AVANCES EN HORTICULTURA – REVIEW

Design and prototype of an innovative mechanized system for vertical cassava stake planting in Argentina

Diseño y prototipo de un innovador sistema de plantación mecanizado de estacas verticales de mandioca en Argentina

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ABSTRACT

Hidalgo, R.; Prieri, M.; Zanenga, J.; Burgos, A.; Medina, R.; Camprubí, G. & Basterra, J. (2025). Design and prototype of an innovative mechanized system for vertical cassava stake planting in Argentina. Horticultura Argentina 44 (113): 156-165. https://id.caicyt.gov.ar/ark:/s18519342/gzwa4p79w

A prototype of a three-furrow cassava planter driven by a low-power tractor, was designed and is currently under construction at the Faculty of Engineering of the National University of the Northeast (UNNE). It features a vertical stake planting system and has the particularity of presenting 6 hoppers, 3 in operation and 3 for refueling, both of which are novel patented features. These allow the planter to have an approximate operating capacity of one hectare per hour. Another characteristic of this planter design is that it requires only one operator to perform the planting task. Planting stakes vertically has the advantage of facilitating observation and early replacement of those that have not sprouted, enabling the plants to grow more uniformly, which positively affects yields and profitability. Furthermore, since the buds of the vertically planted stakes sprout faster, the plants cover the soil surface earlier than those planted horizontally, achieving early weed control and reducing future herbicide applications with less environmental impact and the consequent economic advantage since it reduces 34% the cost of operation in the plantation.

Keywords: mechanization, operational capability, planter.

RESUMEN

Hidalgo, R.; Prieri, M.; Zanenga, J.; Burgos, A.; Medina, R.; Camprubí, G. & Basterra, J. (2025). Diseño y prototipo de un innovador sistema de plantación mecanizado de estacas verticales de mandioca en Argentina. Horticultura Argentina 44 (113): 156-165. https://id.caicyt.gov.ar/ark:/s18519342/gzwa4p79w

En la Facultad de Ingeniería, perteneciente a la Universidad Nacional del Nordeste (UNNE) se diseñó, y está en proceso de construcción, un prototipo de plantadora de mandioca de tres surcos traccionada por un tractor de baja potencia. Cuenta con un sistema de plantación de estacas en forma vertical y la particularidad de tener 6 tolvas, 3 en funcionamiento y 3 de repostaje, ambas características novedosas y patentadas que le permite tener una capacidad operativa aproximada de 1 hectárea por hora. Otra propiedad de este diseño de plantadora es que solamente necesita un operario para realizar la tarea de plantar. La plantación de estacas en forma vertical tiene la ventaja de facilitar la observación y el remplazo anticipado de aquellas que no han brotado permitiendo que las plantas tengan un crecimiento más uniforme lo cual incide en los rendimientos y rentabilidad. Además, al brotar más rápidamente las yemas de las estacas que las plantadas horizontalmente, posibilitan que las plantas cubran tempranamente la superficie del suelo, controlando las malezas y disminuyendo las aplicaciones de herbicidas a utilizar con menos impacto ambiental y con la consiguiente ventaja económica dado que reduce un 34% el costo de operación en la plantación.

Palabras Claves: mecanización, capacidad operativa, plantadora.

1. Introduction

Cassava (*Manihot esculenta,* Crantz), is a tropical perennial shrub native to the Americas, known worldwide by various names: yuca, manioc, cassava, tapioca and mandioca. It is one of the great American contributions to the food supply of humankind (Diaz Tatis & Lopez Carrascal, 2021).

According to data from the Food and Agriculture Organization of the United Nations in Argentina, in 2022, the planted area reached 20,057 ha with a production of 200,000 tons of roots and an average yield of 10.00 t ha^{-1}, occurring only in the northeast of the country (FAOSTAT, 2024). However, these root quantities are not sufficient to cover the productive capacity of the installed starch industries or satisfy the national demand for starch, which is why the country imports an average of 9,000 tons of starch annually (CAFAGDA, 2023). Similar assessments were provided by Burgos (2018) and Uset (2011), indicating productivity stagnation and a lack of state and/or provincial programs encouraging cassava production.

Both in Argentina and in other producing regions of South America, the mechanization of this crop is one of the main needs of family agriculture, particularly if its potential in regional and national markets is considered. However, there is not a wide technological offer of machinery. Therefore, it is necessary to develop an alternative for mechanizing the crop that is also accessible to all producers (Hidalgo *et al*., 2012). The situation is similar in other South American countries. Peredo Parada & Barrera Salas (2019) conducted studies in which two farming systems (conventional and agroecological) were analyzed in the Mapuche community of the Araucanía Region of Chile. These studies concluded that with the agroecological system they observed, greater crop diversity, a higher percentage of self-production of seed and plant material, higher total income and lower seasonality of such income, which would be enhanced by the mechanization of various tasks in the production of certain crops such as cassava.

The most developed system is the planting of cassava stakes in a horizontal position, for which planting machines are available in the South American market Jensen (2024) and Marchesan (2024).

Vertical planting is another option for mechanized cassava planting, which involves placing 18-20 cm long cuttings vertically in the furrow, with only 50% buried. This system is relatively new and is not yet mechanized in Argentina. Hidalgo *et al.* (2018) have designed a fully automated vertical cassava stake planter, and its prototype is currently under development. Additionally, Camprubí *et al.* (2018) managed the collaborative project involving several public and private institutions.

The advantages of this vertical system include the ability to detect and replace unsprouted stakes in advance, allowing a more homogeneous growth of the plants, which positively impacts yields and profitability. Additionally, the rapid and premature development of the buds enables the plants to cover the soil surface, achieving early weed cultural control and reducing the herbicides applications, furthermore stakes planted in a vertical position exhibited lower values of herbicides phytotoxicity, greater plant height, and higher starch concentration compared to stem cuttings planted horizontally (Pinto Ruiz *et al.,* 2024). Same results were published by Polthanee & Wongpichet (2017) who found that vertical planting gave significantly higher fresh storage root yields than those of horizontal planting method. For these reasons, this system should be considered as a cultural weed control method since there is still no herbicide allowed for this crop in Argentina (Burgos *et al.,* 2021). This represents an economic advantage and a lower environmental impact. Pinto Ruiz *et al.* (2019) found that horizontal planting presented greater phytotoxic effects on all pre-emergent herbicides compared to manually vertical planting. This was determined by evaluating different herbicides on height, plant stand and their degree of phytotoxicity, in two types of cassava stake planting (Horizontal and Vertical).

Moreover, studies by Burgos *et al.* (2021) indicate that the vertical planting system significantly increased the percentage of sprouting stakes regardless of planting density and had a significant positive effect on root yield and on starch content because it optimized the expression of the ecophysiological components that determine roots and starch yields. Furthermore, the optimum vertical plant density found by Burgos *et al.* (2021) for Argentine agroecological conditions was 10.000 plant ha^{-1}, which compensated for the lower number of plants per hectare with the higher yield per plant. Additionally, since the optimum density for vertical planting is low (10.000 plant ha^{-1}), the demand for propagation material is also compensated, as vertical cuttings (20 cm) are twice as long as horizontal ones (10 cm).

The objective of the following work was to develop a vertical cassava stake planter with buffer hoppers that would allow it to achieve an average operating capacity of 1 ha per hour. This objective was set considering that the mechanization of the task would increase productivity and met not only the demand of horticultural production but also the industrial need for cassava starch. In order to complete the aim of the work an economic analysis of the operating costs of the prototype under study was carried out, comparing it with a horizontal stake planter, available in the South American market, with a similar number of rows.

2. Materials and methods

The designed planter consists of a chassis made of square structural members of 80x80x5 mm in its main part where the rest of the constituent elements are mounted. The machine can vary its height through the hydraulic cylinders on the rocker arm, allowing it to plant both on ridges and flat ground, in addition to providing ease of transport. Another notable feature is that it can be used both the direct planting system (without soil removal) and the conventional system (with previously tilled soil). It has six hoppers, three operating and three refueling hoppers that move on a rail, enabling quick and easy changes when the hoppers are empty. This innovative system, patented by the National University of the Northeast (UNNE), ensures an effective operational capacity of one hectare per hour (Figure 1, a and b).

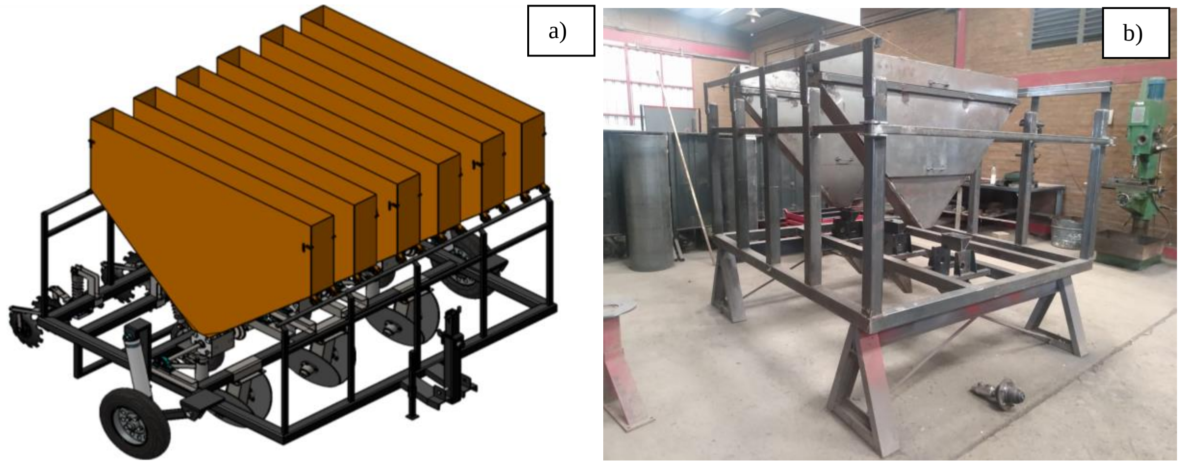

Figure 1: a) Detail of the chassis, hopper arrangement, soil engaging components and hydraulic cylinders. b) Chassis construction. Resistencia, Chaco, Argentina. 2017.

Figura 1: a) Detalle del chasis, disposición de tolvas, tren plantador y cilindros hidráulicos. b) Construcción del chasis. Resistencia, Chaco, Argentina. 2017.

The hopper is just wide enough to hold 18 cm cassava stakes. One of the side walls of the hopper opens like a door, making it easier to load and arrange the stakes with the buds always facing the same side (right), ensuring that they will be pointing upwards during the planting process. Each hopper holds approximately 300 kg of stakes (Figure 2, a and b).

Figure 2: a) Hopper manufacturing. b) Hopper opening details to facilitate loading of cassava stakes. Resistencia, Chaco, Argentina. 2017.

Figura 2: a) Fabricación de tolvas. d) Detalles de apertura de tolva para facilitar la carga de estacas. Resistencia, Chaco, Argentina. 2017.

The metering mechanism consists of four adjustable grooved discs to adjust the cavity to the diameter of the stakes. It removes the stake from the hopper through a rotating movement depositing it in a transition from rectangle to circle. This causes the branch to become vertical as one of the ends of the branch will always impact first on one side of the sheet cone forcing the stake to follow its vertical path, always by the action of gravity (Figure 3, a and b).

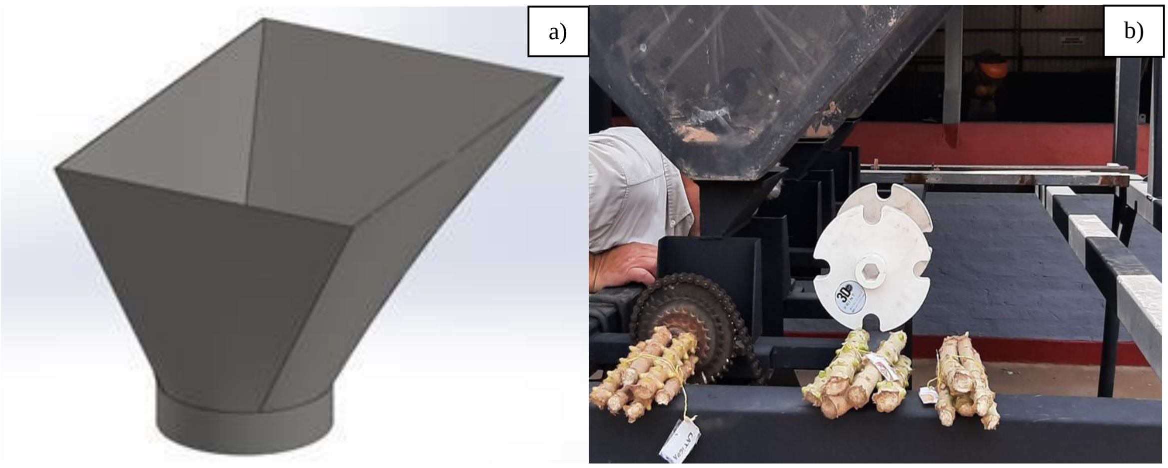

Figure 3: a) Circular rectangular transition. b) Detail of the dosing mechanism constructed and the cassava stakes. Resistencia, Chaco, Argentina. 2017.

Figura 3: a) Transición rectangular-circular. c) Detalle del mecanismo dosificador construido. Resistencia, Chaco, Argentina. 2017.

The planting system is the main innovation of the machine, also patented by the National University of the Northeast (UNNE). It is a simple solution for vertical planting. The stake is placed in the circular tube, where it is supported by a rubber membrane. The crank mechanism moves in synchrony with the entire machine through a chain transmission. The planting sequence is as follows: the stake, deposited in the horizontal-vertical transition, is placed in the tube, the rubber membrane supports it, and the crank pushes it into the furrow (Figure 4, a and b).

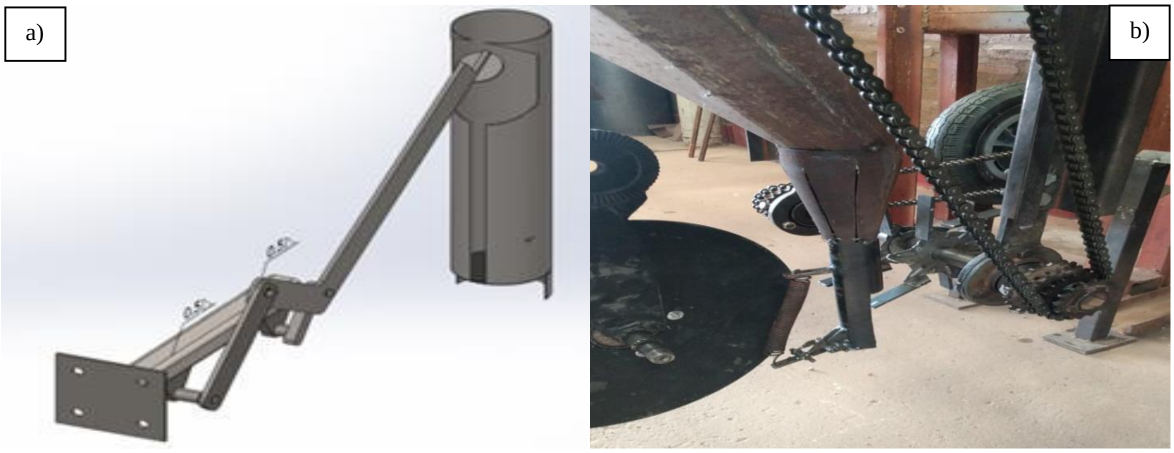

Figure 4: a) Detail of the planter mechanism. b) Planter mechanism of the prototype under development. Resistencia, Chaco, Argentina. 2017.

Figura 4: a) Detalle del mecanismo plantador. c) Mecanismo plantador del prototipo en desarrollo. Resistencia, Chaco, Argentina. 2017.

The furrow opener consists of two 46 cm diameter discs arranged in a "V" shape, manufactured in Argentina. The closing wheels are also of national manufacture and are commonly found in most of the cassava planters available in the Argentine market (Figure 5, a and b).

Figure 5: a) Detail of the furrow opener. b) Detail of the closing wheels. Resistencia, Chaco, Argentina. 2017.

Figura 5: a) Detalle del abresurco. b) Detalle de las ruedas tapadoras. Resistencia, Chaco, Argentina. 2017.

The Table 1 describes the main characteristics of the cassava planter designed in 2017 at the Faculty of Engineering of the National University of the Northeast (UNNE) located in Resistencia, Chaco, Argentina.

Table 1: Main characteristics of the cassava planter designed at the Faculty of Engineering of the National University of the Northeast (UNNE). Resistencia, Chaco, Argentina. 2017.

Tabla 1: Principales características de la plantadora de mandioca diseñada en la Facultad de Ingeniería de la Universidad Nacional del Nordeste (UNNE). Resistencia, Chaco, Argentina. 2017.

Type		trailed
Dimensions	Width	2200 mm
	Lenght	2300 mm
	Height	2300 mm
Working capacity		1 ha/h
Required power		50 HP
Rows		3
Distance between rows		0.8 a 1.2 m
Distance between stakes		0.7 a 1 m
Load capacity		290 kg/hopper
Operators		1
Novelty		Stake dosing mechanism
		Vertical planting system
		Buffer hopper system

3. Comparative economic analysis:

An economic analysis of the operating costs of the prototype under study was conducted by comparing it with a horizontal stake planter, present in the South American market (machine A), with a similar number of rows. For operating costs, variables such as the price of fuel and phytosanitary products were taken into account. The calculation strategy was to express these costs on a per hectare basis. Data on basic salaries of rural personnel and costs per hectare for soil tillage and phytosanitary application were obtained from the Argentine Federation of Agricultural Machinery Contractors (FACMA, 2024) and from the agricultural salary scale of the Argentine Union of Rural Workers and Stevedores (UATRE, 2022) (Tables 2 and 3).
It is important to highlight the frequency of herbicide application in both types of planting (horizontal and vertical). For the comparative economic analysis, it was decided to consider five (5) applications for the horizontal plantation and two (2) applications for the vertical system, with an herbicide dose of 2.5 l ha^{-1} and 250 kg ha of urea in both planting systems.

4. Considerations

Autonomy of the prototype: 12 hectares per day (Theoretical). Number of operators of the prototype: 2 (1 Tractor operator and 1 farm worker). Autonomy of Machine A: 6 hectares per day. Number of operators of Machine A: 4 (1 tractor operator and 3 farm workers). Tractor Operator: Basic Salary (10 hours/day) $27.016,79 (Table 2)
General Farm Worker: Basic Salary (10 hectares/day) $24.218,23 (Table 3).
Gas oil: 941$ l^{-1} (fuel value in May 2024). Fertilizer (Urea): 426 U$S t^{-1}. Herbicide: 14,96 U$S l^{-1} of glyphosate (based on a dollar exchange rate of $ 921,50 Central Bank quotation, 12/06/2024). Input values are as of 12/06/2024 (Table 4).
The operational capacity of the machine was determined considering a row spacing of 1,2 m. The machine has three furrows, making the working width 2,4 m. The average operating speed, used in northeastern Argentina, is 4,6 km/h. Taking these considerations into account, the theoretical working capacity is 1,104 ha h^{-1}.

Table 2: Remuneration of the tractor operator. Resistencia, Chaco, Argentina. 2024.

Tabla 2: Remuneración del tractorista. Resistencia, Chaco, Argentina. 2024.

N°	Concept	Incidence	Value
1	Salary for time actually worked	100.00%	$ 27.016,79
2	Derivative + indirect items	53.00%	$ 14.318,99
TOTAL			**$ 41.335,96**

Table 3: Remuneration of the general farm worker. Resistencia, Chaco, Argentina. 2024.

Tabla 3: Remuneración del peón. Resistencia, Chaco, Argentina. 2024.

N°	Concept	Incidence	Value
1	Salary for time actually worked	100.00%	$ 24.218,23
2	Derivative + indirect items	53.00%	$ 12.835,66

TOTAL	**$ 37.053,89**

The results of the economic analysis indicate that the cost per hectare of automated planting, i.e., without the need for farm workers in the planting process, using the vertical planter prototype, is lower than conventional planting using Machine A, requiring one farm worker per row. The new planter reduces the operating costs of the plantation by 34% (Table 4).

Table 4: Comparative economic analysis of both planting systems. Resistencia, Chaco, Argentina. 2024.

Tabla 4: Análisis económico comparativo de ambos sistemas de plantación. Resistencia, Chaco, Argentina. 2024.

Operating costs per hectare		
Category	**Conventional planting ($)**	**Automated planting ($)**
1 Tractor operator	$ 6.889,33	$ 3.444,66
3 Farm worker	$ 18.526,95	$ 3.087,82
Fuel	$ 9.410,00 (10 l ha^{-1})	$ 11.292,00 (13 l ha^{-1})
Soil preparation	$ 50.747,40	$ 50.747,40
Fertilization	$ 98.139,75	$ 98.139,75
Herbicide	$ 172.320,50	$ 68.928,20
TOTAL $	**$ 356.033,92**	**$ 235.639,84**
TOTAL U$S	**$ 386,36**	**$ 255,71**

It is important to highlight that there is an unmet national demand, both for horticultural fresh consumption and for industry. Consequently, it is necessary to increase production to meet market needs. It is believed that mechanizing production will increase production. One of the key steps in the production chain is planting. The availability of a machine that does not depend on human labor to carry out this task, and that is also accessible to producers, will be an important contribution to strengthen cassava production. The Argentine cassava-producing region massively uses the manual planting system with horizontal stake position. However, in some sectors of the province of Misiones, mechanized planting with locally designed equipment has been promoted (Aristizabal & Calle, 2015).

In accordance with the results of Ikejiofor & Eke-Okoro (2012), mechanization reduces drudgery, making farming an attractive enterprise. It therefore has the potential for national economic growth, food self- sufficiency, industrial growth, and employment, leading to poverty reduction.

It can be said that the sector shows some resistance to innovation, creativity and automation in numerous processes specific to the activity. The number of farmers has been significantly reduced, resulting in the concentration of land in fewer hands. However, the concepts presented here improvements in productivity and the comfort and automation elements of the machinery, must be designed and made achievable for this segment, which remains of traditional importance in cultivation. To achieve greater efficiency, acceptance by rural producers will be of vital importance.

It is important to mention the challenges and opportunities that cassava production faces in the future, including the emergence of biofuels to replace fossil fuels, new technologies for bioplastics, and modified starches, all in harmony with the environment,
Therefore, there is an optimistic outlook for the future development of the activity.

5. Conclusion

Improving cassava productivity with a better crop management, should include choosing the appropriate planting system. By having a vertical stake planting machine produced in Argentina, there will be a better competition both with imported machines and with those of national manufacture, offering an economically viable alternative. This would allow exploring new potentials that, today, due to lack of raw materials, are not realized. The validation of the performance of this prototype is an outstanding task, which will be carried out at the end of its construction.

6. Conflict of interests

The authors declare that this work does not present conflict of interests.

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