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Production costs of golden button *Tithonia diversifolia* and corn *Zea mays* silage

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ABSTRACT

Currently, there is growing interest in the golden button plant, *Tithonia diversifolia* (Hemsl.) A. Gray (TD), a perennial shrub with a pantropical distribution that is native to and naturalized in Colombia. This species has demonstrated considerable potential as a forage plant and has been evaluated in silvopastoral systems and as silage for small ruminants. The objective of this study was to perform an economic analysis of the silage production process of *Tithonia diversifolia* (STD) in comparison with whole-plant maize silage (SMA). To estimate the production and ensiling costs of STD and SMA, a matrix was developed based on technical manuals from Agrosavia and price data from the National Administrative Department of Statistics (Dane, for its acronym in Spanish). The analysis was structured into three phases: crop establishment, silage production, and evaluation of productivity indicators. Financial metrics such as Net Present Value (NPV), Internal Rate of Return (IRR), and Return on Investment (ROI) were applied to assess profitability. The differential cost per ton was 85,461 COP for STD and 157,687 COP for SMA. The Total Annual Gross Income (TABI, for its abbreviation in Spanish) for STD exceeded that of SMA, as TD can yield up to five harvests per year, generating revenues of up to 45 million COP in its first year, whereas SMA, with only one or two harvests annually, generates approximately 29 million COP. Based on the productivity indicators for each crop, total annual profits were 22,789,510 COP·ha^{-1} for STD and 6,226,630 COP·ha^{-1} for SMA. From an economic standpoint, producing one ton of STD costs approximately 63% less than producing one ton of SMA.

Keywords: economic analysis, forage conservation, tropical forages, profitability.

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Costos de producción del ensilaje de botón de oro *Tithonia diversifolia* y maíz *Zea mays*

RESUMEN

En la actualidad se indaga de manera enfática en botón de oro *Tithonia diversifolia* (Hemsl.) A. Gray (TD), una hierba arbustiva perenne de expansión pantropical, propia y natural en Colombia, con probado potencial como planta forrajera, que se ha evaluado en sistemas silvopastoriles y como ensilaje para pequeños rumiantes. El objetivo fue desarrollar un análisis económico del proceso de ensilado de *Tithonia diversifolia* (STD) comparado con ensilado de Maíz (SMA) planta completa. Para estimar los costos de producción y ensilaje de STD y SMA, se elaboró una matriz basada en manuales técnicos de Agrosavia y datos de precios del Dane. El análisis se dividió en tres fases: establecimiento del cultivo, elaboración del ensilaje y evaluación de indicadores productivos. Finalmente, se aplicaron indicadores financieros como VPN, TIR y ROI para valorar la rentabilidad y, arrojó un costo diferencial de 85.461 y 157.687 COP\$.ton^{-1} para STD y SMA respectivamente. El Total Ingreso Bruto Anual (TIBA) del STD es superior al de SMA, pues TD con cinco cosechas al año alcanza ingresos de hasta 45 millones COP en su primer año, mientras que SMA, con una o dos cosechas al año, apenas llega a 29 millones COP. Con base en los indicadores productivos que mostró cada cultivo, se logró una ganancia total anual de 22.789.51 y 6.226.630 COP·ha^{-1} para STD y SMA, respectivamente. En términos económicos, producir una tonelada de STD cuesta un 63% menos que de SMA.

Palabras clave: análisis económico, conservación de forrajes, forrajes tropicales, rentabilidad.

INTRODUCTION

In tropical regions such as Colombia, cattle feeding systems are primarily based on direct grazing. However, during the dry season, both the availability and quality of forages decline, leading to increased structural fiber content, reduced digestibility, and higher methane emissions (Morales & Ortiz, 2018; Vargas *et al.*, 2018; Partida *et al.*, 2019; Quintero *et al.*, 2021). Grazing systems depend heavily on soil fertility and climatic variability, both of which directly affect pasture availability (Angulo *et al.*, 2022). Consequently, the use of harvested forages and preservation methods, such as silage, has become essential to ensure a consistent feed supply for livestock (Guatusmal *et al.*, 2020; Miguel *et al.*, 2023).

Tithonia diversifolia (TD) is a pantropical shrub species commonly found in the coffee-growing region of Colombia. It has demonstrated high potential as a forage resource and has been evaluated in silvopastoral systems and as silage (Mejía, Mahecha, & Angulo, 2016). This plant is characterized by high biomass production, drought tolerance, resilience to frequent cutting, low fertilization requirements, and favorable nutritional composition. It contains up to 20% crude protein, high levels of soluble carbohydrates (25.7%), moderate fiber content (NDF: 33–45%; ADF: 26–29%), and secondary metabolites such as phenols and tannins, which contribute to reduced methane emissions (Holguín *et al.*, 2015; Mejía *et al.*, 2016; Meza *et al.*, 2021; Gallego *et al.*, 2016; Hernández *et al.*, 2022). TD thrives naturally at elevations of up to 2,000 m a.s.l. in the coffee-growing region of

Colombia, where it maintains efficient biomass production, persistence during the dry season, tolerance to frequent cutting, and consistently high nutritional value (Holguín *et al.*, 2015; Meza *et al.*, 2021; Vivas *et al.*, 2022).

Ensiling enhances the utilization of TD by enabling early harvest maturity, stabilizing forage availability, reducing production costs, and supporting diversification toward stall-fed livestock systems among small-scale coffee growers (Castaño *et al.*, 2023). In forage and livestock production systems, production costs are typically divided into fixed costs—such as land rental and infrastructure—and variable costs, which fluctuate with production volume and include inputs, labor, fertilization, and machinery (Báez *et al.*, 2023; de las Cuevas *et al.*, 2024). Based on this cost structure, unit costs can be calculated and expressed per ton of forage, allowing for the assessment of technical and financial efficiency within the evaluated systems (Báez *et al.*, 2022).

Economic analysis is crucial in tropical livestock production, as it enables the evaluation of the actual profitability of technologies or forage alternatives, considering their impact on net margins and overall system sustainability (Junca *et al.*, 2025; Murgueitio, 2023). Within this framework, *Tithonia diversifolia* has shown strong potential due to its ecological adaptability, favorable agronomic performance, relatively low production cost, and the added value it provides in animal feeding, whether used as fresh forage or silage (Mejía *et al.*, 2016). Based on these considerations, the present study compares the production costs of *Tithonia diversifolia* silage (STD) and maize silage (SMA) to assess their economic feasibility in tropical livestock systems.

MATERIALS AND METHODS

Study location

The biomass production of *Tithonia diversifolia* (TD) and maize for silage was carried out at the Experimental Center of the Universidad Nacional de Colombia, Palmira Campus (CEUNP, for its abbreviation in Spanish), located in Candelaria (Valle del Cauca) at 3°25'34″ N, 76°25′53″W, at an altitude of 951 m a.s.l. The site has average temperatures ranging from 23 to 27 °C, a relative humidity of 75%, and a mean annual precipitation of 1,000 mm, distributed across two rainy seasons (Vallecillo *et al.*, 2022).

Biological material

Tithonia diversifolia

An established one-year-old *Tithonia diversifolia* field at CEUNP was used, planted at a density of 10,000 shrubs·ha^{-1}. Based on prior experience, a uniformity cut (UC) was performed at a height of 40 cm, followed by a single irrigation to field capacity. Fertilization was applied in three installments—on days 5, 10, and 15 after the UC—using 340, 245, 70, and 30 kg·ha^{-1} of nitrogen (N), phosphorus (P), potassium (K), and micronutrients, respectively. To apply the fertilizer as a root drench (250–300 mL per shrub), a solution was prepared by diluting 7.6, 5.4, 1.6, and 0.66 kg of N, P, K, and micronutrients, respectively, in 200 liters of water (Castro, 2019; Holguín, 2016). The TD was harvested at 60 days of growth, during the pre-flowering stage, and cut at a height of 40 cm.

Maize (Zea mays)

As a control, a 6,400 m² plot was planted with Pioneer 30F35VYHR maize from

Corteva. For biosafety, conventional hybrid maize was sown in four rows surrounding the test plot. Conventional sowing practices were followed: soil preparation involved one pass of a plow and two passes of a harrow. Direct seeding was carried out with a Montana pneumatic planter–fertilizer machine, spacing rows 0.8 m apart and 7–8 plants·m^{-1}. The management plan was based on the guidelines provided by Corteva, Inc. and the technical manual for maize cultivation developed by Fenalce.

A pre-emergent herbicide (Prowl®, 2 L·ha^{-1}) was applied before sowing. Fertilization at planting included 20% of the nitrogen (Amidas) at 100 kg·ha^{-1}, 150 kg·ha^{-1} of monoammonium phosphate (MAP), and 50% of the potassium chloride (KCl) at 100 kg·ha^{-1}. At stages V4–V6, glyphosate herbicide (1.0 L·ha^{-1}) was applied, along with 40% of the nitrogen (200 kg·ha^{-1}) and the remaining 50% of KCl (100 kg·ha^{-1}). At V10–V12, the final 40% of nitrogen (200 kg·ha^{-1}) was applied. The irrigation system consisted of a 2-inch mainline drip system with 16 mm drip tape and 15 cm emitter spacing, operated for one hour per day depending on rainfall availability to avoid water stress. Maize was harvested at 90 days, during the R3 (milk) stage.

Silage Production

Tithonia diversifolia Silage (STD)

TD was manually harvested at 60 days, during the pre-flowering stage, and left in the field for 24 hours to reduce moisture content. Chopping to a length of 1 cm was performed using a manually fed forage harvester (IDEAGRO SIGMA 2002), followed by transportation. Under shelter, the chopped material was sprayed during baling with a 50:50 (v/v) molasses–water mixture and a microbial inoculant (Sil-All 4x4) at 10 g·t^{-1}, using a backpack sprayer. Baling was carried out with a stationary compactor (IDEAGRO SILO PACK J–402; 2 t·h^{-1}), and the material was packed into black polyethylene bags (gauge 6; 60 kg capacity), sealed with 0.4 mm polypropylene twine, labeled by date and treatment, and stored in a clean, dry, cool location.

Maize Silage (SMA)

Whole-plant maize was harvested at 90 days, during the R3 stage. Except for the field-wilting step (which was not performed for maize), the silage process was identical to that used for TD, employing the same equipment (IDEAGRO SIGMA 2002 and SILO PACK J–402) with continuous field processing and subsequent bagging.

ECONOMIC ANALYSIS

To estimate the production and silage costs associated with STD and SMA, a cost matrix was developed based on the *Manual de costos y análisis financiero para el sistema productivo de ganadería de ceba en la Orinoquía colombiana* and the *Guía de registro para costos de producción de pequeños y medianos agricultores de cultivos transitorios en el piedemonte llanero* (Agrosavia, 2020).

Agricultural input prices were obtained from updated data from the Agricultural Sector Price Information System (SIPSA, for its abbreviation in Spanish) of the National Administrative Department of Statistics (Dane, 2020) and from the 2020 Agricultural Cost Guide published by the Department of Rural Development, Agriculture, and Fisheries of the Government of Valle del Cauca.

The economic analysis was structured in three stages: (1) estimation of crop establishment costs, (2) estimation of silage processing costs, and (3) evaluation of financial profitability. First, cost types were identified and categorized. Fixed costs included those independent of production volume, such as land rental, while variable costs were directly associated with agricultural management and silage processing, including soil analysis, machinery use, fertilization, irrigation, labor, inputs, and storage. Unit costs were then calculated per ton of forage produced (COP·ton^{-1}) by dividing the total cost by the projected yield per hectare. This classification enabled a comparative analysis between the two crops, considering both absolute investment and relative efficiency per unit of product (Báez Quiñones *et al.*, 2023).

In the second stage, specific silage production costs for STD and SMA were integrated, encompassing the preparation of plant material and the associated use of machinery, labor, and preservation materials. Additionally, the productive parameters of each crop were characterized, including cycle duration, number of harvests per year, and yield (t·ha^{-1}).

Finally, a financial profitability analysis was conducted using three classical indicators proposed by Ross, Westerfield, and Jordan (2021):

- Net Present Value (NPV): estimates the present value of expected net returns, discounted at a 15% rate.
- Internal Rate of Return (IRR): reflects the annual effective return of the production system.
- Return on Investment (ROI): represents the ratio of cumulative net profit to initial investment.

The calculation of net cash flows and the subsequent analysis were carried out using Microsoft Excel 2016 spreadsheets. This methodological approach has been previously validated and applied in economic studies on silvopastoral systems and tropical forages such as *Tithonia diversifolia* (Báez Quiñones *et al.*, 2023; Junca Paredes *et al.*, 2025; Mejía-Díaz *et al.*, 2016).

RESULTS AND DISCUSSION

Establishment cost

The initial stage of establishing *Tithonia diversifolia* (TD) and maize is determined by the green forage yield of each crop. As shown in table 1, the difference between the two lies in the number of annual harvests and the yield per cut. TD outperformed maize, yielding 80 t·ha^{-1} per cut compared to 70 t·ha^{-1} for maize.

TABLE 1. Gross field yield for *Tithonia diversifolia* and whole-plant maize *Zea mays*

Characteristic	TD	MAIZE
Sowing to harvest time (days)	60	90
Yield (ton ha^{-1})	80	70
Harvests per year	5	2

Where: TD : *Tithonia diversifolia*

Source: own elaboration.

The total estimated costs were divided into variable and fixed components. For TD, these are presented in Table 2. Variable costs included machinery use, seed procurement, irrigation, fertilization, and labor, totaling a Total Variable Cost (TVC) of COP $9,601,908·ha^{-1}. Fixed costs comprised the monthly land lease, resulting in a Total Fixed Cost (TFC) of COP $440,000·ha^{-1}. Consequently, the Total Establishment Cost (TEC) for TD was COP $10,041,908·ha^{-1}.

For TD, the total establishment cost per hectare represents a one-time initial investment at the start of the project. As TD is a perennial species, the productive lifespan (PL) of a plantation was estimated at five years. To more accurately reflect the financial conditions faced by a producer, it was assumed that this investment was financed through a five-year consumer loan with fixed monthly payments of COP $245,306, calculated at an annual interest rate of 4.7% (Bancolombia). Accordingly, the establishment cost was amortized over the PL rather than being allocated entirely to the first year.

Regarding unit costs, the breakdown was as follows:

- Unit Fixed Cost (UFC): COP $5,500·t^{-1}
- Unit Variable Cost (UVC): COP $120,024·t^{-1}
- Total Unit Cost (TUC): COP $125,524·t^{-1}

Assuming five harvests annually throughout the PL and incorporating debt servicing (interest rate of 1.34%), the per-harvest establishment cost was estimated at COP $245,306·ha^{-1}·cut^{-1}. This estimate offers a more realistic long-term cost perspective and supports effective financial planning.

TABLE 2. Variable and fixed costs associated with the establishment of *Tithonia diversifolia* and maize

Item	**TD (COP·ha^{-1})**	**Maize (COP·ha^{-1})**
Variable costs		
Soil analysis	114,000	114,000
Machinery	166,666	318,266
Fertilization	1,898,900	3,401,500
Irrigation	972,342	298,950
Seeds	6,000,000	1,800,000
Labor	450,000	650,000
Total variable costs (TVC)	9,601,908	6,582,716
Fixed costs		
Land lease, infrastructure, etc.	440,000	660,000
Total fixed costs (TFC)	440,000	660,000
Total establishment cost (TC)	10,041,908	7,242,716
Plantation lifespan (years)	5	N/A
Estimated monthly installment (loan, 4.7%)	245,306	—

Note: The Total Cost (TC) corresponds to the sum of Total Variable Costs (TVC) and Total Fixed Costs (TFC) per hectare (TC = TVC + TFC).

Source: own elaboration adapted from Production Cost Recording Guide (Agrosavia, 2020) and Agricultural Sector Price Information System – SIPSA (Dane, 2025).

Table 2 also presents the establishment costs for maize. The TVC—including machinery, seed, irrigation, fertilization, herbicides, and labor—was COP $6,582,716·ha^{-1}. The TFC, corresponding to the monthly land lease, amounted to COP $660,000·ha^{-1}, resulting in a TEC of COP $7,242,716·ha^{-1}. With an estimated yield of 70 t·ha^{-1}, the unit costs were as follows:

- UFC: COP $9,429·t^{-1}
- UVC: COP $94,039·t^{-1}
- TUC: COP $103,467·t^{-1}

The relatively low UFC is attributed to the combination of affordable land leasing and high projected yields, which reduce the fixed cost per ton. When comparing total establishment costs per hectare between maize and TD, maize is approximately 7% less expensive. However, considering the higher yield potential of *Tithonia diversifolia* (80 t·ha^{-1}), the difference in total unit cost narrows to 5%.

Recent research on the "Altoandina" variety of oats showed that, although maize generally produces higher green and dry matter yields, its establishment costs exceed those of oats (Gallo *et al.*, 2022). Crops such as maize, which require extensive fertilization, weeding, and phytosanitary management to achieve optimal performance, tend to incur higher establishment costs (Villalobos *et al.*, 2013). Consequently, maize cultivation demands greater investment, increasing production costs and reducing profit margins. It is therefore advisable to balance input use to avoid excessive application rates (Castro & Huertas, 2018) and to select resistant genotypes or genetically modified hybrids (GMOs) that require fewer inputs while delivering better overall performance.

In contrast, although TD requires a larger initial investment, its high biomass yields help amortize these costs over time (García *et al.*, 2007). Implementing agronomic practices tailored to the crop's characteristics, together with the use of proven clonal material, can enhance adaptation and improve resource-use efficiency (Villalobos *et al.*, 2015). Consequently, shrubby forages such as TD may offer economic advantages over annual crops by lowering production costs through higher green forage yields and extended longevity (Báez *et al.*, 2023).

Silage production costs of Tithonia diversifolia and maize

The costs associated with the silage production of TD (STD) are detailed in table 3. These include:

- Machinery: COP $998,000·ha^{-1}
- Additives: COP $911,500·ha^{-1}
- Bagging: COP $1,920,400·ha^{-1}
- Labor: COP $600,000·ha^{-1}

In addition, the amortized establishment cost over five years was considered, corresponding to the 60-day growth cycle required for TD to reach harvest maturity. This cost amounted to COP $490,612·ha^{-1}.

Maintenance costs, including irrigation and fertilization, were also included, totaling COP $1,886,342·ha^{-1}. Summing all components, the total silage production cost for STD reached COP $6,836,854·ha^{-1}, equivalent to COP $85,461·t^{-1}.

For maize silage (SMA), machinery costs were equal to those for TD. Additional costs included:

- Additives: COP $887,000·ha^{-1}
- Bagging: COP $1,710,400·ha^{-1}
- Labor: COP $200,000·ha^{-1}

The total silage production cost for SMA was COP $3,795,400·ha^{-1}, or COP $54,220·t^{-1} based on yield.

The production costs of silage from *Tithonia diversifolia* include amortized

TABLE 3. Costs of silage production for STD and SMA

Description – bagged silage	STD	SMA
Machinery		
Harvest machinery (COP $\$\cdot ha^{-1}$)	400,000	400,000
Silo pack ensiler (COP $\$\cdot ha^{-1}$)	598,000	598,000
Machinery subtotal (COP $\$\cdot ha^{-1}$)	998,000	998,000
Additives		
Molasses (COP $\$\cdot ha^{-1}$)	810,000	810,000
Sil-All (COP $\$\cdot ha^{-1}$)	101,500	77,000
Additives subtotal (COP $\$\cdot ha^{-1}$)	911,500	887,000
Packing inputs		
Bags ($1,200/bag)	1,920,000	1,680,000
Polypropylene roll ($15,200/roll)	30,400	30,400
Packing subtotal (COP $\$\cdot ha^{-1}$)	1,950,400	1,710,400
Labor – silage conditioning		
Cutting (COP $\$\cdot ha^{-1}$)	200,000	
Transport (COP $\$\cdot ha^{-1}$)	200,000	
Packing (COP $\$\cdot ha^{-1}$)	200,000	200,000
Labor subtotal (COP $\$\cdot ha^{-1}$)	600,000	200,000
Establishment cost (amortized over 5 years)		
Amortized cost per cut (COP $\$\cdot ha^{-1}$)	490,612	
Establishment subtotal (COP $\$\cdot ha^{-1}$)	490,612	
Maintenance		
Urea 46% (50 kg sack)	500,000	
Triple 15 (50 kg sack)	414,000	
Irrigation application	972,342	
Maintenance subtotal (COP $\$\cdot ha^{-1}$)	**1,886,342**	
Total silage production cost (COP $\$\cdot ha^{-1}$)	**6,836,854**	**3,795,400**
Total cost per ton of silage ($\$\cdot ton^{-1}$)	**85,461**	**54,220**

Where: STD = *Tithonia diversifolia* silage; SMA = maize silage; Harvest machinery = Tractor with forage harvester header and transport trailer.

Source: own elaboration adapted from Production Cost Recording Guide (Agrosavia, 2020); the values for variable and fixed costs were taken from agricultural inputs reported on the Dane agricultural inputs website (2023).

establishment expenses, calculated by dividing the total establishment cost by the number of harvests expected over the plantation's productive lifespan. These are combined with per-harvest silage processing costs, debt servicing, maintenance (irrigation and fertilization), and labor (harvesting and transportation) (Beltrán & Lemus, 2015). The detailed costs for STD and SMA are presented in table 3.

TD harvesting is manual, whereas maize is mechanically harvested. Consequently, per-ton silage costs are:

- SMA: COP $54,220·t^{-1} (production only) and COP $157,687·t^{-1} (including establishment)
- STD: 47% lower than SMA when including establishment

This positions *Tithonia diversifolia* silage as a cost-effective alternative for specialized dairy systems, offering:

- Greater production efficiency.
- Improved profit margins.
- Demonstrated economic viability (Angulo *et al.*, 2022).

These results align with previous studies indicating that mixed silages (e.g., *Mucuna pruriens* with *Pennisetum purpureum*) can reduce production costs. In particular, maize–*Mucuna* silage has demonstrated superior biomass yield potential for bovine feeding (Beltrán & Lemus, 2015).

High-quality silages such as STD improve:

- Farm profitability through increased milk production and income (Villalobos *et al.*, 2015).
- Nutritional efficiency, enhancing microbial biomass synthesis.
- Nitrogen utilization, potentially reducing emissions (Bernardes & Rego, 2014; Pérez *et al.*, 2023).

Productive indicators of Tithonia diversifolia and maize

According to table 2, establishing *Tithonia diversifolia* (TD) requires an initial investment of COP $10,041,908·ha^{-1}, amortized over five years through 60 fixed monthly payments of COP $245,306. This corresponds to COP $490,612·ha^{-1}·cut^{-1}. In contrast, maize establishment involves a one-time investment of COP $7,242,716·ha^{-1} (table 4).

When considering silage production costs, the following values are observed:

- STD (*Tithonia diversifolia* silage): COP $6,346,242·ha^{-1}
- SMA (maize silage): COP $3,795,400·ha^{-1}

The combined costs of establishment and silage production result in:

- STD: COP $6,836,854·ha^{-1}
- SMA: COP $11,038,116·ha^{-1}

In terms of cost per ton of silage produced, the values are:

- STD: COP $85,461·t^{-1}
- SMA: COP $157,687·t^{-1}

These results indicate that, although TD has higher initial establishment costs, its perennial nature and greater biomass productivity substantially reduce the total cost per ton of silage. Specifically, the cost of STD is 46% lower than that of maize silage, representing a considerable economic advantage for medium- and long-term forage systems.

Total revenue

Maize silage (SMA) commands a higher unit price (COP $210,250·ton^{-1}) than *Tithonia diversifolia* silage (STD; COP $113,948·ton^{-1}). However, STD offsets this price difference through its higher annual yield, resulting from its perennial nature and harvesting frequency every

TABLE 4. Comparison of costs, revenues, and annual profitability per hectare between STD and SMA

Total costs	STD	SMA
Total establishment cost (COP $\$\cdot ha^{-1}$)	490,612	7,242,716
Total silage cost (COP $\$\cdot ha^{-1}$)	6,346,242	3,795,400
Establishment + silage process cost (COP $\$\cdot ha^{-1}$)	6,836,854	11,038,116
Cost per ton ($\$\cdot ton^{-1}$)	85,461	157,687
Total revenues		
Unit price (COP $\$\cdot ton^{-1}$)	113,948	210,250
Total revenue per cut (COP $\$\cdot ha^{-1}$)	9,115,805	14,717,488
Total annual revenue (COP $\$\cdot ha^{-1}$)	45,579,027	29,434,976
Total profits		
Unit profit (COP $\$\cdot ton^{-1}$)	28,487	52,562
Total profit per cut (COP $\$\cdot ha^{-1}$)	2,278,951	3,679,372
Total annual profit (COP $\$\cdot ha^{-1}$)	11,394,757	7,358,744

Source: own elaboration.

60 days (Mejía-Díaz *et al.*, 2016). Based on data from this study, annual revenue reaches COP \$45.5 million·ha^{-1} for STD, compared with COP \$29.4 million·ha^{-1} for SMA. The advantage of STD lies in its stable productivity and lower recurring costs: as a perennial crop, it avoids annual planting expenses, unlike maize, which requires reinvestment each cycle. This structural efficiency (Murgueitio, 2023; Báez Quiñones *et al.*, 2023) translates into higher annual profitability despite lower unit margins. Furthermore, STD can amortize its initial investment within one to two years and reduces reliance on external inputs (de las Cuevas-Milán *et al.*, 2024). As Ross *et al.* (2021) observe, systems characterized by frequent cash flows and low fixed costs tend to optimize net margins. Consequently, STD represents an attractive option for sustainable intensification, combining continuous production, reduced financial pressure, and medium-term stability.

Total profitability

Although maize silage (SMA) yields higher unit profits per ton, the *Tithonia diversifolia* system (STD) demonstrated greater annual profitability per hectare due to its high biomass yield and frequent harvesting (every 60 days). This intensive management exceeded the 37.9 t·ha^{-1} reported by Londoño *et al.* (2019), aligning with the findings of Guatusmal *et al.* (2020). Despite its higher initial cost—primarily driven by seed expenses (Padilla *et al.*, 2023)—the investment in STD, when amortized over five years and requiring minimal fertilizer and supplementation, can be recovered between the first and second year (Báez Quiñones *et al.*, 2023). Moreover, as highlighted by Buitrago and Vargas (2017), STD offers stable and increasing profitability, unlike SMA, which depends on replanting. Consequently, STD emerges as the more profitable medium-term option, particularly for systems prioritizing continuous production, cost reduction, and financial sustainability.

Financial analysis

Table 5 summarizes the economic performance of the STD production system over a five-year period, including gross income, operating costs, net income, and key financial indicators. The analysis applies a conservative 10% technical adjustment to the fresh biomass yield per hectare, in line with recommendations for modeling forage systems under field conditions (Cenicaña, 2021; Gallo *et al.*, 2021), and assumes five harvests annually. This adjustment is intended to reflect realistic field scenarios, where climatic variability, management practices, and physiological exhaustion may reduce effective productivity.

The initial establishment of the STD system required an investment of COP \$10,041,908·ha^{-1} (Year 0), covering land preparation, planting, and infrastructure. Although this stage concentrated the highest financial risk, the project achieved rapid recovery: in the first year, it generated gross income of COP \$45.5 million·ha^{-1} (production: 80 t·ha^{-1}) and a net profit of COP \$11.4 million·ha^{-1}. Even as productivity declined to 40 t·ha^{-1} by year five, costs were reduced by 44% through management optimization. Financially, the project demonstrated strong performance, with a net present value (NPV) of COP \$30.7 million·ha^{-1} (at a 15% discount rate), an internal rate of return (IRR) of 115%, and a return on investment (ROI) of 510%. These indicators confirm that, despite the initial financial challenge, the STD model is profitable, sustainable, and efficient, with early positive cash flows that support adoption—particularly among producers with access to credit (Londoño & Pérez, 2019; Rodríguez *et al.*, 2019; FAO, 2021).

TABLE 5. Five-year projection for the SBO and SMA systems, considering an inflation rate of 8% and an interest rate of 10%

Discount rate 15%								
Item	**Year**	**Yield (ton·ha^{-1})**	**Total annual gross income (COP/year)**	**Total ensiling + maintenance costs (COP/year)**	**Total annual net income (COP/year)**	**NPV**	**IRR**	**ROI**
SBO	0			\$ 10,041,908	-\$10.041.908	\$30,772.49	115%	510%
	1	80	\$ 45,579.03	\$ 34,184.27	\$ 11,394.76			
	2	70	\$ 43,072.18	\$ 31,381.16	\$ 11,691.02			
	3	60	\$ 39,872.53	\$ 26,673.99	\$ 13,198.55			
	4	50	\$ 35,885.28	\$ 22,672.89	\$ 13,212.39			
	5	40	\$ 31,004.88	\$ 19,271.96	\$ 11,732.93			

Discount rate: 15%. IRR = Internal Rate of Return; NPV = Net Present Value; ROI = Return on Investment. All monetary values are expressed in Colombian Pesos (COP).

Source: own elaboration.

OUTLOOK

Botón de oro (Tithonia diversifolia) silage is projected as a valuable forage resource and a cost-effective alternative to other preserved forages, offering significant advantages in financial profitability. This potential underscores its suitability as a foundational component in the development of livestock systems in Colombia.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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DECLARATION ON THE USE OF ARTIFICIAL INTELLIGENCE

Generative artificial intelligence was used exclusively to enhance language economy and fluency.

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