Article

Agrotechnical evaluation of manual implements for corn planting

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Abstract

Planting is a critical activity in the production of corn and the crucial step to obtain good yields. Traditional hand tools are mostly hand-made and manual sowing demands a high investment of labor and time. On several occasions, efforts of more than 50 hours of work are reported to carry out the manual planting of one hectare. Modernizing these tools allows small producers to optimize their resources, perform their tasks on time and make them less fatiguing (Aikins *et al.*, 2010). With the objective of determining parameters that allow the analysis of the most useful tools for the manual sowing of corn, six seeders were evaluated determining their effective capacity in the field, with values obtained between 0.020 and 0.055 ha/h. When analyzing the time used to select a bed with different operators, significant differences were found between the operators for the Boshima, Fitarelli planters and the paddle (p-value = 0.017, 0.037 and 0.028 respectively). The emergence of the crop was characterized by the functionality of the tools, reaching values of 71.1% with handspike and only 10.5% with the Fitarelli. Contributing to the methodologies of conventional agrotechnical evaluations, a weighting was made considering the ease of use, accuracy and efficiency in the field. In its entirety, the most recent tools are better results compared to modern tools, probably due to its simplicity and low maintenance demand. However, some modern tools stand out strongly in the specific areas of performance.

Keywords: agrotechnical evaluation, agricultural tools, effective capacity, small producers, sowing manual.

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Introduction

The yields of the main cereals used as food are suffering a greater and mainly caused by the degradation of agricultural surfaces. The increase in food production requires the implementation of sustainable and favorable intensification practices in the conservation of the planet's natural resources, which requires its use of appropriate mechanization technologies (Sims and Kienzle, 2015).

Producers with agricultural extensions of 2 ha or less produce up to 70% of the food in the world (Maass- Wolfenson, 2013) and most of these small farmers are found in regions of the developing world such as sub-Saharan Africa, the south and southeast of Asia, as well as Central and South America (Harman, 2016). Therefore, to increase yields in the production of basic grains in these regions, a strategy is needed that includes a focus on the operations of the manual company, as well as the tools used to do so. In effect, these tools are an integral part of the mechanization solutions that facilitate the realization of greater sustainability and productivity in the field, as do animal-drawn tools or actions by motors (Kienzle and Sims, 2014).

In Mexico, manual planting of corn is mostly done with simple equipment such as mirrors, hoes or shovels that make this operation a heavy task. Usually, in each blow, two of three seeds are placed to ensure germination, and this practice is not only an inefficient use of inputs but also competition between plants that reduce yields. According to Chim *et al.* (2014), the singularization of seeds in the planting of corn can increase yields up to 40% compared to the practice mentioned above. Another important factor is the private company, especially in temporary conditions. In effect, Lawles (2006) and Hodgen (2007) indicate that the delay in the emergency may result in a significant reduction in performance.

Smithers *et al.* (2010) indicates that the requirements to be taken into account for the development of a manual planter are a simple design that facilitates the use and maintenance, the speed of sowing, the flexibility to be able to plant with different shapes and sizes, and finally the cost. These same authors compare in the field a prototype of their own against a tool traditionally used in South Africa requiring only 30% of the time compared to the conventional tool, attributing this superiority to the mechanical doser and the sharp tip of the tool.

On the other hand, Osei- Bonsu *et al*. (2015) evaluated in Ghana a sowing machine of Chinese origin Boshima (Boshima, 2017), a seeder manufactured locally and a machete tool traditionally used for the sowing of corn in different conditions of preparation of soil and stubble obtaining 8.59 h (implement Boshima type) and 23.58 h (machete) as minimum and maximum values, respectively, to perform the sowing task on one hectare. They mention as a disadvantage of the seeder of Chinese origin the construction material, which is mostly plastic.

In another study, Osei Bonsu *et al.* (2016) obtained values of 2.48, 8.05, 6.32, 14.37 h/ha with a seeder mounted to a 4-wheel tractor, and the three manual seeders previously evaluated respectively. Comparisons made by Aikins *et al.* (2010) show little control in the

dosing system of manual sowing drives for nailing (jab-planter) which leads to a wrong seeding density that ends with poor performance.
Omara *et al.* (2016) and Dhillon *et al.* (2017) described the development of the GreenSeeder planter (INDIGDEV, 2017) and focused on the improvement of the doser to achieve the singularization and reduction of faults by varying the dimensions of the cavity that houses the seed according to the requirements. The authors recorded a reduction in multiple dosed seeds and failures, with a successful singularization 80% of the hits.

Based on the methodologies used in the aforementioned studies and the guidelines presented by the Food and Agriculture Organization of the United Nations (FAO, 1994), this work shows the results obtained from the field evaluation of six manually operated seed drills for the sowing of corn with the objective of knowing the performance of the traditional tools used in Mexico, in contrast with several modern and commercially available sowing machines. Finally, the methodology used will allow interpreting the results of the agrotechnical evaluation to facilitate the identification and selection of the best options of manual tools for small-scale producers.

Materials and methods

The field evaluation was carried out within the facilities of the International Center for Improvement of Maize and Wheat (CIMMYT) located in The Batan, Texcoco, State of Mexico. At an altitude of 2 240 meters above sea level, with a semi-dry temperate climate, an average annual temperature of 15.9 °C and an average annual precipitation of 686 mm (INAFED, 2018). The soil classification of the plot according to the World Reference Base (WRB) is a Phaeozem Haplico (FAO, 2007).

The manual seeders that were included in the evaluation are representative of tools traditionally used in Mexico and equipment commercially available in various regions of the world. In the Figure 1 shows the different equipment used in the evaluation, while Table 1 shows the general characteristics of each one.

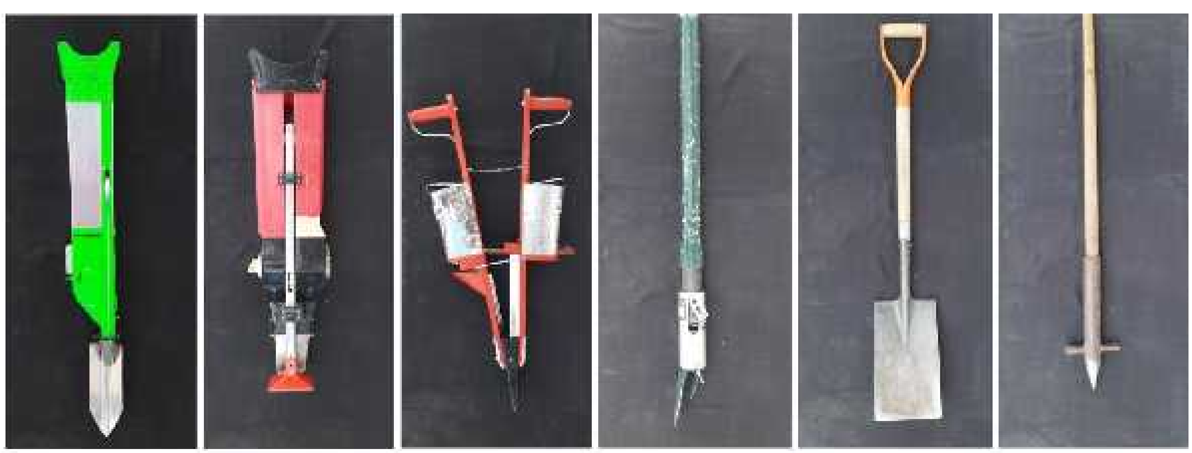

Figure 1. Manual tools used in agrotechnical evaluation: Yufeng, Boshima, Fitarelli, GreenSeeder, Shovel and Handspike (left to right).

The tool Yufeng brand of Chinese origin, made of plastic material mostly has only a deposit for seeds. The dispenser is a roller with a series of holes in its periphery. The tip is formed by a preload compartment and a shovel 25 cm long, responsible for making the hole in the ground. Its dispenser is activated with the vertical push movement towards the ground.
Also of Chinese origin, the Boshima planter has compartments for seed and fertilizer (Boshima, 2017). Its dosers are driven similarly to the aforementioned planter, but it has two 9 cm long tips that place the seed and fertilizer simultaneously on the ground. The material of its structure is plastic.

The Brazilian seed drill Fitarelli is composed of a wooden body and has tanks for seed and fertilizer; two steel tips of 13 cm in length guide the inputs to the ground (Fitarelli, 2017). The activation of the mechanisms for the loading/unloading of seed and fertilizer is carried out by means of the opening and closing movement of the arms. This tool is considered one of the first drilling drive sowing machines (Johansen *et al.*, 2012).

The GreenSeeder seeder developed by the University of Oklahoma in the United States of America consists of a PVC tube that serves as a seed container and an aluminum dispenser with a single cavity roller (INDIGDEV, 2017). In the lower part has a small blade of 11 cm long responsible for making the hole in the ground. Its mechanism works with the blow to the ground and a spring that rotates the roller inside the doser.

The two conventional tools used for manual corn seeding do not contain any dosing device or deposit for seed or fertilizer. The seed is transported by the operator in a container at waist height; the dosage and placement of seed is completely done manually. In comparison to the shovel formed by a blade of steel with edge on its edge with width of 16 cm and height of 30 cm, the handspike simply has a steel component in a conical shape that serves to make a hole in the ground and deepen a maximum of 12 cm.

Table 1. General description of the sowing machines used in agrotechnical evaluation.

Seeder	Empty mass, kg	Dimensions (L, A, H), cm	Doser seeds	Fertilizer doser	Containers capacity, l
Yufeng	2	14, 15, 97	Roller	N/A	3
Boshima	2.2	15, 19, 81	Roller	Roller	1.5
Fitarelli	3.5	12, 48, 90	Reciprocating plate	Gate	1.5
GreenSeeder	2.3	8, 8, 169	Roller	Roller	1
Shovel	1.7	10, 17.5, 106	N/A	N/A	N/A
Handspike	1.4	5.1, 15, 143	N/A	N/A	N/A

Characterization of the seed used in the evaluation
The dimensions, sphericity, mass of 1 000 seeds and bulk density were determined as reported in Coşkun *et al*. (2006). The moisture of the seed was determined using a John Deere moisture analyzer model SW08120 (John Deere, 2017) with 10 repetitions. A germination test as established by Warham *et al.* (1997) was carried out to know the percentage of viable seed.

Determination of effective sowing capacity

Each tool was evaluated by sowing 4 beds of a length of approximately 26 m made in june 2016. In the center of each bed was placed a rope, marking the blows at regular intervals. The distance between blows was defined at 0.23 m, to obtain a density of approximately 58 000 plants per hectare in beds of 0.75 m in width. The seed used was white creole corn 'Santiaguito', from the municipality of Texcoco, State of Mexico. The previously established crop in this area was wheat, so the beds still had a sparse stubble cover.

Each tool was calibrated to deposit one seed per hit and in order to compare results of the operator's performance, the 2 people were selected to operate each of the instruments. As described by the FAO (1994), a record was taken of the number of strokes per bed, the time to complete each bed and the number of interruptions that occurred during the course of the planting activity. A failure or obstruction of the mechanism, the need to clean the tips or to refill the seed deposit was recorded as an interruption in which the measurement of time was suspended.

Adapted from Hancock *et al*. (1991), we proceeded to determine the effective capacity (C_e) in ha/h for each planter as described in equation 1, with the values of working width in meters (A_t), the distance traveled in meters (D) obtained from the number of hits made, and the time (t) in seconds required to finish.

$$C_e = \left(\frac{A_t * D}{t}\right) * 0.36 \tag{1}$$

Crop emergence

The determination of the percentage of emergence of the crop was made 20 days after having sowed. A record was taken of the number of blows with the presence of emerged plants per bed, as well as the total of blows with the presence of doubles (2 emergent plants) or triples (3 emergent plants) for the 4 beds corresponding to each evaluated tool.

Overall efficiency of seeders

In order to determine the general efficiency of work or the ability to adequately meet the sowing activity of each evaluated tool, the values obtained in the field were transformed to a scale of 1 to 10, where 1 represents the lowest performance rating and 10 of higher performance. Then, three evaluation categories were established, each one composed of different aspects evaluated in the study. Subsequently, the different aspects were weighted, based on the degree of relative importance of the work of a manual seeding. The categories, corresponding aspects and weighting are the following:

- Ease of use: accessibility for the operator (20%) and versatility offered by the tool (15%).
- Accuracy: the percentage of emergency (26.25%) and the occurrence of doubles (6.25%).
- Efficiency of work: the effective capacity (21.25%) and the number of interruptions during the sowing activity (11.25%).

For the versatility, the characteristics of the seeders were revised, giving the best score (10) if the tool has a device that allows to plant and fertilize simultaneously, because this would generate a saving in labor. An intermediate value (5) was given to the tools that have seed dosing systems only and the lowest value (1) was given to the tools that do not have any dosing device.

It was assumed that the difficulty of operating a type of planter or accessibility for the operator is represented by the unifactorial Anova of *p*-value of the time used to plant a bed between operators. Therefore, regardless of the statistical significance, it was possible to infer the accessibility of a tool for an operator with said result. In this sense, a high *p*-value represents a wide accessibility and a reduced *p*-value indicates a more complex system to operate. By performing the same transformation on a scale of 1 to 10, the qualification used was obtained.

To obtain the final score for each tool, the qualification of each aspect was multiplied by the applied weighting and said summed products.

Results and discussion

Characterization of the seed used in the evaluation

The seed used during the evaluation presented on average 5.44, 7.91, 4.2 mm in length, width and thickness respectively, the average sphericity of the seed was 0.52, the mass of 1 000 seeds was 367.7 g and the apparent density of 0.74 g/cm^3 with a moisture content of 9.63%. In the seed germination test, an average value of 92% of germinated seeds was obtained.

Determination of effective sowing capacity

The effective capacities obtained during the sowing activity are presented in Table 2, where it can be seen that the Boshima planter obtained the best performance with an average of 0.055 ha/h, that is, it takes around 23 h of work to finish a hectare. In addition, a great variation can be observed in the results obtained with the other seeders, mainly due to the difference in time used by operators with different seeders. The lowest effective capacity was presented with the Yufeng planter, which required more than 50 hours to finish a hectare of work.

This result is surprising, since the seed dosing systems of both tools are practically the same. However, the difference can be attributed to the fact that in the case of the Boshima planter there is no visibility to ensure the correct placement of the seed, so in many cases it is assumed that it has been deposited correctly and continues with the next blow without setbacks, while with the Yufeng planter you have the visibility of the discharge of the seed at the moment of the blow. By not visualizing the seed placement, the operator intuitively proceeds to repeat the action, requiring a longer time. This action is also reflected in the study by Osei Bonsu *et al*. (2015) where the traditional tool resulted with the longest time in finishing a certain surface because the operators made sure to place the seed properly.

If this is the case, the possibility of visualizing a successful seed placement should be reflected in a higher percentage of emergence of the crop later on.

Table 2. Summary of results obtained in the field of the six seeders evaluated.

Seeder	C_e, ha/h	Surface time, h/ha	Average interruptions
Boshima	0.055	22.9	1.25
GreenSeeder	0.023	45.0	3.25
Shovel	0.026	39.3	0.00
Yufeng	0.020	50.9	1.50
Handspike	0.023	44.5	0.25
Fitarelli	0.029	36.1	4.00

In general, no significant difference in the time used to plant a bed was found among the operators (p-value = 0.19), but there are significant differences between operators for the use of the Boshima, Fitarelli and paddle planters (p-values = 0.017, 0.037, 0.028 respectively). This result indicates that the ability or experience of the operator to work with certain equipment is important to consider, and that some equipment is more accessible than others. The values obtained in this evaluation surpass those provided by Osei- Bonsu *et al.* (2015; 2016) since the topological arrangement was different.

Finally, in Table 2 you can see the average of the interruptions during the sowing activity in which the spade and spade tools require less attention. This suggests because they are traditionally the tools preferred by farmers. The Fitarelli and GreenSeeder planters presented the most interruptions for adjustments, with an average of more than three interruptions in a stretch of 26 m.

Crop emergence

As mentioned above, the time it takes the operator to place the seed in the soil and the visible confirmation of a successful seed placement must be reflected in the crop emergence percentage. In fact, analyzing the data captured 20 days after sowing (Figure 2); this hypothesis can be confirmed because the average values of germination in the row of sowing were 71.1%, 62.8%, and 64.9% for the specimen, the Yufeng seeder and the shovel tool respectively. The lowest values were obtained with the Fitarelli planter, presenting an average germination of 10.5% with respect to the total number of blows made, while the Boshima planter showed the greatest variability.

Probably, these results are also due to the penetration system of each planter. The three most successful systems, apart from having high visibility when depositing the seed, have only one piece that is in contact with the ground and generate a cut (ie Yufeng and the shovel) or hole (ie handspike) on the ground before depositing the seed. In contrast, the Fitarelli and Boshima have a system of mobile points to penetrate and open the floor, which are limited to find areas that are compacted and easily obstructed when performing a wrong operation. In this sense, the GreenSeeder seeder presents an exception because the tip of this tool is made up of a single piece. However, there are internal components that hinder and delay the fall of the seed, resulting in a bad placement of the seed repeatedly.

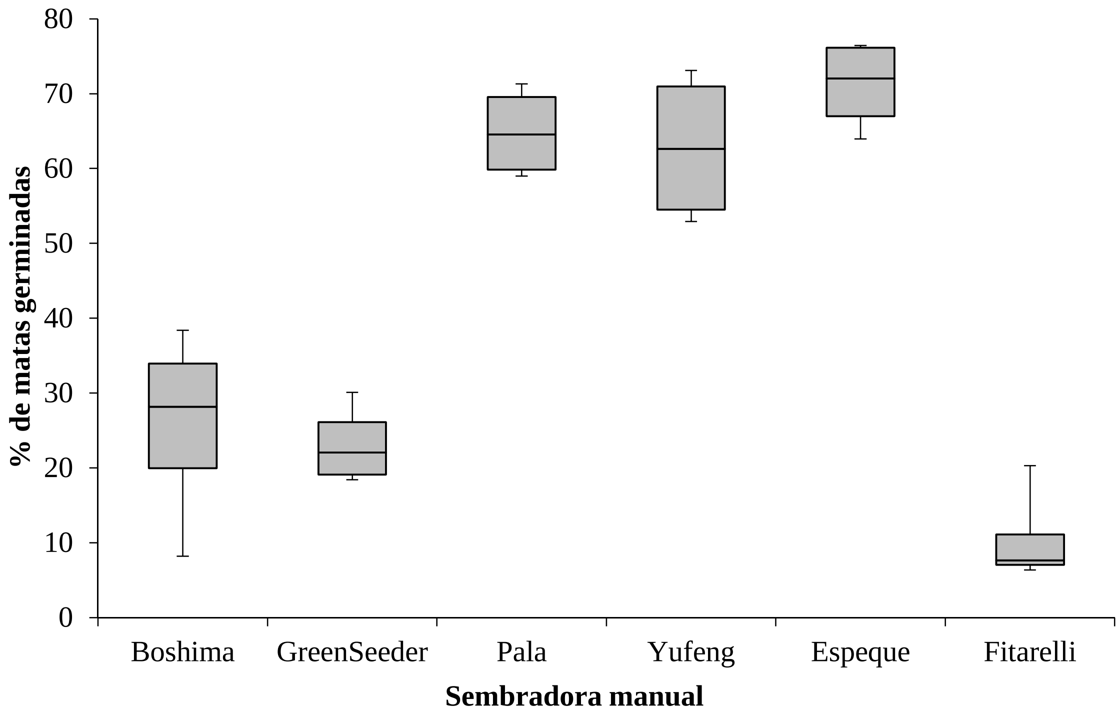

Figure 2. Percentage of blows that presented germination for each bed to 20 days after planting.

During the registration of emergency data, the number of plants emerged per stroke was taken into account, which indicates the efficiency of the singularization of the sowing plant dosing system. A high incidence of two plants emerged per stroke was observed in the 4 furrows established with the Boshima planter with 18.4% of the total number of blows made. Other values found were 15.9%, 14.3% and 11.3% for the Yufeng, GreenSeeder and Fitarelli seeders respectively. The tool shovel and handspike presented the lowest values with 3.3% and 2.3% respectively. Only in a minimum number of cases were three plants emerged per blow, which is why they are not considered in this study.

Overall efficiency of seeders

The results obtained when carrying out the weighting and transformation on a scale of 1 to 10 to determine the overall performance of the seeders are shown in Table 3, according to what is indicated in the methodology.

Table 3. Results of the weighted evaluation to define the efficiency of the implements.

Seeder	Ease		Precision		Efficiency		Total
	Operator	Versatility	Germination	Doubles	C_e	Interruptions	
Boshima	1.00	10	3.26	1.00	10.00	7.19	5.6
GreenSeeder	4.16	5	2.88	3.31	3.05	2.69	3.5
Shovel	1.88	1	9.07	9.44	4.74	10.00	5.6
Yufeng	10.00	5	8.77	2.38	1.00	6.63	6.2
Handspike	4.16	1	10.00	10.00	6.94	9.44	6.8
Fitarelli	1.48	10	1.00	4.97	5.76	1.00	3.7

In this analysis, the specialist finishes with the best rating of all with a final score of 6.8. This result confirms that the implement has been the preferred option of many farmers to date and demonstrates how robust the selection is for generations of users. However, two modern manual sowing machines are positioned in second and third place, with 6.2 and 5.6 points for Yufeng and Boshima, respectively. Both have similar dosing systems, but the visibility and the ease of penetrating the ground make Yufeng outperform Boshima even though the latter has greater versatility. It is important to note that the speed of advancement and a successful establishment of the crop behave in opposite ways. The shovel tool is located in the fourth place, losing field because it is simple and rough for the less experienced operator.

In the last positions are located the Fitarelli and the GreenSeeder with values of 3.7 and 3.5 respectively. The reason for the lower performance of these tools is due to the way to open and deposit the seed on the ground. The Fitarelli, due to its scissors system, is often covered up, causing constant interruptions to clean the tips similar to that reported by Johansen *et al*. (2012), while the GreenSeeder has problems in synchronizing the fall of the seed mentioned above, making it imprecise and impractical.

In this way, the parameters obtained allowed to characterize the performance of the different tools studied where advantages and disadvantages of each one are observed. Tools that can be manipulated more quickly provide an increase in effective capacity in the field; however, there is a risk of not placing the seed properly severely affecting the successful establishment of the crop. Traditional tools ensure proper placement, but depend in a certain way on the operator's experience. However, using creole seeds, the dosing systems integrated in modern seeders also do not always provide the required precision.

Factors not evaluated in this work, but equally important to consider are: the construction material and its robustness (as mentioned by similar studies, the tools made of plastic tend to have a short lifespan due to the deterioration of their components), the complexity of the Dosing mechanisms (a high number of small components often cause setbacks in settings) and fatigue generated in the operator by the use of a certain tool. This last factor was not considered in the presented work due to the fact that the reduced work area did not allow reaching significant levels of fatigue, apart from requiring specialized instrumentation.

Conclusions

The agrotechnical evaluation of 6 manual sowing machines was carried out by sowing corn in the field. Two of the evaluated tools are traditionally used by producers and they lack seed and fertilizer dosing mechanisms; the rest have modern mechanisms commercially available in various regions of the world. The versatility of an implement, such as the option of sowing and fertilizing at the same time, represents an advantage for the saving of work that implies a second activity such as fertilization.

In summary, in order to meet the needs of producers it is necessary to have a robust and easy to operate tool in general, with satisfactory accuracy. Based on the analysis presented, the species is still a tool that meets the best results, including these criteria. However, there are several options that approach the performance of traditional tools and offer a solution for less experienced operators, increasing work efficiency. Nowadays, this aspect is extremely important within the rural demographic context that is in a strong decrease of people interested in getting involved in field activities.

The results of this work explain why farmers still prefer their traditional implements to carry out the planting of corn manually. However, with the demands of intensifying agriculture in small farms and the increase in the cost of labor, there is a need to look for more versatile, precise and efficient tools in changing conditions. From this perspective, the presented analysis describes a relatively simple methodology to evaluate the general efficiency of various tools for the manual sowing of corn, taking into account the most important characteristics according to the needs of the region. In the future, it will be necessary to expand the study including more tools, different soil conditions and a variety of seeds, among others.

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