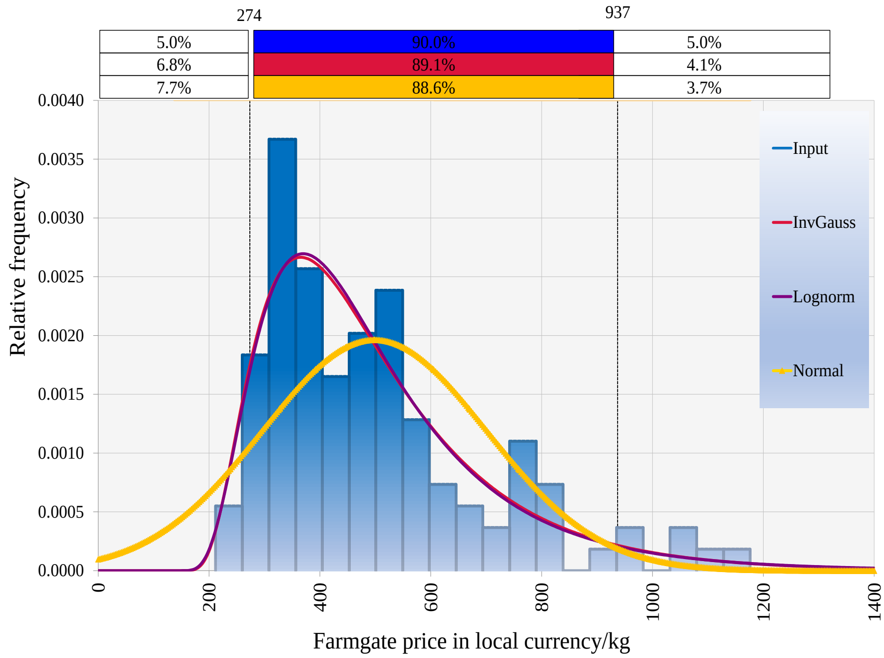


Figure 2. Alternative Probability Distributions Fitted for Farm Gate Onion Price (2012-2021)

4.2 Measuring the Profit and Risk Level

Regarding the selling price of onions, the producers interviewed expect to receive on average 0.83 US$0.83/kg.

However, when the simulation is run under risky conditions, the mean estimated with the Inverse Gaussian distribution (best fit) is 0.64 $ USD / kg, almost 23% less than the price expected by the producer.

The values of the other risk variables were defined by means of the Triangular distribution adjusted to the values according to the expert judgment of the farmers. The values of the parameters selected for the simulations are shown below (Table 3). The values for the static scenario according to the information reported by the producers are highlighted in gray.

The simulation of the static scenario without incorporating the risk of variability in the parameters showed an increase of 14% in the profitability of the covered crop system with coverage compared to the conventional system. Table 4 summarizes the results of the simulation in the static scenario applying the values of the parameters according to the expert judgment of the farmers.

Table 3. Parameters Settings for Risk Variables Used in Simulation Analysis

Item	Mean	Expected Mean	Minimum	Maximun	Standard deviation	Probability distribution
Farmgate price ($/kg)	0.83	0.64			0.35	Inverse Gaussian
Seed unit cost ($/pound)	266.67	266.67	258.33	283.33	5.20	Triangular
Conventional labors & inputs cost ($/m²)	2.11	2.11	1.55	2.35	0.17	Triangular
Mulch - Labors & inputs cost ($/m²)	2.39	2.39	2.19	2.51	0.07	Triangular
Conventional -Seed requirement (pounds/mz)	3	3	2	5	0.62	Triangular
Mulch -Seed requirement (pounds/mz)	2	2	2	2	0.00	Triangular
Conventional system -Yield (kg/mz)	24000	24000	15000	35000	4089.28	Triangular
Mulch system - Yield (kg/mz)	32375	32375	29600	33300	786.10	Triangular

Table 4. Summary of Simulation with Static Conditions

Item	Value in US Dollars ($/mz)		Percentage over Income	
	Conventional	Mulch	Conventional	Mulch
Income	20000	26979	100.00%	100.00%
Tax on value added*	200	270	1.00%	1.00%
Net income	19800	26709	99.00%	99.00%
Seed cost	800	533	4.00%	1.98%
Labors & inputs cost	14787	16721	73.94%	61.98%
Total production cost	15587	17254	77.94%	63.95%
Profit	**4213**	**9455**	**21.06%**	**35.05%**

Note: */ Tax rate of 1%.

Table 5. Results of Simulation Under Risk Conditions in 10.000 Scenarios

Item	Value in US dollars ($/mz)	
	Convencional	Mulch
Investment (production cost)	15587	17254
Static profit	4213	9455
Expected profit under risk	604	2943
Lowest expected profit	-14168)	-14307)
Highest expectived profit	68826	$94825
Standard deviation of profit under risk	8953	$10897
Coefficient of variance	1482.74%	370.23%
Probability of loss	57.16%	47.99%
Return over investment under static conditions	27.03%	54.80%
Return over investment under risk	3.87%	17.06%

Under risky conditions, onion production in the alternative system with mulch and fertigation was more profitable than in conventional systems. On the other hand, the level of risk measured by the probability of loss decreased from 57.16% in the conventional system to 47.99% in the system with mulch and fertigation. Despite the improvement in the profitability and risk parameters, the probability of loss is high in both simulations due to the extreme volatility of onion prices.

The high risk in the onion production activity in Costa Rica is reflected in Figures 4 and 5, where the net income can be very high and also very low, which is consistent with the response of farmers to market conditions.

In the conventional production system, 3 pounds of onion seed were used and a yield of 24 tons / mz was obtained, while in the system with mulch and fertigation, 32 tons were obtained in the same area with 33% less seed. This indicates that the yield per seed is better in the mulch system.

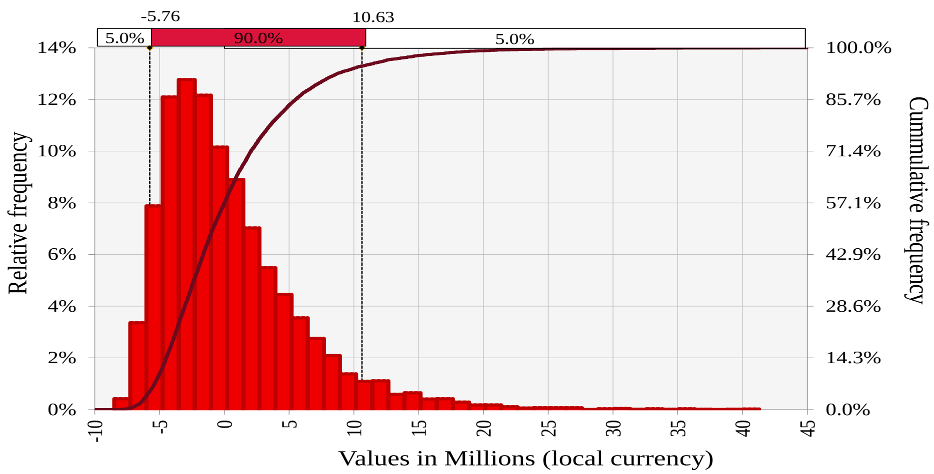


Figure 4. Probability Distribution of Conventional Onion Production System Under Risk

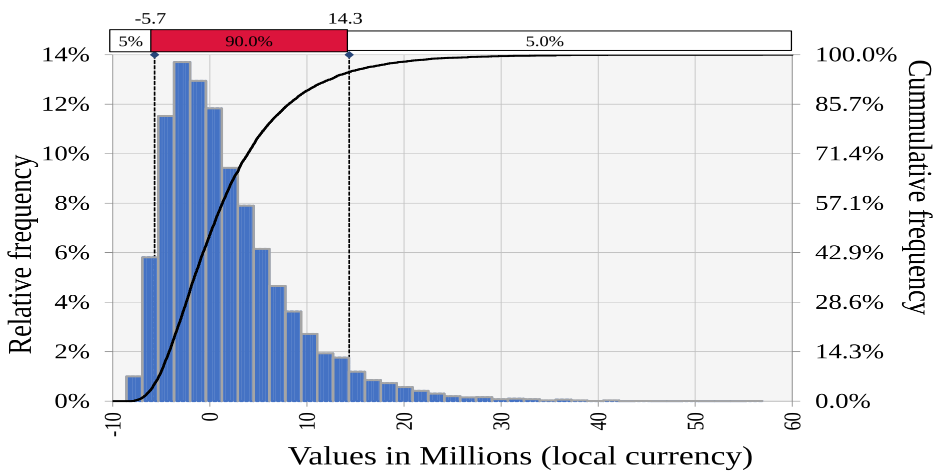


Figure 5. Probability Distribution of Alternative Onion Production System (Mulch) Under Risk

The interaction between the type of mulch and the crop is of utmost importance to improve agricultural performance, whether plastic materials or some type of organic material are used, so the response in yield may differ depending on the type of material and soil conditions (Frutos, et al., 2016). Likewise, the suppression of weed growth favors improvements in yield, since the fertilizer applications will be located mainly in the crop (Rosemeyer, 1995).

The results of this research are consistent with those obtained by González (2011), who shows a higher percentage of first quality bulbs and consequently a higher profitability. The drowning of the plant due to excess water is reduced (Hernández, Noguera, Cruz, & Indrani, 2008), which in the case of onion cultivation in Cartago is of great help for the producer, since it is an area of high rainfall during the rainy season.

5. Conclusions

This research shows that the use of mulch in onion cultivation is efficient for producers in the Northern Zone of Cartago, since it generates higher yields per area despite higher production costs.

The higher cost associated with production with plastic mulch was recovered in the same production cycle, giving the producer greater profitability than in the conventional system, as long as the farmer's practice is technically efficient.

Risk is affected by price volatility, and the results show that, regardless of the production system used, the probability of losses always exists, although to a lesser extent when mulch is used. Future research can analyze market risk hedges to manage risk for agricultural producers.

Despite the economic benefits obtained with the implementation of mulch, it is suggested to analyze mitigation measures against the possible negative effects caused by the use of plastic materials and inadequate treatment after its useful life in the crop. Alternatively, the use of biodegradable materials can be promoted.

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