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Trajectory Characteristics of Falling Seed Released from Vacuum Type Seeding Unit and Its Interpretation in View of Seed Spacing Accuracy

İsmet ÖNAL, Adnan DEĞİRMENCİOĞLU, Arzu YAZGI
Ege University, Faculty of Agriculture, Department of Agricultural Machinery
35100-Bornova-İzmir-TURKEY
ismet.onal@ege.edu.tr

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Abstract: The precision seeding is such phenomena that two processes have to be achieved and the objective is to precisely place seeds at requested seed spacing. The first process is the capture of seeds by the vacuum plate and this should be done without missing or doubling. The second process is the release of seeds from vacuum plate and the incorporation of seeds into the soil. The objectives of this study related to second process were to obtain the trajectory characteristics of falling seed released from vacuum type seeding unit and interpret the results based on theoretical considerations presented in this study and literature based knowledge.
Keywords: Seed trajectory, vacuum plate, precision seeding

INTRODUCTION

From the point of precision seeding technique and for meeting agro-technical needs, maize seeds should be sown precisely without causing doubling and missing during field operations. Doubling and missing in the row are unwanted since doubling affects yield and dry matter while missing causes a reduction in yield (Rintelen, 1971; Zweifler, 1965). The calibrated maize seeds were used in mechanical types of metering units in the past (Bernhardt, 1967; Brinkmann, 1971) but starting 1970's, pneumatic type of precision seeders were started to use and became widespread since they are not much affected from uncalibrated seed use and provide an even distribution during the metering process.

The studies conducted in the past on plant density population and its effect on plant morphology and lint quality in cotton production revealed important knowledge for those who work in the field of Agricultural Mechanization and seeder designers. Bainer et al. (1955) stated that cotton plants can tolerate the unevenness spacings in the row. Similarly, Randolp (1932) concluded that cotton plants can adapt the differences in plant densities and this may help agricultural engineers for reducing or totally removing the labor for in-row hoeing operations.

According to Corley et al. (1960), the effect of increased seed spacing accuracy on seed cotton yield isn't so much evident. But in a study that revealed contradictory findings to this, Meek (1974) found that the mechanized cotton production requires precision and timeliness farming and he stated that the field operations starting with seedbed preparation and seeding, hoeing operations should be done precisely. Similarly, in a four year field study conducted in Texas in loam soil Wanjura (1980) used Tamcot 788 and Paymaster 909 cotton varieties and found that the seed cotton yield was affected by the seed spacing accuracy. Önal (1981) defined the fundamental engineering principles of precision seeding of cotton seeds with and without thinning process.

Many studies in the past were conducted in order to determine the performance of precision seeders. These studies revealed information about how a metering system of a precision seeder performed in the laboratory or in the field. The studies on the performance of a precision seeder mostly focused on vacuum pressure applied to the vacuum plate, the most common metering system in precision seeders.

In a recent study, Singh et al. (2005) examined the effect of operational speed of the vacuum plate, vacuum pressure and shape of the entry of seed hole and evaluated the precision in spacing, miss index, multiple index and quality of feed index. However, they assumed that the appropriate hole diameter for cotton seeds was 2.5 mm. They found that the metering system with a speed of 0.42 m s^{-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 of 8.6% in spacing.

In another study, Panning et al. (2000) evaluated five seeder 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.

Moody et al. (2003) evaluated a row crop seeder performance in a field study and tested a vacuum type seeder at three peripheral speeds of 0.16, 0.23 and 0.31 m s^{-1} with corresponding forward speeds of 1.33, 2.0 and 2.7 m s^{-1} using cotton and maize seeds. From the study, they concluded that the variability in seed spacing increased with increased peripheral speed.

Sticky belt test involving a computerized measurement system (CMS) results indicated that 16 seeds s^{-1} was the upper limit of *SRF* for cotton and maize seeds (Önal and Önal, 2009a). Permissible upper limit of vacuum plate peripheral speed was found to be 0.34 m s^{-1} (Önal et al., 2010). The use of 72 holes vacuum plate at 6.3 kPa vacuum creates a vacuum band in the width of 10 mm around holes and this increases the multiple index that will result in a reduction in seeding performance once the basic principles of fluid mechanics and the aerodynamic properties of seeds are considered. For this reason the use vacuum plates with 52 or 60 holes are recommended for cotton seed even though the permissible reduction in the number of seed holes increases the peripheral speed of the vacuum plate while seed placement into soil at a steeper angle but lower impact velocity is achieved. The traveling speed of either 1.0 or 1.5 m s^{-1} is recommended for the seed spacing of 0.05 and 0.10 m, respectively.

Aerodynamic calculations verified that widely used vacuum plates with 26 holes are the appropriate ones for seeding maize seeds. As a proof of this conclusion, it was found that the performance of the precision seeder while seeding maize seeds at seed spacing of 0.10 m at 1.5 m s^{-1} forward speed was classified as excellent. But the seeding performance of the precision seeder went down at seed spacing of 0.10 m and a forward speed of 2.0 m s^{-1}. Seeding at excellent quality at seed spacing of 0.202 m is possible at traveling speed of 2.0 m s^{-1}. (Önal et al., 2010)

Stieger (1974) focused on constructional principles of four different types of pneumatic metering unit and used calibrated maize seeds. These metering units were: I. Pneumatic metering unit with blower (positive pressure range used: 1.77 and 1.37 kPa), II. Vacuum type metering unit (vacuum range used: 5.9–8.8 kPa), III. Vacuum type metering unit with a single seed plate with double row holes (vacuum range used: 5.9–8.8 kPa), IV. Vacuum type metering unit with lugs (vacuum range used: 5.9–8.8 kPa). Stieger (1974) used maize seeds as calibrated at four different ranges: These were: ϕ 7–8 and # 4–5 mm; ϕ 8–9 and # 4–5 mm; ϕ 8–9 and # 7–8 mm; ϕ 9–10 and # 7–8 mm. From the study, Stieger (1974) concluded that the seed holding ratio of the metering unit I went down for maize seeds with a thickness of 4–5 mm and in the diameter of 7–8 mm. The performance of metering unit IV was found to be less affected from the calibration of the maize seeds. On the other hand, the capture of seeds by holes on vacuum plate was better for the metering unit IV due to the availability of small lugs as compared to other metering units.

The performance of vacuum type metering unit was the main interest in many studies conducted by Önal (1981), Önal (1987), and Önal et al. (2009b) used delinted cotton or maize seeds for their studies. On the other hand, the studies conducted on constructional related parameters in the literature are limited (Weller, 1958; Stieger, 1974; Önal et al., 2009b; Önal, 2011).

The objectives of this study were to obtain the trajectory characteristics of falling seed released from vacuum type metering unit with lugs and interpret the results based on theoretical considerations presented in this study and literature knowledge.

MATERIAL and METHOD

Seeds

Hybrid maize (AG 9241) and delinted cotton seeds (Deltapine 388) were used in this study. The physical properties of these seeds are given in Table 1.

Vacuum type precision seeder

In the experiments, a vacuum-type precision seeder was used and it had a ground-driven wheel with 0.64 m diameter that transfers the motion to the vertical vacuum plate with a combination of gears available (Fig. 1a, 1b). The height of the seed drop is 0.10 m, and the holes were drilled on a circle in the diameter of 0.19 m on vacuum plate. The vacuum plates with 5.5 and 3.5 mm holes were used for seeding maize and cotton seeds, respectively. The general view of the seeder and its components are depicted in Fig. 1a. Seeds from the vacuum plate are released at an angle of 60^o from horizontal and the vacuum pressure applied was 6.3 kPa.

Table 1. The specifications of seeds used in this study

Seeds	Seed dimensions, mm ($\overline{X}_i \mp S_e^{**}$)			Sphericity* (s), %	One thousand seeds mass, g/1000 seeds
	Length (a)	Width (b)	Thickness (c)		
Hybrid maize (AG 9241)	11.5 ±0.18	8.6 ±0.18	6.9 ±0.15	76.6	437.0
Delinted cotton seed (Deltapine 388)	8.5 ±0.11	4.9 ±0.11	4.3 ±0.07	66.1	74.2

$\overline{X}_i$, average of the seed dimensions; S_e, standard deviations of the seed dimensions

*) $s = \frac{(abc)^{1/3}}{a} 100$ (Mohsenin, 1970)

**) probability, $P<0.05$

Theory of trajectory characteristics of falling seed released from vacuum type seeding unit

The precision seeding is such phenomena that two processes have to be achieved and the objective is to precisely place seeds at requested seed spacing. The first process is the capture of seeds by the vacuum plate and this should be done without missing or doubling. The second process is the release of seeds from vacuum plate and the incorporation of seeds into the soil. These physical processes are highly affected by the design and soil conditions, physical properties of seeds and operational variables. Among design conditions, the number of holes drilled on vacuum plate, the structure of the metering unit and diameter of holes are considered to be the most important ones while physical properties of seeds such as mean particle diameter, sphericity and the mass of seeds affect the phenomena. As a result of different design conditions and seed properties, operational variables such as the level of vacuum, the diameter of holes and the peripheral speed of the vacuum plate differentiate from one seed to another. Hence the physical phenomena should be clarified theoretically to understand how the precision seeding mechanism works.

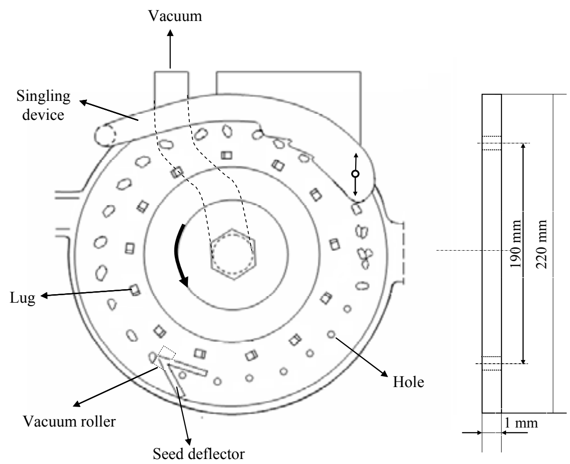

Figure 1a. Metering unit of the vacuum type precision seeder
Figure 1b. Dimensions of the vacuum plate

The seeding quality of precision seeder depends on peripheral speed of the vacuum plate and vacuum pressure. The availability of small lugs fixed on vacuum plate also helps capturing seeds by holes, especially for seeds with greater seed mass. These lugs accelerate seeds toward holes (Önal, 2011).

The peripheral speed of the vacuum plate, V_p, and the forward speed of the seeder, V_f, are found as (Fig. 2);

$$V_p = \frac{\pi \, d \, n_p}{60} \quad (1)$$

$$V_f = \frac{n_p}{60} k \, Z_t \quad (2)$$

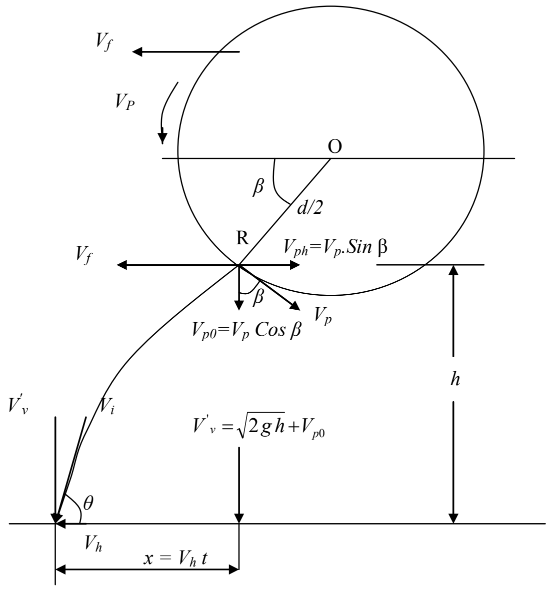

Fig. 2. External force feed mechanical disc and vacuum type metering unit (-6 $V_p \geq V_f \leq$-13.4 V_p).

Where *d* is the pitch diameter of holes (vacuum plate diameter) in m; n_p is the rpm of the vacuum plate in min^{-1}; *k* is the number of holes on vacuum plate; Z_t is the theoretical seed spacing in m.

Substituting $k = \pi d / l$ into Eq. 2 results in

$$V_f = \frac{\pi\, d\, n_p\, Z_t}{60\, l} \qquad (3)$$

Then, the ratio of V_f / V_p becomes,

$$\frac{V_f}{V_p} = \frac{Z_t}{l} = m \qquad (4)$$

where, *l* is the arc distance between two holes and m is the velocity ratio.

The above written equation means that in order to increase the forward speed to achieve higher work rate in the field, the peripheral speed of the vacuum plate should be increased and/or the number of holes drilled on vacuum plate should be maximized.

Seed releasing frequency, *SRF*, is the number of seeds released from the metering unit in one second. At specific theoretical seed spacing, the *SRF* and the forward speed relationship is written as in the following.

$$Z_t = \frac{V_f}{SRF} \qquad (5)$$

A metering unit that is adjusted to the *SRF* of 20 means that seeds can be released from the metering unit at a seed spacing of 0.10 m while the forward speed is 2 m s^{-1}. In order to reduce the seed spacing down to 0.05 m means that forward speed could be 1 m s^{-1} at a *SRF* of 20 seeds s^{-1}.

If the rpm of the vacuum plate in one second is $n_p/60$ then the following relationship can be written;

$$\frac{n_p}{60} = \frac{SRF}{k} \qquad (6)$$

If Equation 6 is substituted in Equation 1 results in

$$V_p = \pi d \frac{SRF}{k} \qquad (7)$$

The transmission ratio for a seeder driven by a ground wheel is given as

$$i = \frac{n_p}{n_w} \qquad (8)$$

where rpm of the vacuum plate, n_p, in min^{-1};

$$n_p = \frac{60\, V_p}{\pi\, d} \qquad (9)$$

and rpm of the ground wheel, n_w, in min^{-1};

$$n_w = \frac{60\, V_w}{\pi\, D} \qquad (10)$$

If these are substituted in Eq. 8 then the following relationship is obtained for the transmission ratio.

$$i = \frac{V_p}{V_w} \frac{D}{d} \qquad (11)$$

Forward speed, V_f, is equal to peripheral speed of ground wheel, V_w, at no-slippage conditions. The transmission ratio of the transmission system as shown in Fig. 3 was calculated for the precision seeder with a ground wheel diameter, *D*, of 0.64 m and pitch diameter, *d*, of 0.19 m on which the holes were drilled on vacuum plate.

Finally, the theoretical seed spacing can be written as a function of the diameter of ground wheel, transmission ratio and the number of holes on vacuum plate as in the following.

$$Z_t = \frac{\pi\, D}{i\, k} \qquad (12)$$

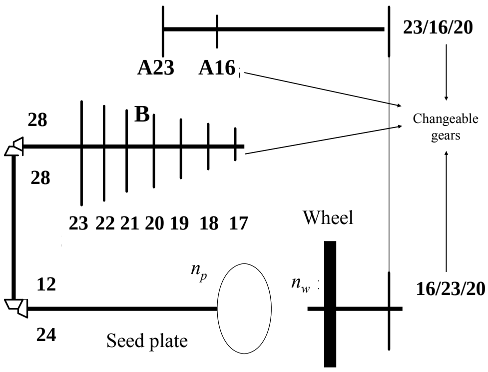

Figure 3. Schematic view of the transmisson system of the precision seeder. rpm of the vacuum plate, n_p; rpm of the ground wheel, n_w; gear group 1, A; gear group 2,B; The numbers symbolize that the number of teeth on sprockets (Wheel diameter, *D*=0.64 m; Pitch diameter of holes, *d*=0.19 m).

In precision seeding, metering units are primarily responsible from seed incorporation into soil accurately but the importance of soil engaging components can not be ignored. The requirements for incorporation of seeds into soil are as follows.

I. Seeds could be sown at required depth homogeneously,

II. Seed spacings based on the agro technical needs could be adjusted,

III. Rolling, bouncing and displacements of seeds in the row must be prevented. Increase the V_H, V_i, V_p, V_f and decrease the θ, increase the rolling, bouncing and displacement of seeds in the row (Önal, 2006).

The seed fall from the metering unit is highly affected by the seed physical properties such as seed mass and sphericity etc.

The free fall velocity, V_v, and peripheral speed of vacuum plate, V_p, as associated with forward speed, V_f, determine the seed fall trajectory. If air resistance is ignored (Fig. 2) then the free fall velocity, V_v, is written as;

$$V_v = \sqrt{2\,g\,h} \tag{13}$$

where *h* is the height of fall; *g* is the acceleration due to gravity.

If there exists an initial velocity, V_{p0} during t=0, then the velocity of the seed once it completes the fall at the bottom of the seed drop tube will be V_i during time *t* and the vertical component of this velocity, $V_V^{'}$, will be the sum of initial velocity of V_{p0} and V_v written as;

$$V_V^{'} = \sqrt{2\,g\,h} + V_{p0} \tag{14}$$

The horizontal component of the seed released from the vacuum plate, V_h, can be obtained by subtracting the forward speed, V_f, of the seeder from the horizontal velocity component of the vacuum plate peripheral speed, V_{ph}, and this vector difference is written as;

$$V_h = V_f - V_{ph} \tag{15}$$

$$V_h = V_f - V_p Sin\beta \tag{16}$$

The impact velocity of the seed during time *t* is found as;

$$V_i = \sqrt{V_V^{'2} + V_h^{\,2}} \tag{17}$$

If the equivalents of $V_V^{'}$ and V_h are substituted in the above equation, then V_i can be calculated as;

$$V_i = \sqrt{(\sqrt{2\,g\,h} + V_p \cos\beta)^2 + (V_f - V_p \sin\beta)^2} \tag{18}$$

The seed hits the soil surface at an angle of θ and this is the ratio of $V_V^{'}$ and V_h and written as;

$$tg\,\theta = \frac{V_V^{'}}{V_h} \tag{19}$$

The seed is released from the vacuum plate at point *R* and incorporated into the soil at a time *t* by falling from a height of *h*. The height of seed drop is calculated as;

$$h = t\,(\sqrt{2\,g\,h} + V_p \cos\beta) \tag{20}$$

The flight time of the seed, t, is

$$t = \frac{h}{\sqrt{2\,g\,h} + V_p \cos\beta} \tag{21}$$

The distance traveled, *x* by the seed in the direction of travel can be found as;

$$x = V_h\, t \tag{22}$$

RESULT and DISCUSSION

Results from theoretical calculations for cotton and maize seeds

The theoretical seed spacings calculated using Eq. 12 at different gear combinations for the precision seeder used in this study are shown in Fig. 4. The diameter of ground wheel and the vacuum plate are 0.64 and 0.19 m, respectively. As seen from the Fig. 4, the theoretical seed spacing varies between 0.029 and 0.399 m and 205 different seed spacing can be achieved in this range by using the gear combinations as shown in Fig. 3. The calculations using the theoretical equations, the technical characteristics of the seeder used in this study can be readily obtained from the monogram depicted in Fig. 5, 6a, 6b, 6c and Table 2. Different options where $V_p \leq 0.25$ m s^{-1} condition is met, can be easily found using Fig. 4, 5, 6a, 6b, 6c and Table 2.

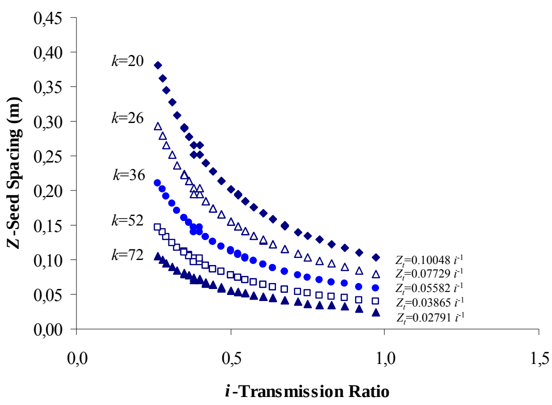

Figure 4. Theoretical seed spacing options provided by vacuum plates holes, *k* with 20, 26, 36, 52 and 72 at different transmission ratios; (D=0.64 m, d=0.19 m).

These options and the results from the application of the above written equations for cotton seeds are as follows;

- The seeding operation can be achieved at a theoretical seed spacing of 0.05 m at a forward speed of 1.25 m s^{-1} by using a vacuum plate with 72 holes at a *SRF* of 25 seeds s^{-1}. Once the forward speed of 2.5 m s^{-1} is required then the seed spacing of 0.10 m should be selected and the use of vacuum plate with 72 holes is needed. The both distances are appropriate for cotton seeding with or without thinning operation after the emergence in the field (Fig. 5 and 6a). At a theoretical seed spacing of 0.05 m, if V_f is 1.25 m s^{-1}, k is 72 and at a SRF of 25 seeds s^{-1} then m (V_f/V_p) would be 6.03, V_i is 1.85 m s^{-1} and θ would be 54.5°. Cotton seed will fall 0.0712 m release point R as it follows a parabolic trajectory and calculated values at drop height (Fig. 6a, Table 3).

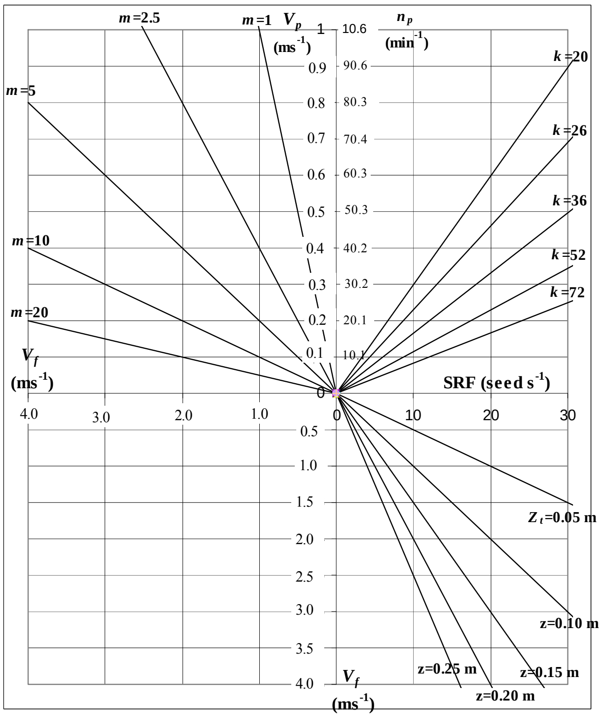

Figure 5. Monogram developed for finding the technical characteristics of the precision seeder (D=0.64 m, d=0.19 m).

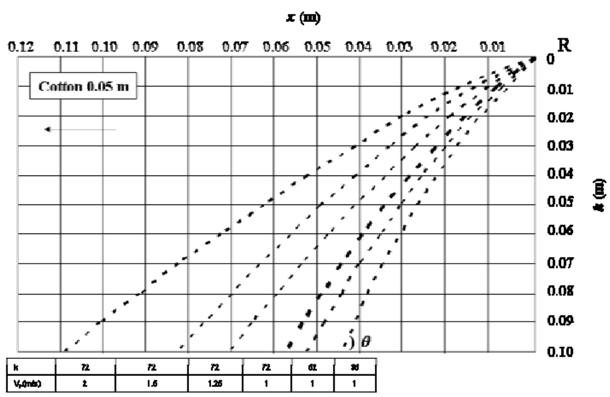

Figure 6a. Cotton seed fall trajectory at 0.05 m seed spacing.

- The *SRF* values obtained from the use of vacuum plates with 36 and 52 holes by meeting the condition of $V_p \leq 0.25$ m s^{-1} are 15 and 20 seeds s^{-1}, respectively. At a *SRF* of 20 seeds s^{-1}, the forward speed should be 1 m s^{-1} for a seed spacing of

0.05 m and similarly at the same *SRF* value, the seed spacing should be 0.10 m at a forward speed of 2 m s^{-1}. When the vacuum plate with 52 holes is used at a seed spacing of 0.05 m, the constructional related parameters, V_f, m, V_i, θ, and x at a *SRF* of 20 seeds $s^{-1}$and a peripheral speed of 0.23 m s^{-1} would be 1.0, 4.358, 1.72, 62.21° and 0.053 m, respectively (Fig. 6 a, Table 3). The use of 36 holes vacuum plate at 0.05 and 0.10 m seed spacing requires forward speeds of 0.75 and 1.5 m s^{-1} respectively (Fig. 5).

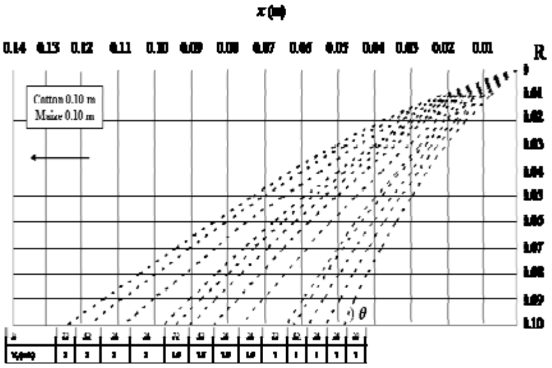

Figure 6b. Cotton and maize seed fall trajectory at 0.10 m seed spacing.

- At a seed spacing of 0.10 m which is a planting to a stand type seeding operation, the use of vacuum plate with 72 holes at a peripheral speed of 0.166 m s^{-1} and *SRF* of 20 seeds s^{-1}, the constructional related parameters V_i, m and θ would be 2.37 m s^{-1}, 12.07 and 38.55°, respectively (Fig. 5, 6 b, Table 3). Cotton seed will be placed 0.125 m release point R. The performance of the soil engaging components of the seeder are of importance due to a high m velocity ratio, reduced impact angle and increased impact velocity of the seed to soil.
- Seeding operation using a vacuum plate with 52 holes at a seed spacing of 0.10 m, the peripheral speed of the vacuum plate, impact velocity and impact angle at 2 m s^{-1} forward speed will be 0.23 m s^{-1}, 2.36 m s^{-1} and 40.16°, respectively (Table 3). As seen from Fig. 6 b, reducing the number of holes on vacuum plate and forward speed makes the seed fall trajectory steeper. Working with vacuum plates with 52 or 72 holes at a seed spacing of 0.100 m and forward speed of 1.0 or 1.5 m s^{-1} rather than 2.0 m s^{-1} will make cotton seed fall at a steeper angle and a lower impact velocity (Fig. 6 b, Table 3).

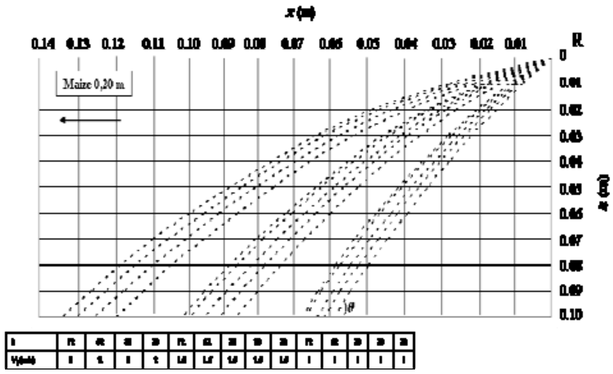

Figure 6c. Maize seed fall trajectory at 0.2 m seed spacing.

The results obtained from the theoretical equations as they are applied for seeding maize are given below.

- Maximum number of holes on a vacuum plate would be 48 once a vacuum plate with a diameter of 0.19 m and 12.5 mm long maize seeds is considered. Hence, the use of 20, 26 and 36 hole vacuum plates seems to be appropriate. But, the selection and use of 26 hole vacuum plate is believed to prevent the vacuum band on vacuum plate and will provide a better capturing on holes and a steeper fall trajectory for seeds.
- The peripheral speed of the vacuum plate and *SRF* become 0.469 m s^{-1} and 20, respectively if the seeding process with a vacuum plate with 26 holes is achieved at 2 m s^{-1} forward speed and a theoretical seed spacing of 0.10 m (Fig. 6 b, Table 2). There seems to be a problem in this case as it was verified by the tests carried out in the laboratory. Once the forward speed is reduced to 1.5 m s^{-1} then the *SRF*, the peripheral speed of the vacuum plate, velocity ratio, seed impact velocity, angle and the horizontal travel distance of the seed would be 15, 0.344 m s^{-1}, 4.358, 1.98 m s^{-1}, 52.56° and 0.077 m, respectively (Fig. 5, 6 b, Table 2). In this case, it is recommended not to carry out seeding process at forward speeds higher than 1.5 m s^{-1}.

At a theoretical seed spacing of 0.10 m by using a vacuum plate with 26 holes should be achieved at a velocity ratio of 4.358 and a transmission ratio of i = 0.773 (Fig. 4, Table 2).

Table 3 . Characteristic values of pneumatic seeder at 0.05, 0.10 and 0.20 m seed spacing

Z_t	k	V_f	SRF	n_p	V_p	m	i	V_h	V'_v	V_i	θ	t	x
			Eq.5	Eq.6	Eq.7	Eq.4	Eq.11	Eq.16	Eq.14	Eq. 18	Eq.19	Eq.21	Eq.22
m		m s^{-1}	seed s^{-1}	min^{-1}	m s^{-1}			m s^{-1}	m s^{-1}	m s^{-1}	(º)	s	m
Cotton seed (Fig. 6a)													
0.05	36	1.0	20	33.33	0.331	3.017	1.116	0.713	1.57	1.72	65.58	0.064	0.046
	52			23.08	0.230	4.358	0.773	0.801	1.52	1.72	62.21	0.066	0.053
	72			16.67	0.166	6.035	0.558	0.857	1.48	1.71	59.92	0.067	0.058
	72	1.25	25	20.83	0.207	6.033	0.558	1.071	1.50	1.85	54.5	0.066	0.071
	72	1.5	30	25.00	0.249	6.034	0.558	1.285	1.52	1.99	49.79	0.066	0.084
	72	2.0	40	33.33	0.331	6.035	0.558	1.713	1.57	2.32	42.51	0.064	0.110
Cotton and maize seed (Fig. 6b)													
0.10	20	1.0	10	30.00	0.298	3.352	1.005	0.742	1.55	1.72	64.42	0.065	0.048
	26			23.08	0.230	4.357	0.773	0.801	1.52	1.71	62.06	0.066	0.053
	36			16.67	0.166	6.034	0.558	0.857	1.48	1.71	59.93	0.067	0.058
	52			11.54	0.115	8.726	0.386	0.901	1.46	1.72	58.32	0.069	0.062
	72			8.33	0.083	12.07	0.279	0.928	1.44	1.71	57.20	0.069	0.064
	26	1.5	15	34.62	0.344	4.358	0.773	1.202	1.57	1.98	52.56	0.064	0.077
	36			25.00	0.249	6.034	0.558	1.285	1.52	1.99	49.79	0.066	0.084
	52			17.31	0.172	8.716	0.386	1.351	1.49	2.00	47.80	0.067	0.091
	72			12.50	0.124	12.068	0.279	1.392	1.46	2.01	46.37	0.068	0.095
	26	2.0	20	46.15	0.469	4.357	0.773	1.594	1.63	2.28	45.64	0.061	0.098
	36			33.33	0.331	6.035	0.558	1.713	1.57	2.32	42.51	0.064	0.109
	52			23.08	0.230	8.715	0.387	1.801	1.52	2.36	40.16	0.066	0.119
	72			16.67	0.166	12.07	0.279	1.857	1.48	2.37	38.55	0.067	0.125
Maize seed (Fig. 6c)													
0.20	20	1.0	5	15.00	0.149	6.702	0.503	0.871	1.47	1.71	59.35	0.068	0.059
	26			11.54	0.115	8.718	0.386	0.901	1.46	1.72	58.32	0.069	0.062
	36			8.333	0.083	12.069	0.279	0.928	1.44	1.71	57.20	0.069	0.064
	52			5.769	0.057	17.431	0.193	0.950	1.43	1.72	56.40	0.070	0.067
	72			4.160	0.041	24.137	0.140	0.964	1.42	1.72	55.83	0.070	0.068
	20	1.5	7.5	22.50	0.224	6.705	0.502	1.306	1.51	2.00	49.14	0.066	0.086
	26			17.31	0.172	8.716	0.387	1.351	1.49	2.01	47.80	0.067	0.091
	36			12.50	0.124	12.068	0.279	1.392	1.46	2.02	46.37	0.068	0.095
	52			8.650	0.086	17.442	0.193	1.426	1.44	2.03	45.28	0.069	0.099
	72			6.250	0.062	24.155	0.139	1.446	1.43	2.03	44.68	0.070	0.101
	26	2.0	10	23.08	0.230	8.715	0.387	1.801	1.52	2.36	40.16	0.066	0.119
	36			16.67	0.166	12.070	0.279	1.857	1.48	2.37	38.55	0.067	0.125
	52			11.54	0.115	17.437	0.193	1.901	1.46	2.40	37.52	0.069	0.130
	72			8.333	0.083	24.137	0.140	1.928	1.44	2.41	36.76	0.069	0.134

Z_t, in-row seed spacing; k, number of holes on vacuum plate; V_f, forward speed; *SRF*, seed release frequency; n_p, rpm of the vacuum plate; V_p, peripheral speed of the vacuum plate; m, the ratio of V_f / V_p; i, transmission ratio; V_h, horizontal component of the seed released from the vacuum plate; V'_v, vertical velocity at the bottom of seed drop tube; V_i, resultant (impact) velocity of the seed during time t; θ, seed impact angle at the bottom of seed drop tube; t, time to capture the seed (traveling time of the seed); x, the distance traveled by the seed in the direction of travel

- Seeding maize at a theoretical seed spacing of 0.20 m, the condition that meets V_p ≤0.25 m s^{-1} is to work at 2 m s^{-1} forward speed with a vacuum plate of 26 holes. In this case, the *SRF* would be 10 seeds s^{-1} (Fig. 5 and 6 c, Table 2).
- Increasing the seed spacing allows working at reduced *SRF* values and provides higher field work rate by increasing the forward speed (Fig. 5).
- To work at 0.20 m seed spacing and 2 m s^{-1} forward speed by using a vacuum plate with 26 holes means a peripheral speed of 0.23 m s^{-1}, velocity ratio of 8.715 and a transmission ratio of I=0.387 (Fig. 4, Table 2). In this case, the impact velocity of the seed would be high (2.36 m s^{-1}) and impact angle will be low at 40.16° and the seed traveling distance would be 0.119 m. These conditions make the soil engaging components more important due to the risk seed rolling, bouncing and displacement in the row.

CONCLUSIONS

The followings were drawn from the study;

Theoretical evaluation of seeding unit showed that higher seed spacing and/or lower forward speed allowed at working reduced SRF values (Table 2). Reduced *SRF* means higher *QFI*, lower miss, and multiples indexes (Önal et al, 2010). On the contrary, lower forward speed means lower field capacity. In order to increase the forward speed to achieve higher work rate in the field especially for lower seed spacing, the peripheral speed of the vacuum plate should be increased and/or the number of holes drilled on vacuum plate should be maximized. On the other side, higher peripheral speed (>0.33 m s^{-1}) and higher number of holes on vacuum plate (for cotton seed k > 60; for maize seed k > 48) are restrictive factor for seed spacing accuracy (Önal et al., 2010).

In order to decrease the seed spacing (for example, from 10 cm to 5 cm) without peripheral speed -and hole number (per plate or line) increase, twin vacuum plate, vacuum plate which have holes at concentric two or three lines or cylindrical vacuum seeding unit could be used. All of these seeder units have to be combined with proper soil engaging components (Fig. 7a).

In another case, if we increase the forward speed of seeder at the same seed spacing and peripheral speed of vacuum plate, seeds hit the soil furrow at a smaller impact angle of θ, because of the higher velocity rate ($m = V_f / V_p$), and this results seed rolling and bouncing in a row. For example, at the same seed spacing (10 cm) and the number of holes on vacuum plate (k=26), using the twin vacuum plates (k= 2*26) instead of single vacuum plate, the forward speed of the seeder will be twice without peripheral speed increase. In this case, the impact angle of the seed will be smaller (Fig. 7b). Seed rolling, bouncing and displacement in the furrow may be higher at small impact angle. It is concluded that the seeding performance of the vacuum type precision seeder could be improved either increasing the permissible peripheral speed of single vacuum plate or using the twin vacuum plates which are worked as possible as higher peripheral speeds and combining the seeder with proper soil engaging components.

To work at 0.20 m seed spacing and 2 m s^{-1} forward speed by using a vacuum plate with 26 holes means a *SRF* of 10 seeds s^{-1} peripheral speed of 0.2295 m s^{-1} and velocity ratio of 8.715. In this case, the impact velocity of the seed would be high (2.35 m s^{-1}) and impact angle will be low at 39.98° and the seed traveling distance would be 0.119 m. Greater impact angle of seed causes the trajectory of seed steeper. For this reason, one of the efford to improve the seed spacing accuracy could be focused to work at higher peripheral speed (>0.50 m s^{-1}). Internal force feed mechanical seed disc for only coated seeds was a good example to solve this problem (Brinkmann, 1971; Önal, 2011).

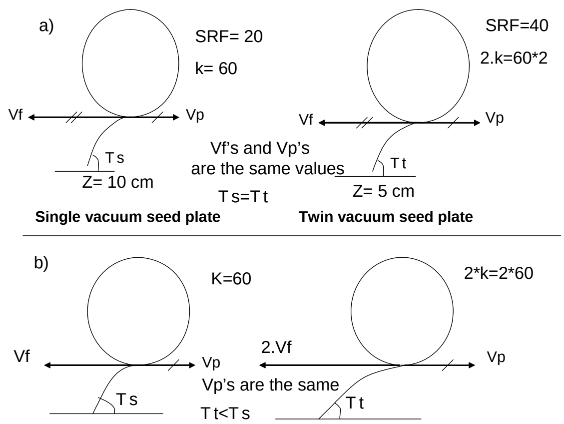

Figure 7. Single and twin vacuum plate comparison

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