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DEVELOPMENT OF MECHANICAL EQUIPMENT FOR TRANSPLANTING SUGARCANE (*Saccharum* spp. HYBRIDS) SPROUTS

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ABSTRACT

Manual planting of sugarcane (*Saccharum* spp. hybrids) in Mexico is slow, and eye bud germination is deficient. Alternative planting methods must be adopted in order to improve sugarcane field productivity. This study evaluated the field performance of a tractor-mounted planter prototype when transplanting two-month-old nursery-grown sugarcane sprouts in relation to the following parameters: sound sprout treatments, row separation between seedlings, upright placement into the soil, appropriate soil covering, and field uniformity at planting. This mechanical equipment was tested on a readily tilled soil suitable for sugarcane planting, although slightly stoney on the surface. The tractor and implement combination were set to travel at a field speed of 0.3 m s^{-1} when laying seedlings into the row at 900 mm separation. Transplanting separation between seedlings onto the row had a variation of 3.4 %. When assisted by two laborers for planting, the tractor and implement combination achieved a field capacity of 2.5 ha d^{-1}. Thus, for a field capacity of 2 ha d^{-1} and 120 workdays per planting season, the investment in the machine can be returned in two years. Consequently, planting sugarcane sprouts using the planter prototype is up to eight times more cost-effective than manual transplanting.

Keywords: mechanization, agricultural machinery, mechanical transplanting, planting, seedlings.

INTRODUCTION

Mexico is the seventh global producer of sugar. The Mexican sugar industry is one of the most important due to its economic and social relevance for farmhouse inhabitants. This industry generates more than 2.5 million jobs. It takes place in 15 out of 32 Mexican states and benefits 227 municipalities. Raw produce has a value of approximately $1714 million USD. During the 2016–2017 harvest season, 51 sugar factories in Mexico milled 54.329 million Mg of sugarcane (*Saccharum spp*. hybrids) stalks from 0.777 million ha, with an average yield of 68.6 Mg ha^{-1} (CONADESUCA, 2017b). Yield values are far from excellent, so the sugar sector has prioritized increasing crop productive efficiency. Two factors have been identified as critical to achieving this goal: farming practices and environmental concerns.

Planting is the first step in ensuring the consistent growth and profitability of sugarcane (Yadav *et al*., 2003). Each sugar factory in Mexico schedules a series of field operations to prepare the soil for seed placement. However, none of them fully complies according to soil types and available field conditions. The entire planting process is considered semi-mechanized because soil processing for the seedbed is carried out using equipment attached to the farm tractor. This soil processing consists of old stool destruction and field clearing, subsoiling, plowing, disking, leveling, and furrowing (Ortiz-Laurel *et al*., 2016). Farmers are unaware of the required soil tilt for planting. Soil crumbling is poor, and they do not explore more rational and less costly methods, arguing the unavailability of suitable machines and farm equipment. In addition, seed planting is carried out by hand. Sugarcane stalks or billets are placed at the furrows' bottom and covered with a 30 to 50 mm soil layer by using manual tools. A thicker layer or excessive compaction can jeopardize bud eye germination and delay emergence.

Mechanized sugarcane planting is a relatively recent and innovative practice worldwide (Ripoli and Ripoli, 2010). Nonetheless, Mexico has no experience. Sugacane fields in central Veracruz usually have clay soil and are slightly covered with medium-sized stones. Fully mechanized planting has some advantages when compared to a semi-mechanized system. Soil moisture is maintained, as soil is opened and closed straightforwardly. Furrows are more parallel, and germination is improved. Protection chemicals and fertilizers can be applied at once. The number of mechanized operations once the crop develops is reduced. Soil compaction is decreased, and adequate soil consolidation promotes better soil-seed contact (Compagnon *et al*., 2017).

Few sugarcane producer countries have promoted mechanized planting. They use planting machines that perform all the tasks in an integral form (Ripoli and Ripoli, 2010). Generally, those machines handle pieces of sugarcane stalks that are provided by a mechanical harvester (Nova, 2009). However, despite more than a decade of experiences, the main problem is that the amount of seed has not been reduced (Robotham, 2004), and commonly, buds show damages due to deficient handling from harvesters, affecting germination. Nonetheless, whatever planting method is used in Mexico, the quality of the job is less than optimum, expensive, germination is poor (around 70 %), and plant emergence is unreliable. Usually, replanting has to be undertaken on defective spots. The growth of seedlings other than bud chips for seed material is expanding (CONADESUCA, 2017a; Radha *et al*., 2010). Although sugarcane can be planted using seedlings (Patnaik *et al*., 2016), it requires more intensive soil processing compared to using billets, as a suitable tilth and loose soil has to make good contact with roots from seedlings in order to achieve a rapid adaptation to this new environment.

Mechanized planting of sugarcane using seedlings can guarantee an improved crop establishment and could reduce planting costs when compared with the traditional procedure (Srathongtiw and Choedkiatphon, 2022). Similarly, planting operations can be quickly carried out. A uniform planting depth can be achieved, helping develop a healthy root system. However, the need for nurturing seedling facilities, the supply of growing inputs, and the labor involved in germination of buds and management of seedlings until they are ready for field transplanting makes this system expensive (Palma-López, 2018). Similarly, as enough care is put on growing seedlings, it is also important that field transplanting is carried out efficiently, adding that manual transplanting is costly and inefficient (Castillo *et al*., 2003).

Personnel of the Postgraduate College were involved in the design, development, and manufacture of a transplanting device for sugarcane seedlings. A protocol was scheduled to carry out a set of field trials to evaluate the performance of this equipment. Factors to be analyzed were reliability, field capacity, and precision when planting into the soil. The above will lead to the promotion of technological development to increase planting efficiency and reduce production costs of sugarcane cropping.

MATERIALS AND METHODS

The Motzorongo Regional Experimental Center (CERMOTZ) in Veracruz, Mexico, has gained experience for growing, caring for, and handling sugarcane seedlings. They also provide advice on manual transplanting; thus, their expertise was valuable for the purpose of this study. A randomized sample of 100 sugarcane (*Saccharum* spp. hybrids) sprouts from several varieties, of the same age and ready for transplanting, were selected for physical identification (Figure 1). Useful dimensions were selected for manufacturing materials and designing mechanical equipment that ensures the precise distribution of seedlings in the field, such as the dosing mechanism. The main parameters were those for the root system capsule, including shape, large and small diameter, height, resistance (moisture content, root size), weight, and the size of final foliage before transplanting.

Mechanical seedling transplantation can be a substitute for conventional sugarcane manual planting, where the operation uses seedlings sprouted from several weeks. This is achieved by designing some mechanical mechanisms according to the specific features exhibited by seedlings, likely dimensions of root portion, weight, and total length of seedling for planting, as well as caring processes. Calculating those mechanisms is required to adjust planting density. Furthermore, a successful system of this kind can increase its versatility by including novel attachments for spraying sanitary and growth facilitators as seedlings reach the soil.

CERMOTZ makes business by selling sugarcane seedlings at a cost of $0.15 USD each, regardless of variety, with a maximum age of two months. Seedlings have uniform physical dimensions; their root capsule has a cone shape, with large and small diameters of 65 and 40 mm, respectively, and a height of 60 mm. When seedlings are

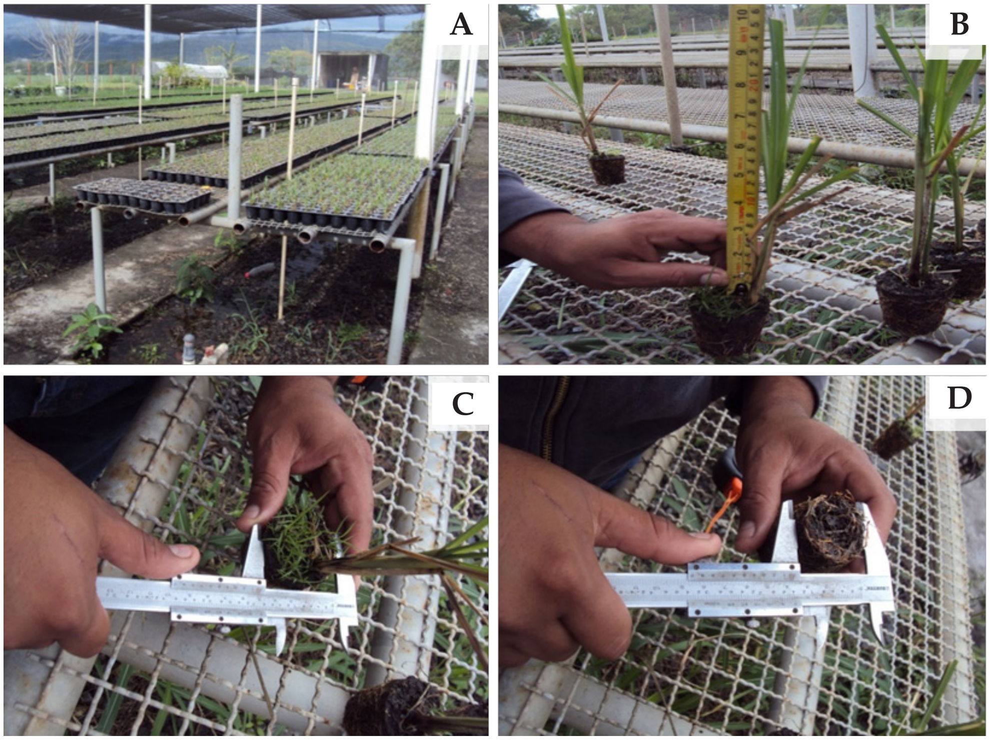

Figure 1. Evaluation of the main dimensions of sugarcane (*Saccharum* spp. hybrids) seedlings raised at the Motzorongo Regional Experimental Center in Veracruz, Mexico. A: nursery for sugarcane seedlings; B: measurement of sugarcane seedling height; C: measurement of the large diameter of the root system capsule; D: measurement of the small diameter of the root system capsule.

delivered to buyers, CERMOTZ personnel cut the top end of foliage so the seedling final length is 200 mm from the top side of the root system capsule (Figure 2).

The information was useful for designing and setting the specifications for the transplanting mechanism, as well as the entire transplanting module. This planter prototype weighs 350 kg and has the following dimensions: 1.4 m high, 1.25 m wide, and 2 m long. Simultaneously, it was necessary to record the manual method for field transplanting of the seedlings. The labor required, time consumption, activities needed, and keeping track of each task were all recorded. The latter was required to improve and reduce operations, as well as to assign value to those tasks according to a level of difficulty to estimate the entire cost of the operation.

CERMOTZ follows a sequence of detailed operations for manual transplanting: where furrows have already been constructed, the separation distance between seedlings is marked on the bottom of the furrows; a hole is dug on each marked spot and a sprout is placed inside it; and finally, the seedling is covered with soil and water. As a reference, transplanting into 1.2 m-separated rows with a 700 mm spacing between

Figure 2. Two-month-old sugarcane (*Saccharum* spp. hybrids) seedlings ready for planting.

seedlings requires 11 904 seedlings per hectare and 18 laborers who charge $8.5 USD each. Thus, labor costs for transplanting are $153 USD per hectare.

The main component from the planter prototype is a carrousel-type distributor with five free-ends vertical tubing. Seedlings with a diameter less than 60 mm can go into those compartments, and when in operation, the distributor turns because of the transmission through the drive wheel when the tractor moves (Figure 3). The discharge tube is located at the bottom section of the distributor, so when turned, the bottom end of one compartment lines up exactly with it, and the seedling slips through the tube into the open furrow, followed by a soil pressing around the seedling to keep it upright, and loose soil is added around it by cover discs. The largest length

Figure 3. Carrousel-type distributor for sugarcane (*Saccharum* spp. hybrids) seedlings dropping into the soil.

allowed for a seedling to slip freely through the discharge tube without being pulled by the tube itself because of forward movement once the seedling is into the soil is 300 mm. When the drive wheel turns, it connects to a calibration mechanism that matches the level of turning of the seedling distributor, so by exchanging some spare parts, the distance each seedling travels in the field can be changed.

Evaluation of the mechanical planting of sugarcane seedlings was carried out on a field prepared for planting at the Postgraduate College Campus Cordoba (18° 51′ 20″ N, 96° 51′ 37″ W, at an altitude of 660 m). The soil on this site has a sandy clay texture and a 500 mm arable layer, and the plot is lightly covered by 150 mm-diameter stones on average. This soil is representative of the sugarcane production region (Figure 4). Performance was evaluated during field work on the transplanting mechanical planter prototype. The main parameters measured were: a) planting distance between seedlings; b) positioning condition; c) soil covering; and d) planting depth. Similarly, the machine's power demand for field transplanting, fuel consumption from the mobile power device, field efficiency for transplanting operations, and time savings and operation costs were compared to manual transplanting.

Figure 4. Evaluation of the mechanical transplanting device for sugarcane (*Saccharum* spp. hybrids) seedlings in fields at the Postgraduate College Campus Cordoba, Veracruz, Mexico.

Furthermore, the transplanting capacity was measured by varying the travel velocity from 0.3 to 2.5 m s^{-1}. The objective was to compare efficiency, field behavior, and transplanting capacity to manual planting with seedlings and varying travel speed up to a maximum slippage of 12 % from the tractor's drive wheels. Once transplanted, the distance between seedlings was measured to determine how much they differed from the initial set of 900 mm. Seedlings placed at various inclination angles were recorded.

RESULTS AND DISCUSSION

The device's performance was evaluated, and its behavior was examined in the field under various operating conditions. When operating in a straight line, an average travel speed of 0.3 m s^{-1} was selected and adjusted to ensure that a seedling was properly placed every 900 mm. Three sections of the planting field, each 50 m long, were chosen at random for accounting measurements. The tractor and planter prototypes spent an average of 140 s planting each 50-m section. After data analysis, it was discovered that seedling separation placement had an average efficiency of 3.4 % higher than established.

For the field transplanting process, power demand was calculated as 20.52 kW per planting unit, average fuel consumption was determined as 13.28 L ha^{-1}, and by using data from operation timing and costs, a comparison was made against manual transplanting and also conventional planting using stalk billets. In all cases, trials showed that a mechanized system for transplanting sugarcane seedlings has the largest advantages. Field cleaning from previous crops and soil preparation for the seedbed are not included in the calculations.

The planter prototype had a field capacity of 2.5 ha d^{-1} on a plot with previously worked soil and an average travel speed of 1.2 m s^{-1}, with seedling spacing of 900 mm and rows separated by 1.2 m. Therefore, with similar field and soil conditions and a single transplanting unit operated by two laborers, it is possible to plant 12 000 seedlings in an eight-hour shift. Field capacity and efficiency can be increased by attaching two units on the toolbar, based on the tractor's capacity. Therefore, it was determined that the operation cost for the transplanting device is $18.3 USD per hectare; thus, the capital investment for the machine can be recovered in two years, as long as it operates at least on 120 d per season and maintains a field capacity of 2 ha d^{-1}. The effectiveness of the transplanter, like any mechanized task in sugarcane, is subject to human factors in terms of their skills and abilities, as well as other factors such as soil and weather conditions.

One of the best features of this planter prototype was soil moisture conservation; by opening a slot into the soil, placing the seedling, and closing the furrow after seedling transplantation, there is no wet soil exposed to the environment or sun radiation. This process is achieved with 99 % efficiency. Finally, it was observed that 9 out of 10 seedlings remained upright after reaching the bottom of the furrow, indicating a slight inclination towards the direction of movement due to inertia.

Mechanized seedling transplantation can be carried out as a planting task. Its main advantage is that the seedlings have already germinated; the best ones with an average length of 250 mm are selected, while those with less vigor are discarded. As a result, it is possible to guarantee a sound crop establishment of more than 90 %, with uniform field distribution and parallel rows. The mainframe of the planter prototype will allow in the near future to add apparatus for applying sanitary and agrochemical products for securing a better crop establishment and plant nutrition in order to reduce crop production costs, although the cost of the machine will increase (Naik *et al*., 2013, 2015).

CONCLUSIONS

The transplantation process of sugarcane (*Saccharum* spp. hybrids) seedlings by using the mechanical planter prototype was 99 % efficient when carried out at an average forward velocity of 0.3 m s^{-1}. In addition, adequate uniformity was achieved for seedling depth placement in the soil, enough soil was added around the seedling after planting, and 2 % of lay-down seedlings were observed after machine discharge onto the furrow. Efficiency for the separation distance between seedlings into the soil was 3.4 % higher than established. Thus, operating the planter prototype along 120 days during the planting season in order to achieve a field capacity of 2 ha day^{-1} had a reduced operation cost by up to eight times than manual transplanting. Capital investment on the machine can be recovered in two years' time.

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