# Hand Planter for Maize (Zea mays L.) in the Developing World

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| Journal: | *Journal of Plant Nutrition* |
| Manuscript ID: | LPLA-2014-0093.R1 |
| Manuscript Type: | Original Articles |
| Date Submitted by the Author: | 12-Jun-2014 |
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| Keywords: | Nitrogen < Macronutrients, Fertilizers, Soil Fertility, Yield, Annual Crops, Precision Agriculture |
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## Abstract

Maize (Zea mays L.) grain yields in the developing world hover near 2 Mg ha$^{-1}$. Planting maize involves placing two to three seeds per hill, with hills being roughly 30 cm apart. Variability in seeds per hill and distance between hills results in heterogeneous plant stands that lower yields. Oklahoma State University (OSU) has developed a durable hand planter with a reciprocating internal drum that delivers single maize seeds per strike and that can also be used for mid-season application of urea fertilizer. Our current prototype has been comprehensively tested and evaluated to deliver at least 80% single seeds (singulation), 0% misses, work well over a range of seed sizes (2652 to 4344 seeds kg$^{-1}$), different operators, and can be used for mid-season fertilizer application.

*Keywords: Hand planter, Maize, Plant population*

## Introduction

Maize is one of the most important cereal crops in the world and serves as a source of food and income for many communities around the globe. In the developing world, maize is a staple caloric source accounting for as much as 50% of that consumed in some African countries (FAO, 2011). Current annual global maize production is estimated to be about 883 million MT of which roughly 180 million MT (20 % of world production) is produced in Latin America and Africa (FAO, 2011). Ray et al. (2013) noted that the production level in developing nations where maize is so important, needs to be doubled in order to meet the rising population demand by 2050. However, the development of soil fertility and improved production techniques have fallen behind in many of these countries, resulting in average yields near 1.8 Mg ha$^{-1}$ (FAO, 2011). Adoption of more efficient production practices are needed to overcome the low productivity commonplace in developing nations (Du Plessis, 2003). In some developing countries, an increased focus on higher yielding varieties has come at the expense of improved agronomic practices. Bekele et al. (2011) noted that using high yielding varieties will not necessarily increase maize yields, unless complemented with needed agronomic practices . In addition, Heisey and Mwangi (1996) noted that yield increases rather than area expansion will become progressively more important for increasing crop production as agricultural land is becoming scarce in Sub-Saharan Africa.

In developed countries, maize is planted using mechanized planters that deliver single seeds at equal depths and spacing resulting in homogenous plant stands and increased yields. Alternatively, production practices currently used for maize planting in developing countries are labor intensive and inefficient (Pradhan et al., 2011). The poor socio-economic conditions of farmers in most developing countries, has limited maize planting mechanization; in many of these countries maize planting is associated with the use of a heavy stick planter and hand hoes (Adjei et al., 2003). The planting stick consists of a wooden shaft with a pointed metal tip to penetrate the soil thus making a hole/depression for seed placement (FAO, 2010). Traditional planting techniques consist of placing two to three seeds within the hole (shaft/tip depression created when striking the ground, commonly referred to as 'hill') and then seeds are covered by the surrounding soil. The process is labor intensive, results in multiple seeds emerging per hill, and non-uniform plant stands (Aitkins et al., 2010).

Non-uniform plant stands can increase inter-plant competition and decrease yields (Nafziger et al., 1991). Boomsma et al. (2011) noted that high plant densities result in reduced per-plant resource availability, increased plant competition, decreased productivity, developmental variability, and ultimately lower yields. Work by Chim et al. (2013) showed that

1 seed per hill at 0.16 m spacing, increased yields by 0.2-0.9 Mg ha$^{-1}$ compared to planting 2-3 seeds at 0.32 and 0.48 m plant spacing. Doerge et al. (2002) reported that for each inch improvement in the standard deviation of equidistant plant spacing, yields can be increased up to 0.25 Mg ha$^{-1}$. This work also reported that when plants were within 0.05 to 0.07 meter spacing, maximum by-plant yields were achieved.

In addition to potential yield and economic losses, seeds are often pre-treated with fungicides, introducing a health risk to the farmer when seeds are handled by hand. These factors and the high price that producers pay for acceptable maize seed, make the improved use of this resource a necessity.

The development of a planter with the ability to make a hole and release a single seed upon penetration of the soil would improve homogeneity of the plant population, decrease plant to plant competition and improve yield potential. The objective of this work was to design and test a hand operated, light-weight planter that could reliably deliver one seed per strike in various soil textures and tillage systems, regardless of seed size and operator.

## Materials and Methods

### Prototype Development

Development and evaluation of the OSU hand planter has required testing of various designs. Initially a square housing with an external spring was used to rotate a reciprocating drum with a prefabricated cavity capable of holding 1 to 2 maize seeds (Figure 1). The current design employs a round housing with an internal spring (Figure 2). The primary focus was to develop a hand planter that delivers at least 80 percent single seeds, and no more than 5 percent misses (no seed delivered). Seed metering performance of the planter depends on the drum and brush specifications.

## Prototype Description and Operation

The hand planter weighs 1.9 kg, with the capacity to contain > 1 kg of seed of various sizes. The seed reservoir is made of a polyvinyl chloride (PVC) round pipe with a diameter of 5.8 cm**.** Attached to the reservoir is a seed metering delivery system which consists of a short tube containing a reciprocating drum, spring, and brush. A sharp pointed tip/shovel is attached to the metering device that can plant seed to a depth of 5 cm in no-till and tilled soils when the planter tip penetrates the soil (Figure 3). Actual depth of placement depends on the force exerted by the planter operator.

Drum cavity depth and angle are crucial for determining the number of seeds that are released with each strike. Representative rotating drums that were tested, accommodating differing seed sizes, are shown in Figure 4. During operation, the drum cavity is overladen with seed that feeds from the vertical hopper, and via a reciprocating drum, receives one seed at a time using a brush that passes over the cavity removing excess seeds (Figure 5). Brushes of differing tensile strength can be used as necessary for differing seed sizes and shapes. The movement of the drum is facilitated by the force applied on the spring when the planter is pressed downward.

The planter is designed for "up-stroke" seed release, where the operator creates a hole in the soil by pushing the tip into the ground. This movement compresses a spring and rotates the drum to capture each seed in the drum cavity. When the spring is released on the "up-stroke", the drum rotates back to release the seed within the soil depression created by the tip. A down-stroke release is also possible by rotating the lever attached to the drum (requires altered design not shown in Figures 2 or 3). The down stroke would release the seed as the planter tip is pushed into the ground.

### Testing and Evaluation

Comprehensive field and laboratory testing was performed to evaluate the effect of various components on the planter's ability to deliver a single seed regardless of seed size and operator. During testing, operator, seed size, drum cavity depth, and brush were recorded. Many drums with varying cavity depth and angle (degrees) have been tested, together with brushes of varying stiffness.

### Seed Size

The inherent differences in maize seed size, weight, and shape can significantly affect the performance of the planter. Initially, the weight of seeds per kg was used as the only criterion for determining performance of the drum. Tests were conducted on maize seed ranging from 2652 to 4344 seeds kg$^{-1}$ (Table 1). Some seeds have the same density (seeds kg$^{-1}$) but have different shapes (medium flats, small round, large round, etc.). However, seed density and volume (seeds L$^{-1}$), determined via water displacement were found to have a 1:1 relationship (Figure 6). Thus either method can be used to determine drum size for differing seed sizes.

### Field Testing

Field performance testing was conducted at OSU Agronomy Research Station at Efaw Stillwater, Oklahoma to evaluate emergence of maize seeds. A randomized complete block design was used with 3 replications and 13 treatments; consisting of 2 housings (H1st and H1so), 2 drum sizes (450s and 450b), and 3 seed sizes (3572, 3263 and 2652). All treatments were planted with Pioneer hybrid maize seed on tilled ground, and a 76 cm row spacing. Emergence counts, including single and multiple seeds, were taken and percent emergence (%) for each treatment was averaged from the three replications.

### Urea Application

An added benefit of the hand planter that has been developed is sidedress application of granular fertilizer. For the application of 50 kg N $ha^{-1}$ as urea (by plant basis, 70,000 plants per hectare) an internal drum was easily modified to deliver 1.6 g per plant, per strike. The ability of the hand planter to deliver granular urea by-plant and corresponding effects on yield were tested in field experiments at Efaw and Perkins, near Stillwater, Oklahoma in 2013. The site at Efaw was located on an Easpur loam (Fine-loamy, mixed, thermic, Fluventic Haplustoll) and the site at Perkins was located on a Teller fine sandy loam (Fine-loamy, mixed, thermic, Udic argiustoll). A randomized completed block design was employed with 9 treatments and 3 replications. The fertilizer sources used were urea and urea ammonium nitrate (UAN) (28-0-0). Fertilizer was either broadcast, dribbled, or side dressed with the hand planter at V12 growth stage (Ritchie et al., 1997). At maturity, ears of the two middle rows were harvested by hand and shelled, after which the grain weight was recorded for each plot. Grain yield for each treatment was averaged over three replications.

## Results

### Drum Cavity Depth and Angle

Results for seed counts presented in Table 2 combined two cavity angles (20 & 25 degrees) for each cavity depth (5.96 and 6.60 mm). With constant modification and development, the number of misses has been reduced and the singulation percentage has increased. Drums with increased cavity depth and angle had more strikes with multiple seeds delivered and fewer misses while drums with a smaller cavity had a higher percentage of misses.

### Seed Size

For a fixed cavity size, smaller seeds (>4000 seeds kg$^{-1}$) had more multiples with fewer misses compared to larger seeds (<3000 seeds kg$^{-1}$). With cavity size, depth, and angle design improvements, the number of singles was significantly improved, and the number of multiples and misses were reduced with repeated modification of the seed metering unit.

### Field Testing

Field performance and emergence testing showed that the internal housing with the soft brush (H1so) combined with drum 450s resulted in the highest percentage of singles (85%) with smaller seed (3572 seeds kg$^{-1}$) having more multiples and less misses than the larger seed (3263 seeds kg$^{-1}$) (Figure 7). In the process of drum modification, more multiple seeds per strike have been allowed in order to obtain fewer strikes with no seeds delivered. This should also assist in decreasing variability in percent emergence.

Results for the urea trial for both the Efaw and Perkins locations showed that by-plant delivery of urea with the hand planter improved yields by 20 to 36% compared to yields achieved by dribbling urea on the surface. Grain yields were increased by as much as 50 to 75% when urea was applied with the hand planter compared to treatments where urea was broadcast applied (Table 3). This can be attributed to reduced ammonia volatilization when urea is sub surface applied versus surface applications (Jones et al., 2007).

### Up -stroke and Down- stroke

The number of multiples and misses using the 'up-stroke' release design have been reduced through continuous evaluation and modification. However, the up-stroke design is more cumbersome as it involves a back and forward planter motion to create an adequate hole for the single seed planting. Observations from field testing indicate that the 'down-stroke' releasing drum design has more promise. Although this design still has lower singulation, it is easier to use, does not involve a back and forward motion and has less soil clogging in the planter tip. Current work is focused on improving singulation and reducing misses in the 'down-stroke' design. Once this design is fully vetted, it will be evaluated under various field conditions, modifying the planter tip to allow for the best soil-seed contact.

## Summary, Conclusion and Recommendations

Significant progress has been made in planter design and singulation results. Current OSU hand planter models have surpassed the initial target goal of 80 percent singulation. Drum cavity size and depth have been shown to be crucial in determining the number of seeds that are released with each strike of the planter. Inherent differences in maize seed make it hard to have a universal drum that works for the array of seed sizes found around the world. Future users of the hand planter are encouraged to first evaluate the drum cavity using seed within their region. Cavity size and depth can then be altered to accommodate the seed used within each production region so as to optimize seed singulation. Furthermore, field observations have shown ergonomic differences among operators. This has impacted planting depth and the precision with which seeds are planted in the soil. Simple training is required for users allowing for more precise delivery of maize seed into the soil.

Notwithstanding, the planter in its current design has shown to be a promising tool to improve current maize production practices in developing countries. This conclusion is based on acquired attributes developed during testing that include at least 80% singulation over a range of seed sizes, is light weight, accommodates mid-season application of granular fertilizer, and has a versatile internal drum that can be modified for seed size and/or seed type. .

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Table 1. Maize hybrids, density (seeds $kg^{-1}$) and volume (ml $kg^{-1}$) of maize seed used in this study

| **Hybrid** | **Density** (seeds $kg^{-1}$) | **Volume** (ml $kg^{-1}$) |
|---|---|---|
| DKC 62-09 | 4210 | 5263 |
| DKC 62-26 | 4344 | 5556 |
| DKC 63-55 | 3263 | 4255 |
| PO876HR | 4050 | 5263 |
| P1395XR | 3846 | 4444 |
| P1395YHR | 2652 | 3448 |
| P1395AM1 | 3572 | 4545 |
| P1498HR | 3017 | 3846 |

Table 2. Treatment means for brush (T4-T8) and drum combinations (235, 260) including misses, singles, and multiple seeds.

| **Brush** | **Drum** | **Misses** | **Singles** | **Multiples** |
|---|---|---|---|---|
| | inch (mm) | | Means (%) | |
| T4 | 0.235 (5.96) | 6.5 | 90 | 3.5 |
| T4 | 0.260 (6.60) | 3 | 85 | 12 |
| T5 | 0.235 (5.96) | 6 | 64 | 30 |
| T5 | 0.260 (6.60) | 5 | 65 | 30 |
| T6 | 0.235 (5.96) | 4 | 76 | 20 |
| T6 | 0.260 (6.60) | 2 | 64 | 34 |
| T7 | 0.235 (5.96) | 5.5 | 89 | 5.5 |
| T7 | 0.260 (6.60) | 4 | 78 | 18 |
| T8 | 0.235 (5.96) | 14 | 84 | 2 |
| T8 | 0.260 (6.60) | 8.5 | 85 | 5.5 |

0.235 and 0.260 are drum cavity depth in inches (mm), T4 to T8 are test brushes with varying location relative to the drum and stiffness.

Table 3. Treatments and grain yield means for Efaw and Perkins, Oklahoma 2013

| **Methods** | **N rate** | **Yield** |
|---|---|---|
| | kg $ha^{-1}$ | Mg $ha^{-1}$ |
| Check | 0 | 6.6 |
| Hand planter (0.9 g/plant) | 30 | 11.2 |
| Hand planter (1.8 g/plant) | 60 | 10.6 |
| Broadcast | 30 | 6.4 |
| Broadcast | 60 | 7.0 |
| Dribble urea | 30 | 9.3 |
| Dribble urea | 60 | 7.8 |
| Dribble UAN | 30 | 7.3 |
| Dribble UAN | 60 | 10.4 |
| SED† | | 1.81 |

Plant density 70,000 seeds $ha^{-1}$

† Standard Error of the Difference

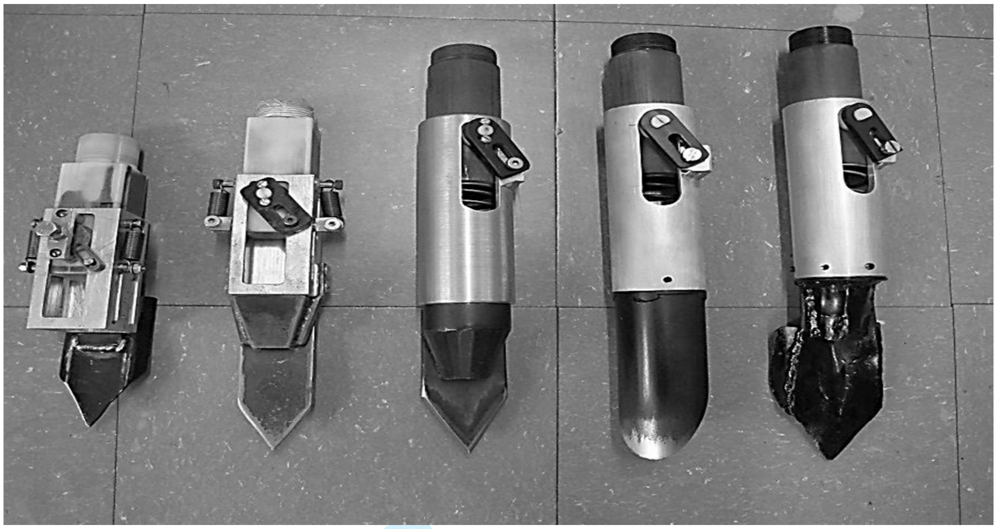

Figure 1: Sequential development (left to right) of the hand planter showing design progress and tip modification 2011 through 2013.

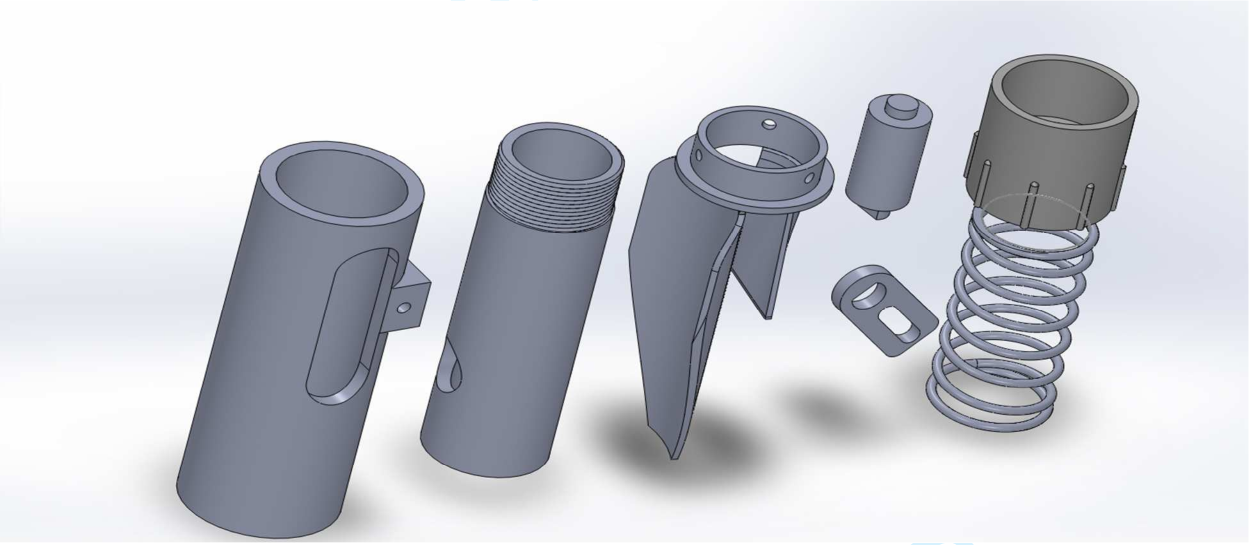

Figure 2: Components of seed metering unit (left to right), including external housing, internal housing planter tip, rotating drum, rotating arm, connecting coupler, and internal spring, Oklahoma State University.

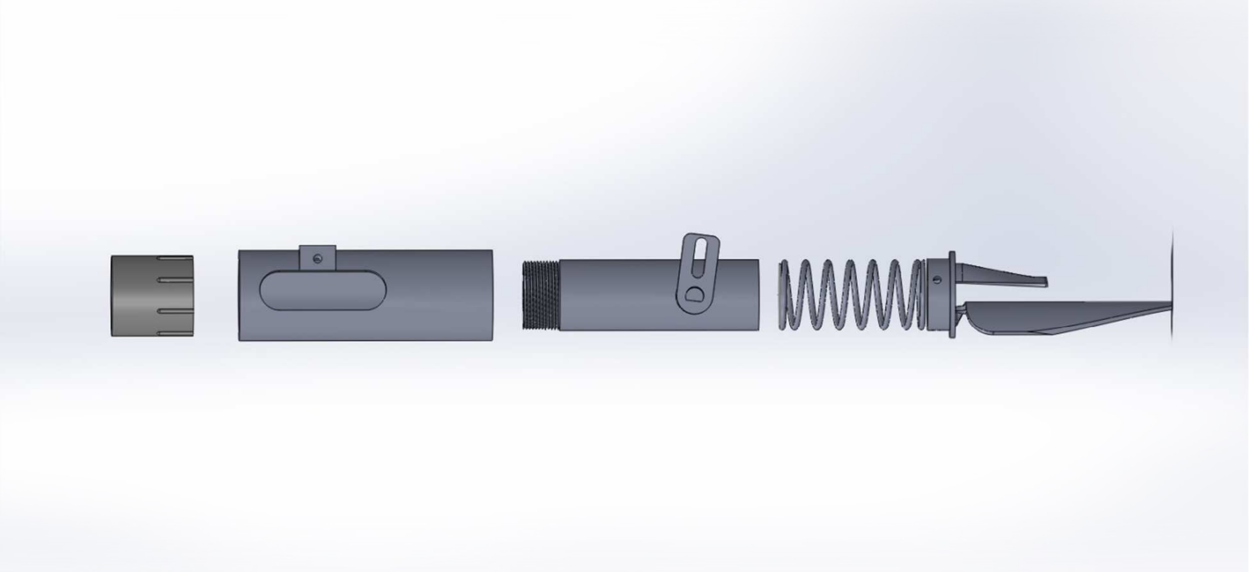

Figure 3: Side view of the hand planter showing (left to right, coupler, external housing, internal housing with rotating arm, spring and planter tip, Oklahoma State University.

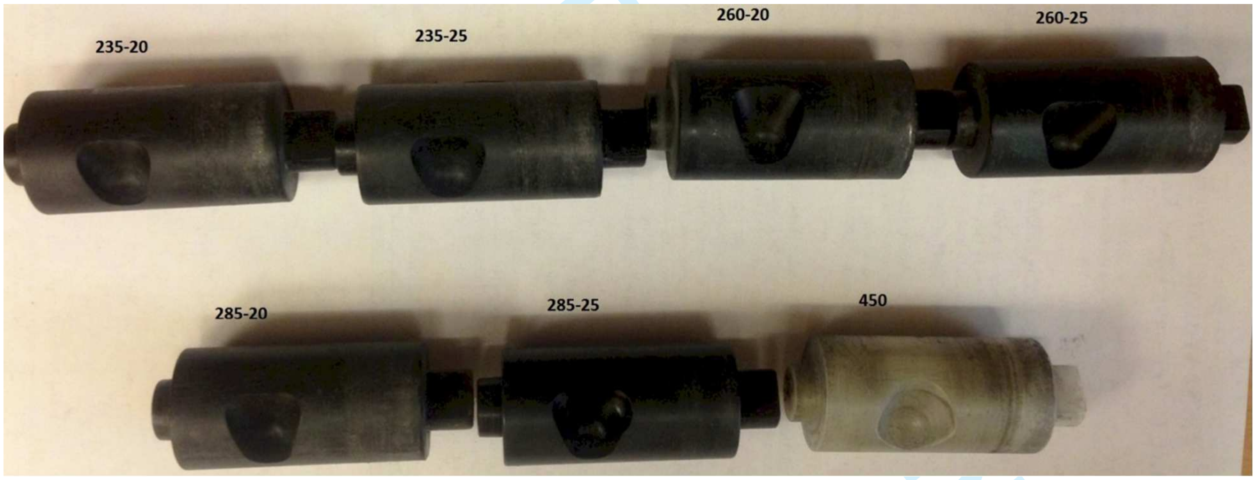

Figure 4: Internal rotating drums with different cavity depths, size, and angle.

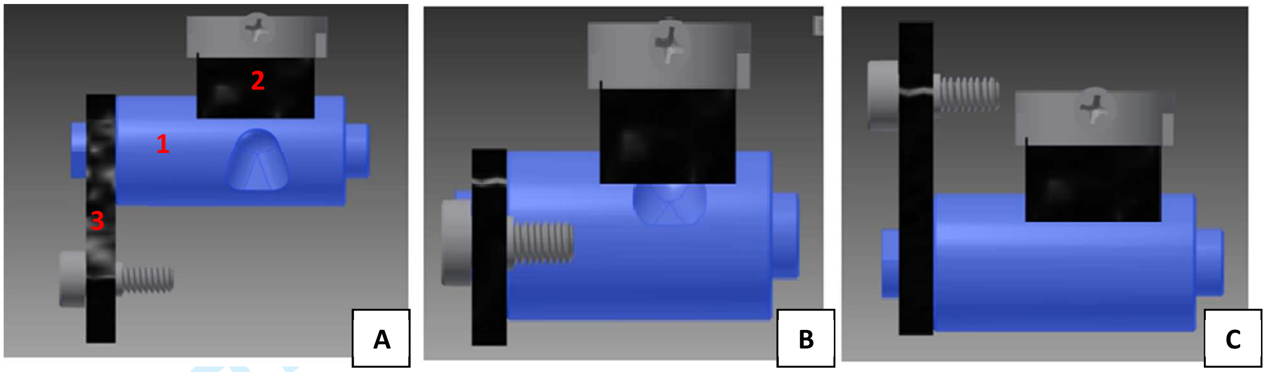

Figure 5: Position of the drum (1), brush (2), and rotating arm (3) during operation. Reciprocating drum in “relaxed” position (A). The drum rotating back as force is applied to the internal spring (B). Spring is fully compressed; drum cavity is exposed to seeds in seed hopper (C).

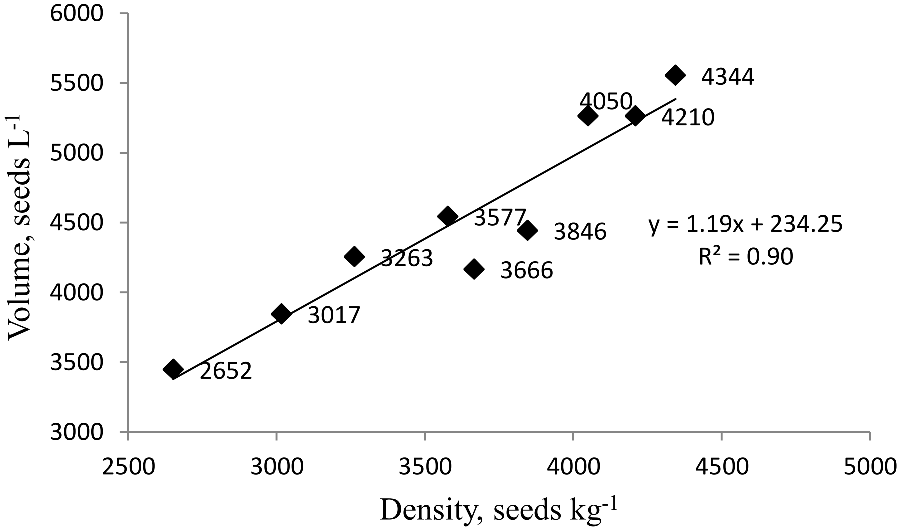

Figure 6: Regression analysis showing the relationship between volume, seeds L $^{-1}$ and density, seeds kg $^{-1}$.

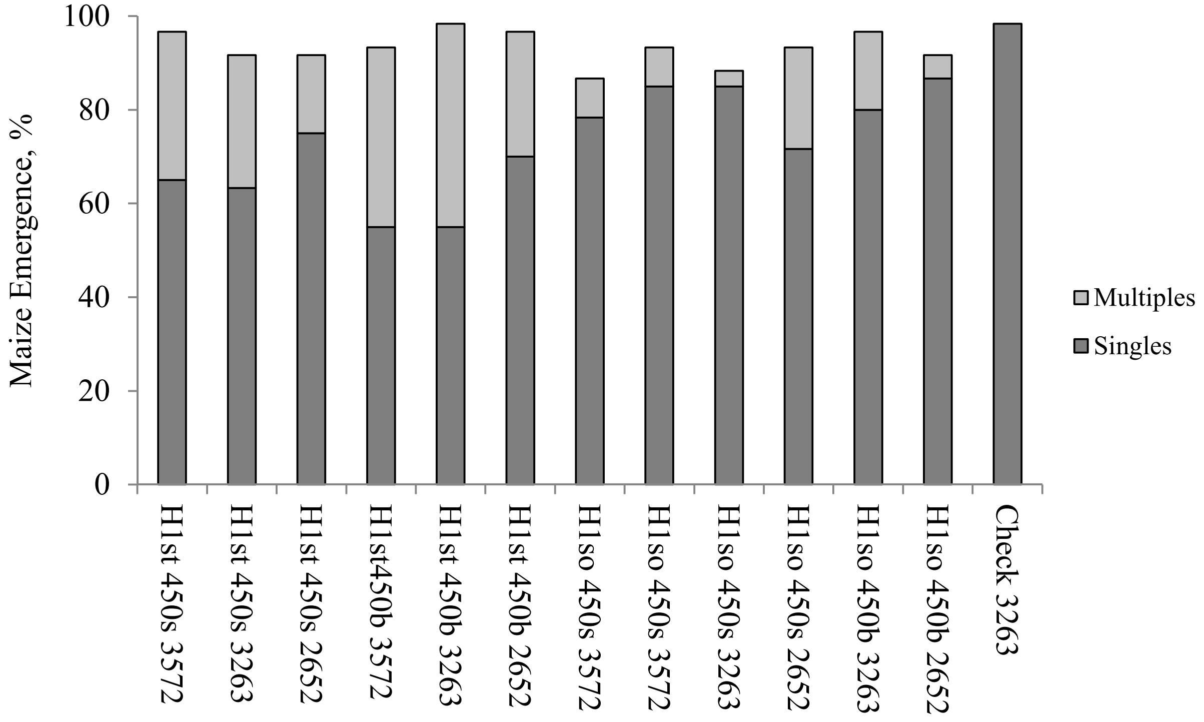

Figure 7: Field performance and emergence tests on seed-drum combinations (H1st, H1so, reflect stiff and soft brushes for the H1 internal housing, 450s and 450b were the two different drums used, and lower numbers are the seed densities, number per kg.).

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