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Performance of the Metering Unit and Soil Engaging Components of a Direct Seeding Machine

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Abstract: The objective of this study was to determine the performance of the metering unit and soil engaging components of a direct seeding machine. For this purpose, the direct seeder was tested using Hybrid Maize and delinted cotton seeds and experiments were conducted in the lab and in situ.
The laboratory experiments included seed rate accuracy while the sticky belt tests were performed in order to determine the seed spacing accuracy performance. The situ tests were performed in a stubble field to find out the performance of the soil engaging components of the direct seeding machine.
The seed spacing and the accuracy were determined as a function of transmission ratio and number of seed holes on seed plate while the range for peripheral speed of the seed plate was found to be the function of forward speed, transmission ratio. The range for seed releasing frequency (SRF) of the seeder was also investigated.
As a result of the study conducted in the laboratory, a linear relationship with a coefficient of determination of 99.57 % was found between SRF and flow rate in the SRF range of 4 -12. On the other hand, the results from the statistical analysis indicated that at a SRF of 12, the population index value defined as the ratio of actual to theoretical flow rate from the metering unit was significantly different than the others. This means that the seed rate will go down at a SRF value of 12 or above. The coefficient of variation in seed flow was found to be 2 % or below except at a SRF value of 4.
The sticky belt tests conducted in the laboratory provided the results of seeding performance of the direct seeder and it was found that the precision in seeding at a theoretical seed spacing ranging between 14.8 and 25.5 cm for maize was lower than 17 %. This is an indicator of a good performance since it is below the acceptable value of 29-30%.
The results obtained by using delinted cotton seeds were evaluated from the point of thinning operations as performed after the plant emergence in the field. The performance indicators such as precision, quality of feed index, miss and multiple index values of the metering unit with a seed plate of 70 holes were lower than the acceptable ones at seed spacing of 5.7 cm as it requires thinning operation in the field. At a SRF of 20 and a forward speed of 1 m s^{-1}, these indicators showed an increase. At a seed spacing of 9.9 cm that is appropriate for planting to a stand (without thinning), the precision value at a forward speed of 1.0 and 1.5 m s^{-1} was acceptable while quality of feed index and multiple index at a forward speed of 1.0 m s^{-1} increased and were better as compared to 1.5 m s^{-1}. The forward speed less than 1.5 m s^{-1} could be recommended for a seed spacing of 9.9 cm.
The tests in the field included the performance of the soil engaging components. It was found that the intensity of surface residue was reduced from 5600 daN ha^{-1} to 1431.5 daN ha-^{1} in the row and an appropriate soil media was established by the seed placement components. The weighed average value of the aggregate diameter was found to be 16.4 mm.
Key words: Direct seeding machine, precision seeding, stubble mulch seeding

INTRODUCTION

The United States, USDA Natural Resources Conservation Service classifies the soil tillage systems based on the organic content coverage of the soil surface (w,%) as in the following.

- Reduced tillage /minimum tillage: w>% 15-30 or 560-1120 daN organic matter per ha
- Conservation tillage: w>%30 or >1120 daN organic matter per ha (Zach, Sommer, 1988).

Conservation tillage is also divided into the following subgroups.

- Mulch tillage
- Ridge tillage/ ridge-till
- Seeding into stubble (seeding into first or second crop stubble),
- Direct drilling (no-tillage= continuous no-till=zero tillage= direct drilling= direktsaat) (Önal, 2005).

Direct seeding is known as a system that the soil is left undisturbed from harvest to seeding and from seeding to harvest. This is known as "No-Tillage" in the United States or "Direktsaat" in Germany.

Direct seeding applications started in 1960's when Imperial Chemical Industries, ICI introduced Paraquat and Diquat weed control chemicals to the market and modern direct seeding started. Obtaining the highest yield in direct seeding requires 70-80% of the soil surface be covered by plant and residues (Van Doren et al, 1975). Direct seeding applications became wide spread mostly in the United States (19.3 million ha), Brazil (11.2 million ha), Argentina (7.3 million ha), Canada (4.1 million ha), Australia (1 million ha) and Paraguay (790 000 ha) according to the data of 1999. (Hoogmood, 2002).

The evaluation of different soil tillage systems from the point of different criteria is given in Table 1. As seen from the table, it is clear that direct drilling type of plant production system is appropriate for heavy or medium soils, protective against to erosion and it provides saving from the energy and mechanization costs and provides higher work efficiency. On the other hand, it should be kept in mind that this production system can be achieved by farmers who have skills, technological knowledge and equipments.

The advantages and disadvantages of direct seeding were declared by Hoogmoed (2002), Allen (1981), Tischler (1953), El Tıtı (1984), Mallow et al (1985), Edwards et al (1969), Mc Calla (1967).

The success of direct seeding depends upon continuous coverage of the soil surface by plant residues, weed control, plant disease and insects control and proper crop rotation.

During and Hummel (1997), Linke (1998) and Melander (1994) studied on herbicide applications for weed control in direct seeding.

Tucer (1966) as a result of literature search reported plant insects that cause problems due to the conversion from conventional to direct seeding in maize production.

Linke (1988) and Onal (2005) presented the manufacturing and engineering basis of direct seeders. The fertilizer applications in direct seeding were studied by Hoogmoed (2002) and Önal (2005).

The list of directs seeders with precision metering units used in Turkey and as well as other countries and their properties are given in Table 2.

The objective of this study was to determine the performance of the metering unit and soil engaging components of a direct seeding machine. For this purpose, the direct seeder was tested using Hybrid Maize and cotton seeds and experiments were conducted in the laboratory and field.

Table 1. Evaluation of different soil tillage systems (Estler, Knittel, 1996)

Evaluation criteria	Soil Tillage		
	Inversion of soil by plough	Tillage by heavy duty cultivator	Direct seeding
Soil structure	Light - medium	Independent	Medium – heavy
Effect on soil structure	High	Medium- low	None existent
Protection against erosion	None existent	Good	Very good
Appropriatness level for field traffic	Low	Medium- high	High
Energy consumption	High	Medium	Low
Mechanization costs	High	Medium	Low
Work rate	Low	Medium	High
Science and management requirements	Low	Medium	High

Table 2. Direct seeders for row crops

Company name	Coulters-row cleaner combination and other components	Hitching to the tractor	Weight (kg)	Number of rows	Power requirement (kW)
John Deere Max Emerge 2 pneumatic[ξ]	Double disk furrow opener, fluted coulter in the front and row clearing unit	Mounted/ Trailed	1246- 1833	6- 9	88- 110
Case- Intern. 900 IR pneumatic[ξ]	Offset double disk furrow opener, single disk fertilizer coulter in the front, row clearing unit	Mounted	1800	6	55- 73
Gaspardo, No-Till 1040[ξ]	Hoe type furrow opener, strip rotary tiller in the front	Mounted	1320- 1570	4- 6	59- 88
Türkay (Kverneland), pneumatic[ξ]	Double disk furrow opener, double side press whell, single disk fertilizer coulter in the front	Mounted	1200	4	65
Gaspardo Leonard[ξ]	Double disk furrow opener, two fluted coulters in the front	Mounted	1470	4	> 50

ξ) Mention of trademark or company name does not imply the endorsement of this product by the authors or the institution they represent. Information given is solely for scientific purposes.

MATERIALS and METHOD

Materials

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 3.

Soil: The performance of the soil engaging components (disk coulters, row cleaning units, runners, coverers and press wheels) of the direct seeder were tested in a field where wheat was grown previously. The stubble height was about 25 cm (S= ± 3.35 cm, CV = % 13.75) and the soil was clay loam and very dry in June, 2008. The seeding in the field was achieved at forward speed of 6 km h^{-1}, seed spacing of 18.7 cm (C1 gear) and at a depth of 6 cm. The stubble density before seeding was found to be 5600 daN ha^{-1} and the soil moisture was near the wilting point. The bulk density of the soil obtained by the use of a coring probe sampler was found to be 1.23 g cm^{-3}.

Precision No-Till seeder: The precision seed metering unit used for these tests was the part of no-till precision seeder named Kuhn (Germany) Maxima HD Model[ξ] (Figure 1) and it was similar to John Deere Max Emerge 2[ξ] and Case- International 900 IR[ξ] type seeders.

The 'Maxima HD Model' vacuum-type precision seeder had a ground-driven wheel that transfers the motion to the vertical seed plate with a combination of gears available. The height of the seed drop is 450 mm, and the holes were drilled on a circle in the diameter of 230 mm on seed plate. The seed 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 Figure 2. Seeds from the seed plate are released at an angle of 51^{o} from horizontal and the vacuum pressure applied was 5.5 kPa.

Table 3. Physical properties of seeds used in the study.

Seeds	Seed dimensions (mm) ($\bar{X}_i \mp S_e^{**}$)			Sphericity* K* (%)	One thousand seed 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

$K^* = \frac{(a.b.c)^{1/3}}{a}.100$ (Mohsenin, 1970), **) (P < 0.05)

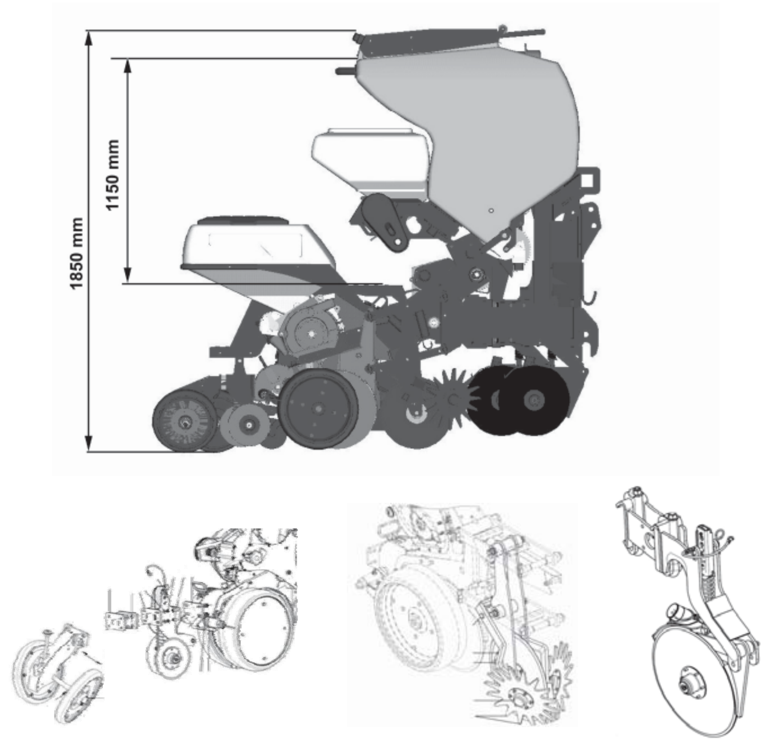


Figure 1. General view of No-till precision seeder and its components

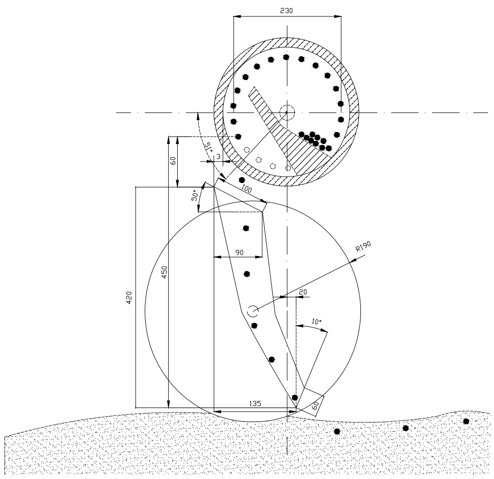


Figure 2. Side view of Kuhn- Maxima HD metering unit and its dimensions

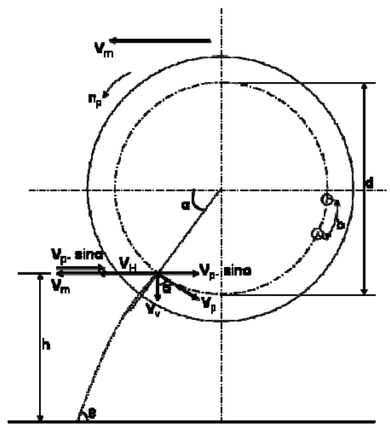


Figure 3. Forward speed (V_m) and vacuum plateperipheral speed (V_p) relationship

Construction Parameters of Precision No-Till Seeder:

The forward speed (V_m) and seed plate peripheral speed (V_p) relationship can be written as (Figure 3).

$$V_H = V_m - V_p \cdot \text{Sin}\alpha \quad (1)$$

$$V_v = Vp \cdot \text{Cos}\alpha \quad (2)$$

In existing precision seeders excluding internally fed systems, V_m and V_p are related to each other in a range given below. (Önal, 2006).

$$V_m = (6....13.4)\ V_p \quad (3)$$

The relationship between the forward speed of the seeder (V_m) can be written as a function of peripheral speed of the seed plate (V_p), theoretical seed spacing (Z_t) and the distance between holes (b) drilled on plate as (Önal 2006),

$$V_m = V_p \cdot \frac{Z_t}{b} \tag{4}$$

To work at higher forward speeds at the same seed plate requires larger seed spacings and higher peripheral speeds of the seed plate. In an another word, the seed plate with maximized seed holes or slower forward speed should be selected in order to reduce seed spacings. Using the above information, some basic calculations can be made in order to find the number of holes that can be drilled on a seed plate. Considering a seed plate where the holes are drilled on a diameter of 230 mm for 12 mm long seeds, there should be 56 holes drilled. In a similar way, for cotton seeds that are 9 mm long, the number of holes on a plate should be 72.

In the experiments, a seed plate with 27 and 70 holes (k) was used for seeding maize and cotton, respectively.

Seed releasing frequency (SRF) is the number of seeds that can be released from the metering unit in a second. It is obvious that the seeder can be used at high forward speeds since SRF is high. If the SRF is known then theoretical seed spacings can be calculated for different forward speeds as given below.

$$Z_t = \frac{V_m}{SRF} \tag{5}$$

For example, a metering unit with a SRF of 20 seeds s^{-1} can achieve seeding at a seed spacing of 10 cm at 2 ms^{-1}. If the seed spacing is 5 cm, then the forward speed should be reduced down to 1 ms^{-1}.

Transmission ratio (i) for a seeder driven by a ground wheel is (Figure 4),

$$i = \frac{n_p}{n_t} \tag{6}$$

Where n_t is the rpm of the ground wheel

$$n_t = \frac{60 \cdot V_m}{\pi \cdot D_t} \qquad 7)$$

Similarly the rpm of the seed plate (n_p) is calculated as

$$n_p = \frac{60 \cdot V_p}{\pi \cdot d} \tag{8}$$

Substituting equation 7 and 8 in equation 6 yields,

$$i = \frac{V_p}{V_m} \cdot \frac{D_t}{d} \tag{9}$$

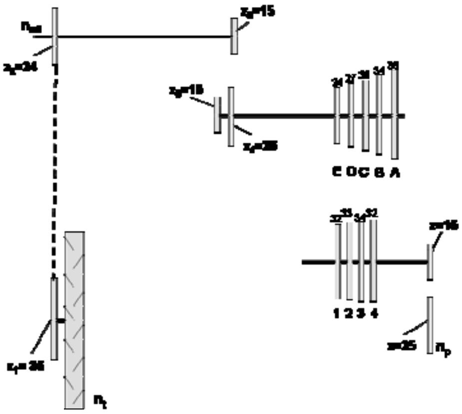


Figure 4. Transmission system of Kuhn- Maxima HD No-till precision seeder

For a ground wheel in the diameter of 76 cm (D_t) and the diameter of the circle on which the holes (d) are drilled 23 cm are substituted into equation 9, the transmission ratio for a specific seeder just like in this study is found as,

$$i = 3.30. \frac{V_p}{V_m} \tag{10}$$

The theoretical seed spacing can be written as in the following.

$$Z_t = \frac{\pi \cdot D_t}{i \cdot k} \tag{11}$$

Method

Seeding Performance and Performance Criteria

The performance tests of the metering unit included the laboratory experiments (SRF and sticky belt tests) while field tests were carried out to find out the performance of the soil engaging components of the direct seeder.

The seeds collected under the coulter for a given period of time were weighed by a digital scale with a sensitivity of ± 0.01 and the objective of this procedure was to determine the seed releasing frequency effect on seed rate.

In order to meet this objective, metering unit of the seeder was driven by a variator at SRF rates of

4,6,8,10,12 and 14 seeds per second. The measured weight of the seeds (N_g) in 30 s. were divided by the theoretical seed rate (N_t) and this was named "Population Index (PI)" and it is written as

$$PI = \frac{N_g}{N_t} \quad (12)$$

SRF tests were triplicated and carried out as a randomized block design type of experiment. Each replication consisted of five measurements made consecutively in 30 seconds. In order to determine the SRF and PI relationship, a total of fifteen measurements were considered for the regression analysis. The standard deviation and coefficient of variation values calculated from fifteen measurements were also used for the seed flow homogeneity.

Seed spacing accuracy tests were achieved on sticky belt and for this purpose, sticky belt test stand was used to measure the seed spacing in the laboratory. In order to facilitate this study, seed spacing measurements and its evaluations were made by means of a computerized measurement system (CMS) (Önal and Önal, 2009). For this reason, a sticky belt test stand was equipped with the 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 Standard indexes of quality-of- feed index, miss index, and precision) and graphical (histogram of seed spacings) forms. Sticky belt test stand has a 15 cm wide leader belt with an 11 m long horizontal viewing surface. The test unit was equipped with a multi-speed drive arrangement to provide a range of belt surface speeds from 1.8 to 7.2 km h^{-1}, relative to stationary seeder mechanism. In order to provide the theoretical seed spacing correctly, the seed metering mechanism was driven by another multi speed drive arrangement. Special care was given to provide the synchronization of the travel speed associated with the peripheral speed of the seed plate and the sticky belt speed. 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. Preliminary tests showed that the greased surface of the leather belt captured the seeds safely below 2 ms^{-1} sticky belt speed.

The seed spacing measurements can be made on sticky belt and the variation in seed spacings is graphically displayed by histograms (Figure 5).

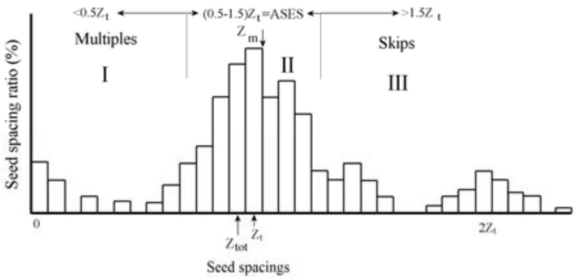


Figure 5. Histogram of seed spacing distribution

Three different seed spacing groups according to Z_t can be classified in Figure 5, and three indexes could be defined:

I-The multiples index is the percentage of spacing that are less than or equal to half of the theoretical seed spacing (Zt) and indicates the percentage of multiple seed drops (0 to ≤ 0.5 Z_t).

II-Quality of feed index (QFI, %) is the percent values having seed spacing within the range from bigger than 0.5 times the theoretical seed spacing to equal or smaller than 1.5 times the theoretical seed spacing. Quality of feed index is the subtraction of miss and multiples index from 100 and indicates the percentages of single seed drops (> 0.5 Z_t to ≤ 1.5 Z_t).

III-The miss index is the percentage of spacing greater than 1.5 times the theoretical seed spacing and indicates the percentage of missed seed locations or 'skips' (> 1.5 Z_t).

Precision is the coefficient of variation (CV_m) of the spacing that is classified as singles after omitting the outliers consisting of misses and multiples (CV of the main seed distribution curve, II). Seed spacing uniformity of the main seed distribution (II), called as precision, is expressed by the coefficient of variation (CV, %):

$$CV_m = \frac{S}{Z_m} \times 100 \quad (13)$$

Where; S is the standard deviation of the main seed distribution and Z_m is the mean seed spacing of the main seed distribution curve (II).

As reported by Kachman, Smith, 1995 and Önal, 2006, the coefficient of the variation (CV_m) of the main seed distribution is preferred to be less than 29-30 %.

The relation between CV_m and QFI is shown in Figure 6. (Önal, 2006). Figure 7 depicts the CV_m and multiples-skips relationship (Önal, 2006).

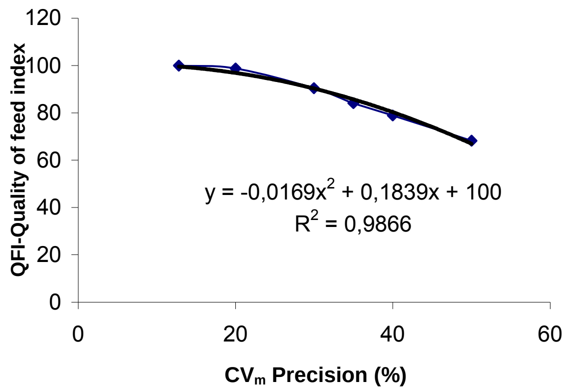


Figure 6. CV_m versus quality of feed index Relationship

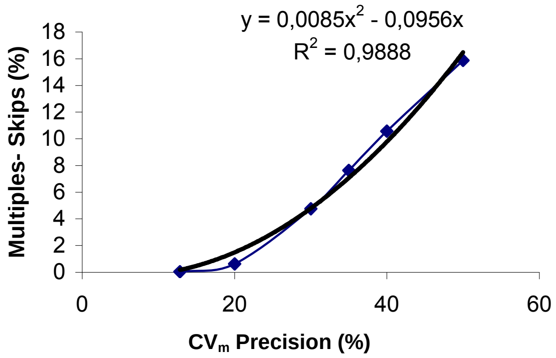


Figure 7. CV_m versus multiples and skips relationship

The sticky belt tests included seeding of maize at 14.8, 17.0, 19.8, 22.7 and 25.5 cm seed spacings while cotton seeding tests were achieved at 5.7 and 9.9. cm seed spacings. The tests were carried out at three forward speeds, 1.0, 1.5 and 2.0 m s^{-1}.

The results obtained from the experiments were evaluated based on the criteria given in Table 4 (Önal, 2006). The evaluation made by Irla, Heuser (1991) suggests that QFI values less than 90% should be considered as insufficient quality of seeding.

Table 4. Performance criterias based on main seed distribution for precision seeding (Önal, 2006)

Performance Criteria	%	Performance	Precision of the main distribution (CV_m)
QFI $_{(0.5-1.5)Z}$	> 98.76	Very good	12.8- ≤ 20
	>94.60 ≤ 98.76	Good	>20- ≤ 25
	≥90.50- ≤ 94.60	Moderate	>25- ≤ 30
	< 90.50	insufficient	> 30
Multiples and Misses	< 0.62	Very good	12.8-≤ 20
	≥ 0.62- < 2.92	Good	>20- ≤ 25
	≥2.92-≤ 4.75	Moderate	>25- ≤ 30
	> 4.75	insufficient	> 30

Field Tests

The performance of soil engaging components (disk coulters, row cleaning units, runners, coverers and press wheels) was tested in a field where stubbles of 25 cm height were left over after the wheat harvest achieved by a combine.

The effects of seeding operation in the row upon the soil aggregation and the intensity of straw mulch (daN ha^{-1}) were determined using the sieve-analysis as described by Thiessig (1975). The seeds in the soil were found by digging the soil without displacing the seeds after the seeding operation and their depth was measured. The homogeneity in seeding depth was characterized by "Breitfuss Goodness" value (Breitfuss,1954) and also by the coefficient of variation.

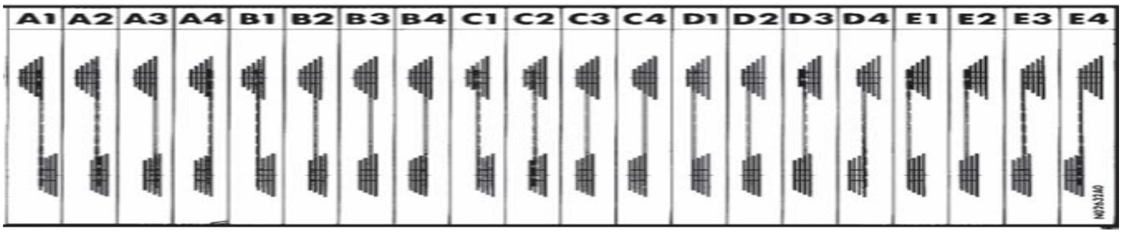
RESULTS and DISCUSSION

Technical Properties of the Precision Metering Unit

The theoretical seed spacings (Z_t, cm), peripheral speed of the seed plate at various forward speeds (V_p, m s^{-1}) and SRF, seed.s^{-1}) values as calculated by using the data from Figure 4 and Equations 1..11 are given in Table 5 for plates with 17 and 70 holes.

As seen from Table 5, the appropriate gear combinations for seeding maize at theoretical seed spacings ranging between 15 and 20 cm are A1.. C4. The transmission ratios in this seed spacing range varies between 0.599 and 0.433 while peripheral speeds of the seed plate at forward speeds of 1.0, 1.5 and 2.0 m s^{-1} are 0.18-0.13, 0.27-0.20 and 0.36-0.26 m s^{-1}, respectively. The SRF values above mentioned forward speeds varied in the range of 6.78-4.90, 10.16- 7.34 and 13.55- 9.79 for maize.

Table 5. Technical properties of the metering unit



Number of holes	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4
	Transmission ratio (i) from Fig.4 and Equation 10																			
	0.599	0.581	0.564	0.548	0.536	0.520	0.505	0.490	0.473	0.459	0.445	0.433	0.426	0.413	0.401	0.389	0.379	0.367	0.356	0.346
	Z- Theoretical seed spacing (cm) from Equation 11																			
1	398.4	410.5	423.0	435.4	444.9	458.8	472.7	486.6	504.2	520.0	535.8	551.5	560.3	577.8	595.3	612.8	630.3	650.1	669.8	689.3
18	22.1	22.8	23.5	24.2	24.7	25.5	26.3	27.0	28.0	28.9	29.8	30.6	31.1	32.1	33.1	34.1	35.0	36.1	37.2	38.3
22	18.1	18.7	19.2	19.8	20.2	20.9	21.5	22.1	22.9	23.6	24.4	25.1	25.5	26.3	27.1	27.9	28.7	29.6	30.4	31.3
27	14.8	15.2	15.7	16.1	16.6	17.0	17.5	18.0	18.7	19.3	19.8	20.4	20.8	21.4	22.1	22.7	23.4	24.1	24.8	25.5
31	12.9	13.2	13.6	14.1	14.4	14.8	15.3	15.7	16.3	16.8	17.3	17.8	18.1	18.6	19.2	19.8	20.3	21.0	21.6	22.2
33	12.1	12.4	12.8	13.2	13.5	13.9	14.3	14.8	15.3	15.8	16.2	16.7	17.0	17.5	18.0	18.6	19.1	19.7	20.3	20.9
48	8.3	8.6	8.8	9.1	9.3	9.6	9.9	10.1	10.5	10.8	11.2	11.5	11.7	12.0	12.4	12.8	13.1	13.5	14.0	14.4
57	7.0	7.2	7.4	7.6	7.8	8.1	8.3	8.5	8.9	9.1	9.4	9.7	9.8	10.1	10.4	10.8	11.1	11.4	11.8	12.1
70	5.7	5.9	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.7	7.9	8.0	8.3	8.5	8.8	9.0	9.3	9.6	9.9
100	4.0	4.1	4.2	4.4	4.5	4.6	4.7	4.9	5.0	5.2	5.4	5.5	5.6	5.8	6.0	6.1	6.3	6.5	6.7	6.9
	V_o – Peripheral speed of the vacuum plate (m/s) from Equation 1																			
V_m																				
1.0	0.181	0.18	0.17	0.17	0.162	0.16	0.153	0.15	0.143	0.14	0.134	0.13	0.13	0.13	0.12	0.12	0.11	0.11	0.11	0.10
1.5	0.27	0.26	0.26	0.25	0.244	0.24	0.23	0.22	0.214	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.162	0.16
2.0	0.36	0.35	0.34	0.33	0.32	0.314	0.31	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.22	0.216	0.21
	SRF- Seed releasing frequency (V_m/z) (seed. s^{-1}) (for vacuum plate with 27 holes) from Equation 5																			
V_m																				
1.0	6.78	6.58	6.38	6.20	6.07	5.88	5.71	5.55	5.35	5.19	5.04	4.90	4.82	4.67	4.54	4.41	4.28	4.15	4.03	3.92
1.5	10.16	9.86	9.57	9.30	9.10	8.83	8.57	8.32	8.03	7.79	7.56	7.34	7.23	7.01	6.80	6.61	6.42	6.23	6.05	5.87
2.0	13.55	13.15	12.77	12.40	12.14	11.77	11.42	11.10	10.71	10.38	10.08	9.79	9.63	9.35	9.07	8.81	8.57	8.31	8.06	7.83
	SRF- Seed releasing frequency (V_m/z) (seed. s^{-1}) (for vacuum plate with 70 holes) from Equation 5																			
V_m																				
1.0	17.54	16.95	16.67	16.13	15.63	15.15	14.71	14.29	13.89	13.51	12.99	12.66	12.50	12.05	11.76	11.36	11.11	10.75	10.42	10.10
1.5	26.32	25.42	25.00	24.19	23.44	22.73	22.06	21.13	20.83	20.27	19.48	18.99	18.75	18.07	17.64	17.05	16.67	16.13	15.63	15.15
2.0	35.09	33.90	33.33	32.26	31.25	30.30	29.41	28.57	27.78	27.03	25.97	25.32	25.00	24.10	23.53	22.73	22.22	21.51	20.83	20.20

For seeding cotton at a seed spacing of 5.7 cm (with thinning) and 9.9 cm (planting to a stand) (Önal, 1981), the gear combinations for a seed plate with 70 holes are in the range of A1..E4. The transmission ratios in this seed spacing range varied between 0.599 and 0.346 while peripheral speeds of the seed plate at forward speeds of 1.0, 1.5 and 2.0 m s^{-1} are 0.18- 0.10, 0.27- 0.16 and 0.36 - 0.21 m s^{-1}, respectively. The SRF values above mentioned forward speeds are in the range of 17.54-10.10, 26.32-15.15 and 35.09-20.20 seed. s^{-1}.

Results from SRF experiments

The experiments conducted to find out the relationship between SRF and weighing experiments in 30 s. sequentially resulted in a linear model with a coefficient of determination of 99.57 % (Figure 8). In general, the CV values that represent a homogeneous flow in samples taken in sequential order from 15 samples are below 2.0 % except at a SRF value of 4 (Figure 8). The acceptable level for CV value should be less than 5% and the values found from the experiments are good as compared to this limit value (Bernacki et al, 1972, Önal, 2006).

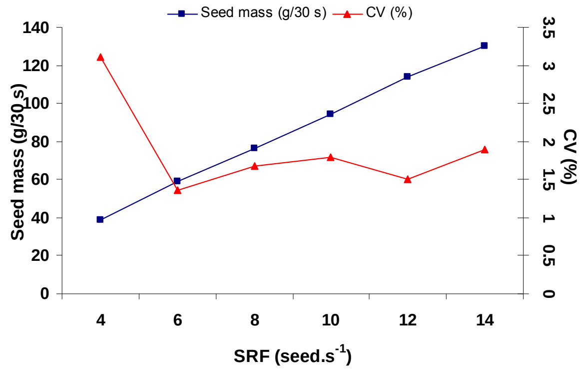


Figure 8. SRF - seed rate and CV relationship

The relationship between SRF and Population Index (PI) that represent the variation in seed rate and statistical groups are shown in Figure 9. As seen from the Figure, the population index goes down as the SRF increases. The variance analysis carried out indicated a significant difference when the SRF value is about 14 seed s^{-1}.

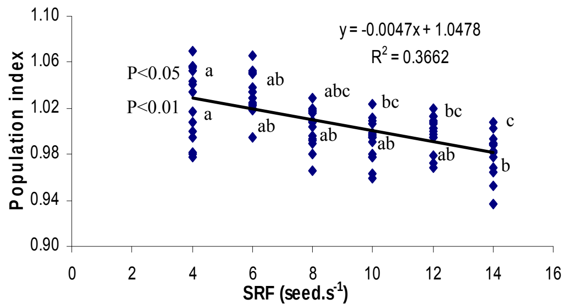


Figure 9. SRF versus population index relationship for maize (The letters indicate statistical differences)

Performance of Metering Units (Sticky belt tests)

The performance test results from sticky belt tests for seeding maize are given in Table 6. When the results were examined from the point of seeding criteria it could be stated that the performance of the metering unit is very good for a seed spacing range between 14.8 and 25.5 cm (3.92 and 13.35 seeds s^{-1}). The performance evaluation of the metering unit at seed spacing range between 18.7-19.8 cm indicated a high quality seeding performance in terms of QFI, miss and multiple index at forward speed of 1.0 and 1.5 m s^{-1} while the QFI and multiple index was in the class of high quality seeding at seed spacing of 19.8 cm. The miss index was good quality. The CVm values of the main seed distribution within the > 0.5 Z_t ≤ 1.5 Z_t range went down at seed spacing of 14.8 and 17 cm. This indicated an improved homogeneity in seed spacing. On the other hand, the CV_m values are negatively affected at forward speed of 2.0 m s^{-1}. But the CV_m values in general were below the acceptable limit of 29-30 %.

The results obtained from the sticky belt tests in seeding cotton seeds with a seed plate of 70 holes are given in Table 7.

The experiments conducted at a theoretical seed spacing of 5.7 cm resulted in insufficient quality in terms of QFI, miss and multiple indexes since the values were below the acceptable limits. The reason for this was an increased SRF values of 20, 30 and 40 seeds s^{-1} at forward speeds of 1.0, 1.5 and 2.0 m s^{-1} even though a seed plate with 70 holes was used in the experiments.

The performance indicators of QFI, miss and multiple indexes on the other hand showed an improvement when the SRF is 20 seeds s^{-1} at a forward speed of 1.0 m s^{-1}.

At 9.9 cm seed spacing experiments, it was found that the precision quality was good at 1.0 and 1.5 m s^{-1} forward speeds while the QFI value was moderately good at 1.0 m s^{-1} and the multiple index was good and miss index was above the acceptable limit. QFI, multiple and miss indexes at 1.5 m s^{-1} forward speed were found to be insufficient since the seed falling height was 45 cm. Once the forward speed increases, the time for falling delays about 0.01 s. (the normal falling time is 0.3 s) this results in a 1.5 cm displacement from the target location while 2 cm displacement occurred at 2.0 m s^{-1} forward speed. It is obvious that the displacement of 1.5 and 2.0 will affect the seeding quality significantly.

Results from the Field Tests

The row cleaning unit of the direct seeder reduced the intensity of surface residue from 5600 to 1431.5 daN ha^{-1} after the seeding and prepared an appropriate soil media for the runner, coverers and press wheels.

Disk coulter, fluted coulter and fertilizer coulters disturbed 25 cm wide soil in the stubble field. Table 8 gives the results from the sieving tests. The weighed mean value of aggregate diameter is found to be 16.4 mm. This result could be considered as normal since Önal and Aykas (1993) reported that the aggregate diameter increases due to working in dry soil conditions. But the soil media could be favorable for the plant emergence after irrigation.

The results from seeding depths are given in Table 9. The coefficient of variation is below the value of 25% that is acceptable to indicate a good performance of the coulters (Mutaf, Önal, 1979).

Table 6. Performance data of the metering unit for maize

Gear combination	Z_t cm	V_m- Forward speed m s^{-1}	SRF seed s^{-1}	Z_m cm	S_m ±	Precision CV_m (%)	Multiples index (%)	Miss index (%)	QFI (%)
		1.0	6.78	14.5	2.46	**16.97***	2.01	0.80	97.19
A1	14.8	1.5	10.16	14.69	2.18	**14.86**	**0.40**	1.61	97.99
		2.0	13.55	14.86	2.44	**16.44**	4.02	0.80	95.18
		1.0	5.88	16.84	2.40	**14.28**	1.61	**0.40**	97.99
B2	17.0	1.5	8.83	16.77	2.44	**14.54**	0.80	**0.40**	**98.80**
		2.0	11.77	16.80	2.57	**15.28**	1.20	1.20	97.59
		1.0	5.35	18.52	2.15	**11.59**	**0.40**	**0.40**	**99.20**
C1	18.7	1.5	8.03	18.77	2.50	**13.34**	**0.00**	**0.40**	**99.60**
		2.0	10.71	18.47	3.06	**16.60**	1.20	1.61	97.19
		1.0	5.04	19.73	2.23	**11.31**	**0.40**	**0.00**	**99.60**
C3	19.8	1.5	7.56	19.71	2.69	**13.66**	**0.40**	**0.40**	**99.20**
		2.0	10.08	19.46	2.85	**14.62**	**0.00**	1.20	**98.80**
		1.0	4.41	22.27	2.94	**13.18**	1.61	**0.00**	98.39
D4	22.7	1.5	6.61	21.99	2.97	**13.50**	1.61	0.80	97.59
		2.0	8.81	22.08	3.21	**14.55**	0.80	2.41	96.79
		1.0	3.92	25.39	2.67	**10.53**	0.80	**0.40**	**98.80**
E4	25.5	1.5	5.87	25.39	2.91	**11.45**	0.80	**0.40**	**98.80**
		2.0	7.88	25.64	3.74	**14.59**	1.61	0.80	97.59

*Bold numbers indicate "very good" quality

Table 7. Performance data of the metering unit for cotton at 5.7 and 9.9 cm theoretical seed spacing

Gear combination	V_m- Forward speed m s^{-1}	SRF seed.s^{-1}	Z_t cm	Z_m cm	Precision CV_m (%)	Multiples index (%)	Miss index (%)	QFI (%)
	1.0	20	5.7	5.85	32.49	13.17	9.14	77.69
A1	1.5	30	5.7	5.81	34.29	10.66	14.74	74.60
	2.0	40	5.7	5.82	33.78	11.98	12.26	75.76
	1.0	10	9.9	10.32	**23.82***	**2.90**	5.80	**91.30****
E4	1.5	15	9.9	10.09	**23.72**	7.04	9.86	83.10
	2.0	20	9.9	9.91	28.85	5.63	5.63	88.73

*) Bold numbers indicate 'good' quality **)Indicates "moderate" quality

Table 8. Results from soil sieve analysis

Sieve size range mm	Mean sieve size (d) cm	Percantage %	Mean particle diameter* mm	S ± mm	CV %
80- 40	60	10.26			
40- 20	30	14.79			
20- 10	15	25.74	16.4	0.8535	13.87
10- 5	7.5	18.19			
5- 2.5	3.75	9.25			
2.5- 0	1.25	21.77			

*) Σd.m : Σm (Estler, Knittel, 1996)

Table 9. Distribution of seeds as a function of soil depth and Breitfuss goodness evaluation

Depth cm	Mean depth cm	Seeds %	Mean seeding depth cm	S ± cm	CV %	Breitfuss Goodness value
0-1	0.5	0				
1-2	1.5	0				
2-3	2.5	0				
3-4	3.5	11				
4-5	4.5	23	5.25	0.8535	13.87	46:4 = 11.25
5-6	5.5	46				
6-7	6.5	20				best:
7-8	7.5	0				100:1= 100
8-9	8.5	0				worse:
9-10	9.5	0				25:4 = 6.25

CONCLUSIONS

The followings were concluded from the study.

- For seeding maize at seed spacings varying between 14.8 and 20.4 cm, the transmission ratios in this seed spacing range varies between 0.599 and 0.433 while peripheral speeds of the seed plate at -forward speeds of 1.0, 1.5 and 2.0 m s^{-1} are 0.18-0.13, 0.27-0.20 and 0.36-0.26 m s^{-1} respectively. The SRF values above mentioned forward speeds are in the range of 6.78- 4.90, 10.16- 7.34 and 13.55- 9.79 for maize. Based on the findings by Brinkmann (1983), the miss index shows a significant increase when the peripheral speed of the seed plate goes above the value of 0.25 m s^{-1}. The highest values of the peripheral speed of the seed plate and SRF in this study were 0.36 m s^{-1} and 13.55 seeds s^{-1}, respectively.
- For seeding cotton at a seed spacing of 5.7 cm (with thinning) and 9.9 cm (planting to a stand) (Önal, 1981), the gear combinations for a seed plate with 70 holes are in the range of A1..E4. The transmission ratios in this seed spacing range varies between 0.599 and 0.346 while peripheral speeds of the seed plate at -forward speeds of 1.0, 1.5 and 2.0 m s^{-1} are 0.18- 0.10, 0.27- 0.16 and 0.36- 0.21 m s^{-1}, respectively. The SRF values at 1.0 and 1.5 m s^{-1} forward speeds are in the range of 17.54-10.10, 26.32- 15.15. These SRF values are considered to be acceptable. The SRF values at 2.0 m s^{-1} forward speeds increase and reach to 35.09- 20.20 seeds s^{-1}.
- In experiments using maize seeds, it was found that the population index goes down as the SRF increases. The variance analysis carried out indicated a significant difference when the SRF value is about 14 seed s^{-1}.
- When the results were examined from the point of seeding criteria in seeding maize seeds with a seed plate of 27 holes, it could be stated that the performance of the metering unit is very good for a seed spacing range between 14.8 and 25.5 cm (3.92 and 13.35 seeds s^{-1}). The performance evaluation of the metering unit at seed spacing range between 18.7-19.8 cm indicated a high quality seeding performance in terms of QFI, miss and multiple index at forward speed of 1.0 and 1.5 m s^{-1} while the QFI and multiple index was in the class of high quality seeding at seed spacing of 19.8 cm. The miss index was good quality. The CV_m values of the main seed distribution within the $>0.5\ Z_t \leq 1.5\ Z_t$ range went down at seed spacing of 14.8 and 17 cm. This indicated an improved homogeneity in seed spacing. On the other hand, the CV_m values are negatively affected at forward speed of 2.0 m s^{-1}. But the CV_m values in general were below the acceptable limit of 29-30%.
- The results obtained from the sticky belt tests in seeding cotton seeds with a seed plate of 70 holes are as in the following.

The experiments conducted (with thinning) at a theoretical seed spacing of 5.7 cm resulted in insufficient quality in terms of QFI, miss and multiple index since the values were below the acceptable limits. The reason for this was an increased SRF values of 20, 30 and 40 seeds s^{-1} at forward speeds of 1.0, 1.5 and 2.0 m s^{-1} even though a seed plate with 70 holes was used in the experiments.

The performance indicators of QFI, miss and multiple index on the other hand showed an improvement when the SRF is 20 $seeds^{-1}$ at a forward speed of 1.0 ms^{-1}. At 9.9 cm seed spacing experiments, it was found that the precision quality was good at 1.0 and 1.5 m s^{-1} forward speeds while the QFI value was moderately good at 1.0 m s^{-1} and the multiple index was good and miss index was above the acceptable limit. QFI, multiple and miss indexes at 1.5 m s^{-1} forward speed were found to be insufficient since the seed falling height was 45 cm. Once the forward speed increases, the time for falling delays about 0.01 s. (the normal falling time is 0.3 s) this results in a 1.5 cm displacement from the target location while 2 cm displacement occurred at 2.0 ms^{-1} forward speed. It is obvious that the displacement of 1.5 and 2.0 cm will affect the seeding quality significantly.

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