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Design and Development of an Universal Vacuum Disc Equipped with Hole Adaptors for Precision Seeders

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Abstract: The objective of this study was to design and develop a vacuum disk equipped with hole adaptors for precision seeding of different crop seeds. In order to meet this objective, a vacuum plate with a pitch diameter of 190 mm and with 36 holes, each in the diameter of 8 mm was designed and manufactured. What makes the disk for using different crops was the idea of adjusting hole diameter with different adaptors at different diameters that makes them suitable for seeding different crop seeds. If necessary some of the holes can be plugged and the number of holes on vacuum plate can be reduced proportionally down to 18, 12 holes etc. This would provide another option to the farmers in order to set the theoretical seed spacing along with a change in transmission ratio via gear box available in precision seeders. The adaptors designed in a special software was manufactured on a 3D printer at a hole diameter of 2.5 and 4.0 mm in order to use for seeding cotton and corn seeds, respectively. The adaptors were then plugged on 8 mm holes and tested in the laboratory conditions by using sticky belt test stand. Seed spacing values were measured by a computerized measurement system (CMS) for the cotton and corn seeds. These tests were conducted in order to find out how the use of adaptor materials as coupled with the steel vacuum plate thus changing the coefficient of friction will affect the performance. The theoretical seed spacing for both cotton and corn seeds was set to 11.8 cm and a vacuum of 6.0 kPa was applied during the tests. The forward speed values were selected to be 0.5, 1.0 and 1.5 m s^{-1}. Quality of feed, multiple and miss indices as well as coefficient of precision (CP3), Precision and E_{rms} were considered as the performance indicators for precision seeding. The quality of feed index for cotton seeds was found to be 84.4 and 88.9% while the miss index contributed to the rest of the seed spacing distribution of 15.6 and 11.1 % at forward speeds of 0.5 and 1.5 ms^{-1}, respectively. The quality of feed index for cotton was obtained to be 100% at a forward speed of 1.0 ms^{-1}. The quality of feed index for corn seeds was found to be 100% at all forward speeds considered in the study.
Key words: Accuracy, measurement, metering unit, precision seeding, seed spacing

INTRODUCTION

Uniform seed spacing is of importance so that each seed can have the same chance to grow and emerge from the soil without any competition with neighboring seeds in terms of moisture, nutrition etc. Many factors contribute the success of precision seeding of row crops and these are mainly related to constructional and operating parameters of the metering unit. On the other hand, seed related properties such as mean particle diameter, and the geometry and mass of the seeds determine the level of vacuum, the diameter of holes and the peripheral speed of the vacuum plate. Yazgi and Degirmencioglu (2007) found that the hole diameter as it interacts with the vacuum and disk peripheral speed (as it linearly changes with forward speed) is a significant variable that affects seed spacing uniformity.

Planter performance factors include variability around the target drop points (drop error), failure of a seed to be dropped, multiple seeds drop at the same time. These are constructional and operating parameters related to metering unit. But seed bounce and roll in the furrow and movement of seeds for the incorporation into the soil are forward speed related issues (Panning et al, 2000).

Many studies in the past have been conducted in order to determine the performance of precision seeders. These, mostly experimental studies, reveal information about how the metering systems of precision seeders performs in the laboratory or field.

Studies mostly focus on the vacuum pressure applied to the seed plate, the most common metering system in precision seeders. In a study, Singh et al. (2005) examined the effect of operational speed of the seed plate (disc), vacuum pressure and shape of the entry of seed hole and evaluated the precision in seed spacing, miss index, multiple index and quality of feed index. However, they assumed that the appropriate seed hole diameter for cotton seeds was 2.5 mm. They found that the metering system with a speed of 0.42 ms^{-1}, and a vacuum pressure of 2 kPa produced superior results with a quality of feed index of 94.7% and a coefficient of variation in spacing of 8.6%. In another recent study, Karayel et al. (2004) focused on vacuum pressure in order to find out the best performance values of a precision seeder for maize, cotton, soya bean, watermelon, melon, cucumber, sugar beet and onion seeds. The performance values were determined as quality of feed, multiple and miss indices and the preciseness. Using the highest performance value of the quality of feed index, Karayel et al. (2004) created a generalised model for predicting the vacuum pressure. They used 3.5 mm hole diameter for cotton seeds and obtained a highest quality of feed index of 92.2% at 3 kPa vacuum pressure. Panning et al. (2000) evaluated five planter configurations for seed spacing uniformity at three field speeds using a seed location method in the field and a laboratory method involving an opto-electronic sensor system. They defined planter seed spacing uniformity by using the coefficient of precision. They used sugar beet seed for the study. Moody et al. (2003) evaluated a row crop seeder performance in a field study and they tested the vacuum-type seeder at three seed meter rotational speeds of 0.16, 0.23 and 0.31 s^{-1} with corresponding ground speeds of 4.8, 7.2 and 9.7 kmh^{-1} using cotton and maize seeds. From the study, they concluded that the variability in seed spacings increased with increasing seed meter rotational speed.

Vacuum disks in precision seeders are manufactured by farm machinery companies and based on the crop to be planted and the number of rows, a set of vacuum disks is provided to the farmers for a specific crops seeds. The number of holes and the diameter of holes on vacuum disks vary from one company to another and also from one crop to another. Hence, different sets of vacuum disks are usually manufactured. There is no such a certain hole diameter for a specific crop such as using a vacuum disk with holes at 3 mm diameter for cotton since any changes in variety of a crop may change the physical properties. Hence a study was conducted to develop a universal vacuum disk and the objective of this study was to design and develop a vacuum disk for precision seeding of different crop seeds.

MATERIALS and METHODS

A modular metering unit that was specially designed for another project was used for the experiments. Vacuum pressure was provided by an electronically controlled fan of a separate unit. A vacuum plate with a pitch diameter of 190 mm and with 36 holes, each in the diameter of 8 mm was designed and manufactured. The holes on vacuum plates were drilled on a laser cutting machine with an accuracy of ± 0.1 mm.

The metering unit with vacuum plate during the experiments was driven separately by an electronically controlled system and the theoretical seed spacing was adjusted to 11.8 cm. The adaptors designed in a special software was manufactured on a 3D printer at a hole diameter of 2.5 and 4.0 mm for cotton and corn, respectively. These adaptors were then plugged on 8 mm holes so that the orifice size from 8 mm was reduced down to such optimum level. The optimum level of the hole diameters was the ones that were obtained from another study (Doğan, 2015) carried out with the same corn and cotton varieties as used in this study. The general view of the vacuum disk and adaptors is depicted in figure 1 while the physical properties of corn and cotton are tabulated in Table 1.

Table 1. Physical properties of cotton and corn seeds

Seed	Length (*l, mm*)	Width (*w, mm*)	Thickness (*t, mm*)	Sphericity (*Φ*,%*)	Thousand seed mass (g)
Corn	10.6±0.8	7.8±0.6	5.7±0.4	73.6	344.3±2.2
Cotton	**9.1±0.7**	**4.8±0.4**	**4.3±0.3**	**63.3**	**87.6±0.4**

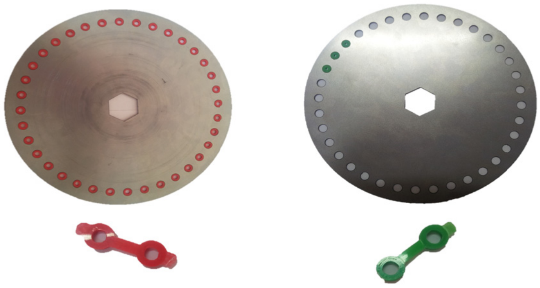

Figure 1. General view of the vacuum disk and adaptors used for corn (on the left) and cotton (on the right)

$$\phi = \frac{(lwt)^{1/3}}{a} * 100$$

Seed spacing accuracy tests were achieved on sticky belt using universal vacuum disk equipped with adaptors (Figure 2). For this purpose, sticky belt test stand was used to measure the seed spacing in the laboratory.

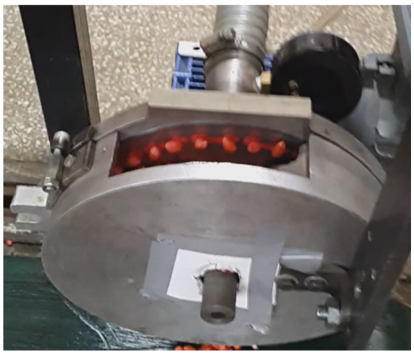

Figure 2. A view from the experiments conducted with universal vacuum disk equipped with adaptors at 4 mm for corn seeding

In order to facilitate this study, seed spacing measurements and its evaluations were made by means of a computerized measurement system, CMS, (Onal and Onal, 2009). For this reason, a sticky belt test stand was equipped with a computerized measurement system. CMS hardware consists of a high precision optical mouse coupled with laser pointer and a notebook computer. The software of the CMS stores coordinate data of the seeds using a simple user interface and sends to Microsoft Excel for further statistical analysis. The developed program analyzes the information and output results in numerical (ISO, 1984 indexes of quality-of- feed index, miss index, and precision) and graphical (histogram of seed spacing) forms. Sticky belt test stand is 0.15 m wide and 11 m long horizontal viewing surface. The measurement of seed distances was carried out at a distance of 7-8 m approximately for each test. The sticky belt stand was equipped with a multi-speed drive arrangement and grease oil was smeared on the top surface of the belt to capture the seed as it was released from the seeder without rolling or bouncing of the seed on the belt surface.

Different performance criteria to evaluate the performance of precision seeders are developed and available in the literature. One of them is the use of quality of feed index (I_{qf}) along with multiple (I_{multi}) and miss indices (I_{miss}). For a better performance, the quality of feed index should be maximized while the multiple and miss indexes are minimized. Seed dispersions for precision seeding were determined according to Table 2 (Kachman and Smith, 1995) and evaluated based on the criteria given in Table 3 (Anonymous, 1999). Other performance criteria used in this study was root mean square error as defined by Yazgi and Degirmencioglu (2007). As an another criteria, the CP3, known as the 3-cm mode range, was used to determine the ability of the precision seeder to space seeds and includes only spacings within ±1.5 cm of the theoretical spacing. Precision is a measure of the variability in spacing between plants after accounting for variability due to both multiples and skips. The precision is the coefficient of variation of the spacings that are classified as singles (Kachman and Smith, 1995).

The acceptable limits of CP3 and Precision are 40% (minimum) (Smith and Kocher, 2008) and 29% (a practical upper limit) (Kachman and Smith, 1995), respectively.

Table 2. Definition of the seed/plant spacing distribution indexes (Kachman and Smith, 1995)

Seed spacing	Definition
< 0.5 Z	Multiple Index
(0.5-1.5) Z	Quality of feed index
(1.5-2.5) Z	Miss index
(2.5-3.5) Z	Miss index
> 3.5 Z	Miss index

Z: Theoretical seed spacing

Table 3. Performance criteria based on seed distribution for precision seeding (Anonymous, 1999)

Quality of feed index (I_{qf} %)	Multiple index (I_{mult}%)	Total miss index (I_{miss}, %)	Classification
>98.6	< 0.7	< 0.7	Very good
>90.4–≤98.6	≥ 0.7–<4.8	≥0.7–<4.8	Good
≥82.3–≤90.4	≥4.8–≤7.7	≥ 4.8–≤10	Moderate
<82.3	>7.7	>10	Insufficient

RESULTS and DISCUSSION

The histograms showing the percentage of seeds at different seed spacings at different forward speeds are depicted in figure 3 thru 5 for corn and in figure 6 thru 8 for cotton.

The histograms drawn and depicted in Figure 3 thru 8 can only give an idea about the percentages of I_{qf}, I_{multi} and I_{miss} performance values and distribution on sticky belt test stand. As seen from figure 3 thru 5 for corn, the I_{qf} values are 100 % at all forward speeds since seeds are between 5.9 and 17.7 cm range (0.5-1.5 Z). But if the histograms are examined carefully it is seen that the distribution is more homogeneous at 1.0 ms^{-1} forward speed since seeds usually accumulate within a narrow range between 10 and 14 cm.

If the histograms are viewed for cotton, it is easy to conclude that an ideal I_{qf} value of 100% can only be obtained at a forward speed of 1 ms^{-1} while there are no multiples but some misses occurred at 0.5 and 1.5 ms^{-1} forward speeds.

It is hard to obtain other performance values from the histograms. Hence the results from calculations made to obtain other performance values considered in this study are tabulated in Table 4 and 5 for corn and cotton, respectively.

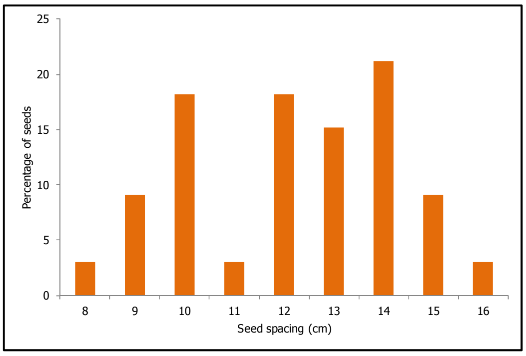

Figure 3. Seed distribution obtained from sticky belt tests for corn at 0.5 ms^{-1} forward speed

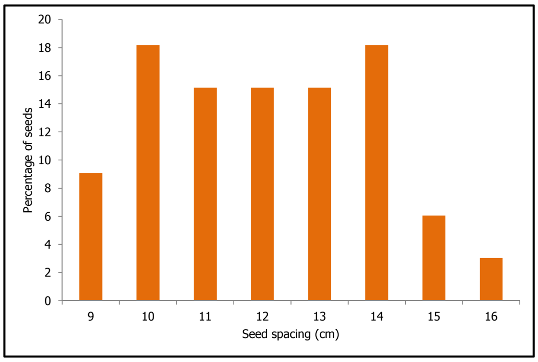

Figure 4. Seed distribution obtained from sticky belt tests for corn at 1.0 ms^{-1} forward speed

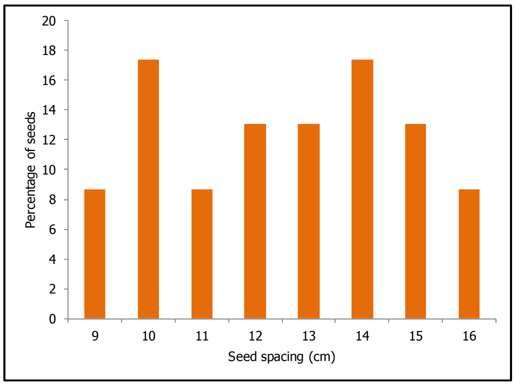

Figure 5. Seed distribution obtained from sticky belt tests for corn at 1.5 ms^{-1} forward speed

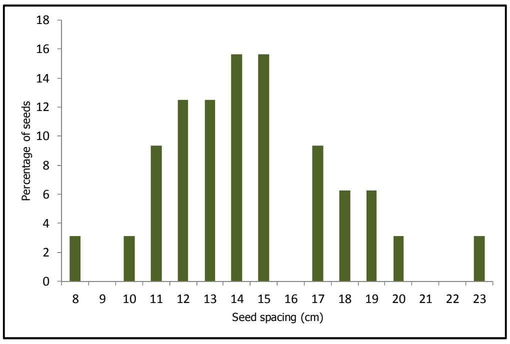

Figure 6. Seed distribution obtained from sticky belt tests for cotton at 0.5 ms^{-1} forward speed

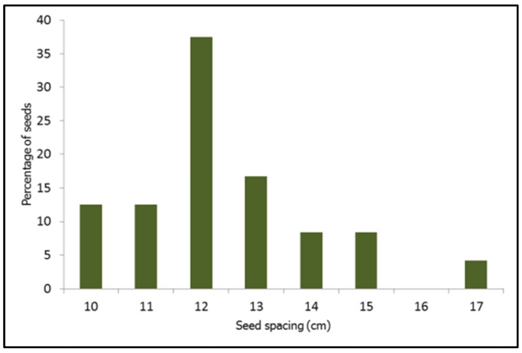

Figure 7. Seed distribution obtained from sticky belt tests for cotton at 1.0 ms^{-1} forward speed

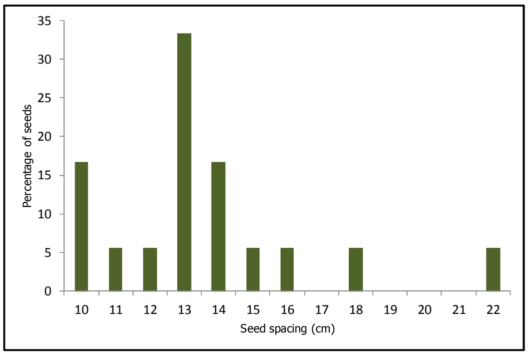

Figure 8. Seed distribution obtained from sticky belt tests for cotton at 1.5 ms^{-1} forward speed

Once the table 4 given below is examined, it can be stated that the performance values of I_{qf} for corn are at an ideal level of 100% for all forward speeds. But based on other performance indicators, it can be said that only the CP3 value of 43.9 % at a forward speed of 1.0 ms^{-1} is an acceptable level while the CP3 values at 0.5 and 1.5 ms^{-1} is lower than the acceptable limit of 40%. The evaluations based on Precision and E_{rms} indicate that the seeding corn at all forward speeds are at acceptable limit while the lowest precision and E_{rms} values are obtained at 1.0 ms^{-1} forward speed. The Z_{mean} values obtained from the sticky belt tests are also acceptable level but the mean seed spacing at 1.0 ms^{-1} forward speed is close to the theoretical one (11.8 cm).

The performance values for cotton have a different tendency as compared to corn values. The I_{qf} is 100% at a forward speed of 1 ms^{-1} only while it is at moderate level based on the performance criteria given in Table 3 at 0.5 and 1.5 ms^{-1} forward speeds since some misses but no multiples were obtained. The CP3 values at 1.0 and 1.5 ms^{-1} are at acceptable level but it can stated that both, CP3 and Precision values are better at 1.0 ms^{-1} than the ones at 1.5 ms^{-1} forward speed.

In general, the behavior of the metering unit with universal vacuum disk equipped with hole adaptors performed in the same way that the conventional metering unit with vacuum plates since Yazgi and Degirmencioglu (2007) found that a forward speed of 1.0 ms^{-1} revealed better results as compared to other forward speeds.

Table 4. Performance values obtained from the experiments for corn

Performance values	Forward speed (ms^{-1})		
	0.5	1.0	1.5
I_{qf} (%)	100	100	100
$I_{mult.}$ (%)	0	0	0
I_{miss} (%)	0	0	0
CP3 (%)	37.5	43.9	31.8
Precision (%)	17.8	17.3	18.5
E_{rms} (cm)	4.5	3.9	5.2
Z_{mean} (cm)	12.0 (2.1)	11.9 (2.0)	12.6 (2.2)

Z_{mean} is the average seed spacing and the numbers in parenthesis next to Z_{mean} values are the standard deviations

Table 5. Performance values obtained from the experiments for cotton

Performance values	Forward speed (ms^{-1})		
	0.5	1.0	1.5
I_{qf} (%)	84.4	100	88.9
$I_{mult.}$ (%)	0	0	0
I_{miss} (%)	15.6	0	11.1
CP3 (%)	32.3	65.2	41.2
Precision (%)	18.3	13.9	17.0
E_{rms} (cm)	16.5	2.9	10.7
Z_{mean} (cm)	14.3 (3.3)	12.2 (1.7)	13.4 (2.9)

Z_{mean} is the average seed spacing and the numbers in parenthesis next to Z_{mean} values are the standard deviations

In general it can be stated that the performance of the metering unit with vacuum plate equipped with hole adaptors performed as desired and the use of adaptors did not deteriorate the seed distribution.

CONCLUSIONS

The followings were concluded from the study conducted:

- The vacuum plate equipped with hole adaptors can be used for precision seeding and did not cause any deterioration in seed distribution.
- The use of vacuum plate with adaptors can help adjusting the hole diameter so that seeding different crops seeds as well as the same crop

seeds but different varieties with different physical properties.

- The designed and developed vacuum plate provides additional seed spacing options for the farmers in addition to the options obtained by the use of gear box on precision seeders.
- The use of only a set of vacuum disks for a precision seeder can help saving material and time since there will be no need for and a different set of vacuum disks and changing them if the crop to be seeded changes.

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