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Development of a Precision Seed Drill for Oilseed Rape

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Abstract: At the present time, the most widely used machine for seed and oilseed planting is a seed drill with a roller-type-metering device. Due to nonuniform spacing of seeds along the rows and lack of control on planting depth, this machine aggravates the growth related problems and degrades the quality of a sensitive crop such as oilseed rape. To solve the above-mentioned problems, an attempt was made to develop a precision seed drill with a roller-type-metering device and a depth control system. Some of the design parameters affecting the uniformity of seed distribution were studied from the view point of roller and brush geometry. Computer software packages were used to design the machine and simulate its operational performance. In the laboratory test, it was found that the precision seed drill performed satisfactorily and its speed and vibration did not affect the performance of metering system significantly. In the field test, a uniform distribution of seed with a reasonable spacing along the row planting was achieved and seed scattering was found to be within an acceptable range.

Key Words: Oilseed rape, precision seed drill, conventional drill

Introduction

One factor affecting the quality of the crop in mechanized crop production systems is the planting operation. The more precise the planting operation, the better the quality of crop harvested. Precision planting reduces seed scattering and excessive use of seeds due to uniform distribution of seeds and by preventing seed from bouncing in the furrow, which facilitates drill calibration on the basis of the number of seeds to be placed along a unit length of the row. Uniform germination and growth of plants makes the subsequent operations, such as weeding and harvesting, easy with less costs (Domier, 1991).

Several types of metering devices are used for precision planters: a vacuum disk type, an inclined plate type, a belt type, a vertical rotor type, and a roller type. The roller type is used most widely in mechanized seeding of crops. It is generally known that the scattering of seeds is caused mainly by the improper design of the metering device and seed tube. The effect of constructional properties (roll length, diameter, etc.) and operational variables (seed rate, travel speed, and seed spacing) on flow metering device have been investigated (Guler, 2005; Boydas and Turgut, 2007). Ryu and Kim (1998) developed a method to design the roller-type metering device for hill dropping planters. As the roller rotates, seeds are fed into the grooves by gravity and the cutoff brush removes the extra seeds above the groove so that the seeds inside the groove can only pass the brush. Wilson (1980) studied the effect of several design parameters on the seed distribution in the roller-type metering device and suggested that peripheral velocity should be equal in magnitude and opposite to the forward velocity. Many attempts were made to improve the seed distribution over an area by decreasing the row width with precision seed drill. Solie (1991) indicated that, by decreasing the row width, drilling increased the yield of small grains significantly. In the roller design, groove shape and the number of grooves are important design parameters. Groove shape is considered the most important factor affecting the seed dropping process from the groove. Boydas and Turgut (2007) studied the flow of

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seed carried by studded feed roller device and showed that increase in seed rate significantly increased the flow evenness. In precision planting, seeds should fall down from the groove along the straight line with a specified spacing and there should be equal time lags between them as they fall through the seed tube. According to Ryu and Kim (1998), to maintain a specified time lag between individual droppings, the sliding surface of the seed in the groove should be flat enough. Therefore, it was thought that this type of groove shape is suitable for simultaneous discharge of seeds from the groove. Thus, seeds can fall down right after the groove passed the brush. Five design variables shown in Figure 1a are defined and used to determine the exact shape of the groove as follows:

d_g: Depth of the groove. It should be slightly larger than the length of seed.

θ_g: The open angle of groove. It is defined as an angle between the 2 straight lines connecting the starting and final points of the groove and the center of the roller, respectively.

β_{ls}: The left side angle of the groove. It affects time delay between the seeds dropped successively from the grooves.

β_{rs}: The right side angle of the groove. This angle determines the seed-holding capacity and the loading process of the groove.

R_e: Denotes radius of the curvature of groove bottom. Round groove bottom prevents seeds or other substances from clinging to the bottom.

The brush removes seeds over the groove and determines the times to drop seeds from the groove. In order to design the brush and analyze its function, Ryu and Kim (1998) proposed 4 position variables as shown in Figure 1b, which are defined as follows:

θ_{cutoff}: Cutoff angle. It is defined as an angle between the upper surface of the brush and the vertical.

$\theta_{release}$: Release angle. It is defined as an angle between the vertical and the line connecting the lower end of the brush and the center of the roller.

$\Delta\theta_{gap}$: Gap angle. It is defined as an angle between the lines connecting the lower ends of the brush and groove with the center of the roller, when seeds are released from the groove (Ryu and Kim, 1998):

$$\Delta\theta_{gap} = \sin^{-1}(2t_s/D) \qquad (1)$$

where

t_s: Thickness of the seed (mm)

D : Diameter of the roller (mm)

γ: Contact angle of brush. It is defined as an angle between the tangent to the surface of the roller and the horizontal at the seed release point.

Improper design of seed tubes leads to unsteady flowing of seeds through the tube, resulting in irregular seed spacing along the row. Seed tube should be designed smooth, narrow, straight, and short. However, its outlet should be close enough to the furrow bottom. At the inlet

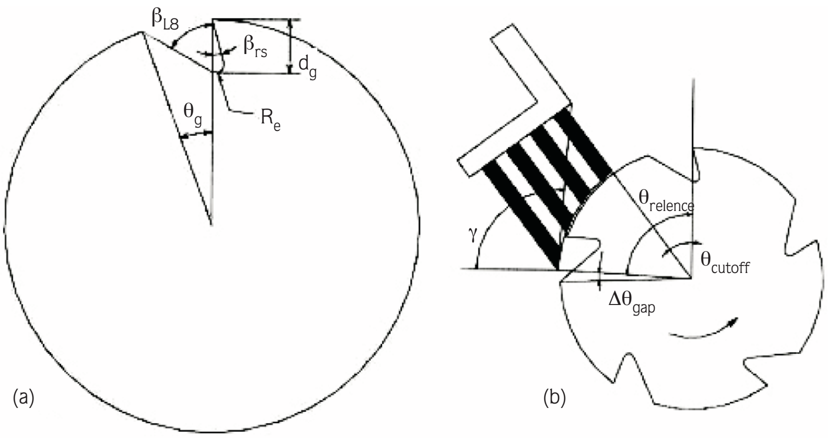

Figure 1. a: Steep triangular-shaped groove (design variables) of seed metering device, b: Design variables of the brush of seed metering device.

point, velocity of seeds in the horizontal direction should be zero, and the friction between seed and tube wall should be minimized. Seed bouncing in the furrow disrupts the regularity of seed spacing along the row. This can be minimized if the horizontal component of the seed velocity relative to the planter is equal and opposite to the forward velocity of the planter. Thus, the seed will drop with zero horizontal velocity relative to the ground. Bufton et al. (1974) studied the displacement of seeds after impact on soil surface using photographs. The minimum displacement was obtained at low impact velocities. Ryu and Kim (1998) investigated the effect of seed tube on dropping performance using 4 different types of seed tubes (bent tube, wide straight tube, narrow straight tube and no tube) and compared their performance. The worst performance was shown by the bent type and the narrow tube showed the best performance.

Accurate planting depth control is needed to minimize the depth-related variation in plant vigor and growth. Constant seeding depth is important to achieve uniform seedling emergence (Chaudhuri, 2001). Seed drills have commonly been used without any planting depth control. These machines have been adjusted according to the operators' intuition, crop to be planted, and soil and weather conditions. Planters and drills must be provided with an effective depth control mechanisms and more sources of vertical forces (down pressure) for soil penetration. Changes in the opener downforce affect the mean depth of seeding by their effect on the individual opener penetration (Gratton et al., 2003). Janelle et al. (1993) studied seed placement of disc opener under 3 different downforces. They reported that the increasing downforce generally increases seeding depth. For precision drilling, it is common practice to use gage wheel with opener. According to Morrison and Gerik (1985a) using a gage-wheel either in front of or behind the opener alone is not the best way. Better results were obtained when either a gage wheel on the side of the opener or 2 gage wheels in tandem, in front of, as well as behind the opener were used (Morrison and Gerik, 1985b). Ozmerzi et al. (2002) indicated that sowing depth did not have a significant effect on sowing uniformity of the horizontal distribution pattern. Heege (1993) reported that in seeding machines for bulk metering, gage wheels attached to the opener do not improve the depth control. Gage wheels attached to drill openers tend to climb over coarse soil clods and lift the light openers. The aim of the preset work was to modify the conventional seed drill in such a way that it can be used as a precision seed drill for planting small seeds, oilseed rape in particular.

Materials and Methods

The seed metering mechanism that was originally developed by Ryu and Kim (1998) was modified and constructed. For sowing oilseed rape, seeding machines need to sow 20 to 25 seeds per meter at equal intervals along the row. The repose angle, ϕ_s, and bulk density, ρ, of oilseed rape were obtained from the literature (Moysey et al., 1988). Friction angles between the groove and seed, ϕ_r and between the brush and seed, ϕ_b, and seed diameter were determined experimentally. The roller was constructed with D = 50 mm, and d_g = 4 mm (considering the case in loading and seed holding capacity of the groove). The left side angle of groove was determined as 64° to make the groove steep enough to decrease the time delay as much as possible between the seeds consecutively dropped from the grooves. A compromise was made between the time delay and the holding capacity of the roller in order to determine the left side groove angle.

The right side angle of groove was determined as 23° to make seeds to be easily fed into the groove. The open angle of the groove was then obtained to be $\theta_g = 15°$.

Assuming 100% degree of seed distribution, the number of grooves was determined by the equation given by Ryu and Kim (1998):

$$n = 360\, D_{sc}/100\, \theta_g \tag{2}$$

where

n : Number of groove

θ_g : Open angle of groove (°)

D_{sc}: Desired degree of scattering (%).

With 24 grooves from Eq. 2, equidistant distribution of seeds was not possible to obtain and it was difficult to distinguish the groups of seeds dropped from 2 adjacent grooves. If the number of grooves is reduced, the roller speed must be increased accordingly to keep the seed spacing constant along the row. However, high roller speed may cause damage to seeds and give insufficient time to load seed into the groove. To reduce the number of grooves and increase roller speed without causing mechanical damage to seeds, thus maintaining uniform seed spacing along the row, a spiral shape of the groove was chosen. The angle of spiral was determined to be 48° from the horizontal. The width of the roller was 30 mm and the projected length of the groove was 10 mm, leaving both sides of the roller a 10 mm margin.

Perimeter of the roller was 157.1 mm. With $\theta_g = 15°$ the length of groove was 14.94 mm. The groove covered 17.65 mm of roller perimeter, in other words, 40.5° out of 360°. Spiral shaped groove had the following advantages:

i. The number of grooves decreased from 24 to 5.

ii. Continuous flowing of seeds into the tube was maintained, resulting in a uniform spacing between seeds along the row.

Gap angel of the brush was determined as $5.47 \cong 6°$ using Eq. 1.

The release angle was then obtained using an equation given by Ryu and Kim (1998):

$$\theta_{release} = 1/2\ (270 + \theta_g - \beta_{ls} - \Delta\theta_{gap} - \phi_b + \phi_r) \qquad (3)$$

From Eq. 3, the release angle of 99.8° was obtained. The cutoff angle can be determined by 2 constraints (Ryu and Kim, 1998). The brush should cover more than half of a groove opening when the roller rotates about the sliding position angle,. That is:

$$\theta_{cutoff} < \frac{\theta_g}{2} + \theta_{sp} = \frac{\theta_g}{2} + (\phi_r - \beta_{ls} + 90) \qquad (4)$$

The brush also can cover the entire opening of the groove, which can be expressed as:

$$\theta_{cutoff} < \theta_{release} - \theta_r \qquad (5)$$

From Eqs. 4 and 5, 2 values of 46.89° and 84° for the cutoff angle were obtained. Based on these constraints, cutoff angle of the brush was determined as 40° (Figure 2). The width of the brush was decided to be W = 30 mm. The length of the brush was determined to be L = 12 mm taking the strength of brush material into consideration. The angular displacement of the roller, when seeds start to fall down, θ_{fall}, can be computed as follows:

$$\theta_{fall} = \theta_{release} - (\theta_g - \Delta\theta_{gap}) \qquad (6)$$

The seeds are dropped from each groove when the groove rotates 9° from θ_{fall} = 90° position or 99° from the vertical line.

In precision planting, precise metering is of little value unless the transport process also distributes the seeds uniformly in the rows. To provide smooth seed flowing in the tube, thus maintaining the distribution uniformity, the upper part of the seed tube must be short, smooth, straight, and vertical. The width of seed tube was about

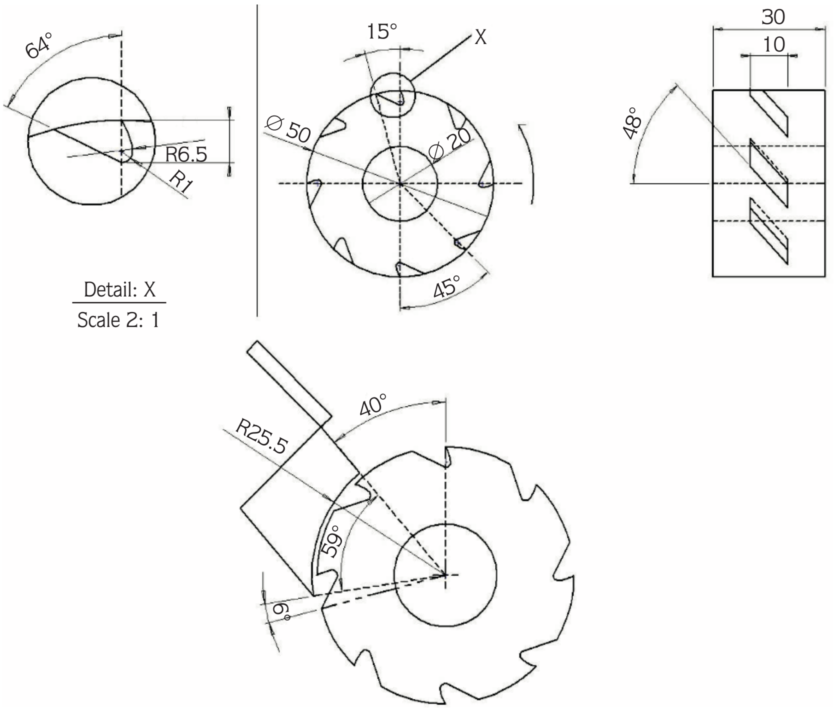

Figure 2. Two dimensional view of a seed metering roller.

one half of the diameter of the roller (Figure 3). The lower part of the seed tube transferring the seeds towards the opener was made of steel. To prevent seeds from bouncing in the furrow, the direction of the lower part of the seed tube was placed in the opposite of travel direction.

For the precise depth control, a gage wheel made of steel was attached to the side of the opener (Figure 4). Diameter of the wheel was 15 cm with a thickness of 3.5 cm. Covering device was a 4 cm wide press wheel of 20 cm diameter and set at a 10° angle from the vertical line. Precision seed drill was constructed with 3-row seeding; 3-seed metering device in hopper, with 25 cm spacing (No.1, No.2, and No.3).

The relationship between speed variation and seed rate was studied in different forward speeds (3, 5, 8, 10 km h^{-1}) and the results with those obtained from the conventional drill (with fluted seed metering device) using a completely randomized design with replications were compared. For every 10 revolutions of the ground wheel, seeds were collected from the machines. The experiment was repeated 3 times. After weighing the seeds, the number of broken seeds was determined.

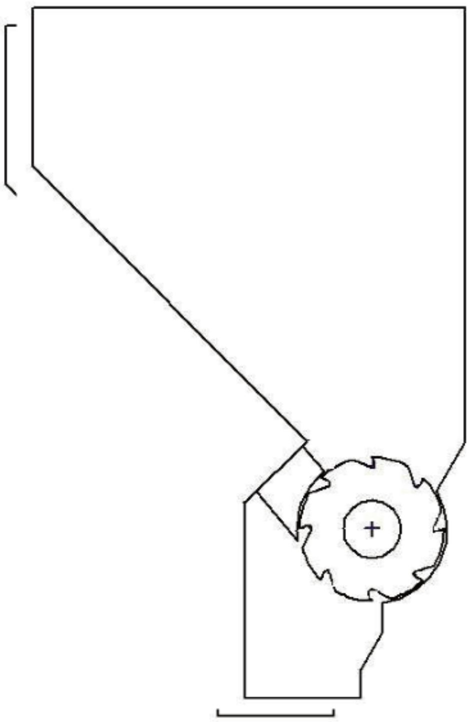

Figure 3. Schematic view of a precision seed drill.

To evaluate the drilling performance of the new machine, field tests were conducted. A factorial experiment based on randomized complete block design was used. Factors were the type of seed bed and the type of machine (new machine and conventional drill).

Results

The performance of the new drill equipped with modified roller-type metering-device, and conventional drill with fluted seed-metering-device was compared experimentally. Laboratory tests indicated that the effect of forward speed on uniformity of seed spacing was not significant in the new drill, but it was significant in the conventional drill (Table 1). In terms of seed breakage, the effect of speed for the modified roller No.1 was significant

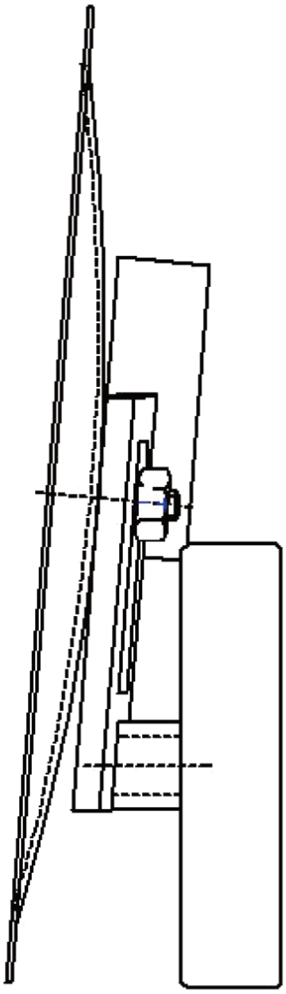

Figure 4. Schematic view of a gage wheel for depth control of precision seed drill.

Table 1. Analysis of variance for drilling performance and seed breakage of modified and conventional drills in the laboratory

Modified drill																	
Conventional drill				No.3				No.2				No.1					
SB		DP		SB		DP		SB		DP		Seed Beakage (SB)		Drilling Performance (DP)		Degree of freedom	Source of variation
M S	F value	M S	F value	M S	F value	M S	F value	M S	F value	M S	F value	M S	F value	M S	F value		
993.33	152.87***	43.75	12.35**	510.0	15.16**	2.54	0.36	396.67	14.69**	0.54	0.44	70.0	6.51*	0.51	1.58	3	Speed
6.5		3.54		33.65		7.14		27.03		1.23		10.7		0.32		8	Error
	1.52		0.93		3.64		0.76		3.24		0.54		1.97		0.28		CV(%)

*,**,*** Significant at 5%, 1%, and 0.1% probability levels
M S = Mean squares (×10^4)

at 5% probability level and for modified rollers No. 2 and No. 3 at 1% probability level. On the other hand, in the conventional drill, the effect of forward speed on seed breakage was large because the related mean square was significant at 0.1% probability level.

The modified roller No.1 was compared with the conventional roller at different forward speeds in term of seed rate. There was a significant difference between the 2 machines for seed rate. The effect of speed and its interaction with the machine type were significant (Table 2). The interaction indicated that the differences between 2 machines were not the same at different speeds.

Means for treatments are given in Figures 5 and 6 for seed dropping and percent beakage, respectively. As shown in Figure 5, by increasing the speed from 5 to 10 km h^{-1}, the amount of seed dropping from the conventional roller decreased considerably but the change of the amount of seed dropping from the modified roller was negligible.

Table 2. Analysis of variance for seed rate of modified roller No.1 and conventional drill.

Source of variation	Degree of freedom	Mean squares	F value
Machine (M)	1	0.019	97.59*
Speed (S)	3	0.002	10.51
S × M	3	0.0024	12.31
Error	16	0.0002	
CV%		0.68	

* Significant at 5% probability level

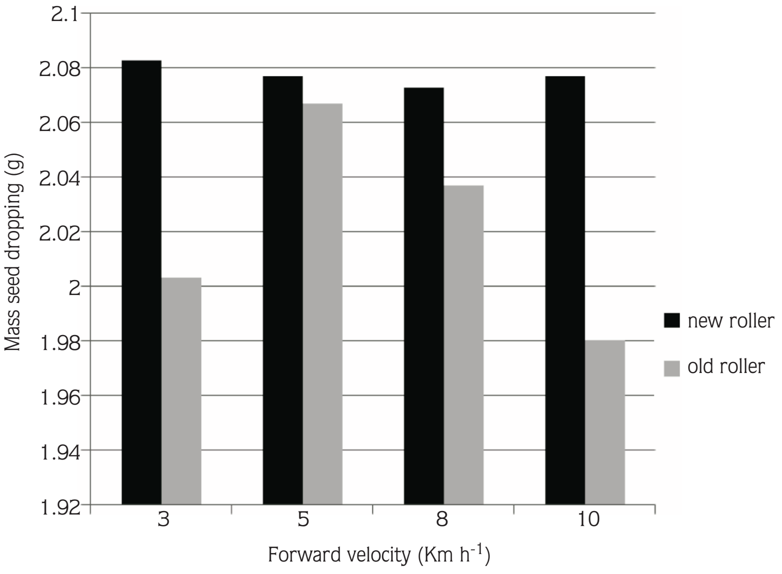

Figure 5. Mean mass of seeds dropping from metering device of modified and conventional drills in the laboratory.

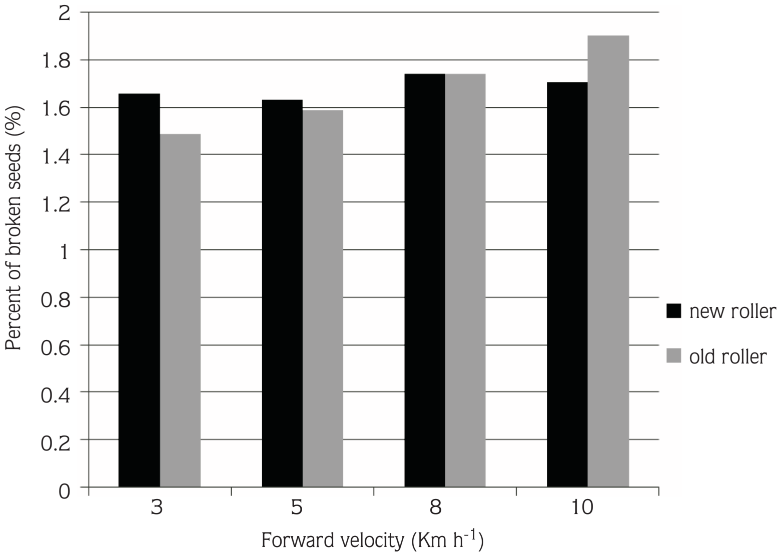

Figure 6. Mean broken seed percentage of modified and conventional drills in the laboratory.

The least seed breakage was obtained at a forward speed of 5 km h^{-1} in the precision seed drill, and at forward speed of 3 km h^{-1} in the conventional drill. As shown in Figure 6, for speeds less than 8 km h^{-1} conventional drill gave better results for seed breakage. However at 10 km h^{-1}, seed breakage was higher in the conventional drill.

Analysis of variance of germination percentage in the field test is given in Table 3. No significant differences were obtained between the 2 seed beds. The interaction of the seed beds with the machines was not significant, either. However, the difference between the machines was significant and the germination percentage of the precision seed drill was higher compared to the conventional drill (92% versus 82.12%).

Table 3. Analysis of variance for germination percentage of new and conventional drillers at 2 types of seed bed in the field.

Source of variation	Degree of freedom	Mean squares	F value
Replication	3	28.56	0.75
Machine (M)	1	390.06	10.22*
Seed bed (S)	1	85.56	2.24
S × M	1	0.063	0.002
Error	9	38.17	
CV%		1.10	

* Significant at 5% probability level

Discussion

The effect of forward speed on seed rate of oil seed rape in the modified roller was not similar to the conventional roller. This result could be due to the appropriate design of the groove profile as well as spiral shape of the groove, which facilitates the easy loading of the groove by seeds. Similair results obtained by Ryu and Kim (1998), who designed a roller-type-metering device for hill dropping planters. With conventional roller (bulk metering system), it is difficult to adjust the seed rate precisely since it depends on the bulk density of the seed as well as on the wheel slip (Heege, 1993). These problems could be overcome by sensing the seed sequence in the seed tubes and adjusting the travelling speed. Karayel et al. (2006) showed that the coefficient of variation (CV%) of seed spacing decreased with an increase in seed rate in wheat and soybean by fluted metering device at the forward speed of 1 m s^{-1}. Ess et al. (2005) compared the belt metering mechanism and fluted metering device at a forward speed of 2.2 m s^{-1} for untreated soybean in field and determined that increasing seed rate led to a numerical decrease in CV% of seed delivery in fluted metering device. The effect of 2 machines on germination percentage of oilseed rape was not similar and it was better in the precision seed drill. This could be resulted from the appropriate depth control of precision seed drill preventing deep seeding. Field observation was indicated the uniform distribution of seed along the row, which is due to the better performance of seed metering device and seed tube in this machine in comparison with the conventional drill. Effects of planters and forward speeds on seed spacing uniformity, depth uniformity, and seed emergence ratios of sunflower were evaluated by Celik et al. (2007) and the best seed depth uniformity was obtained with the precision planter. With the precision seed drill using gage wheels for each opener, uniform distribution of seed was obtained (Gebresenhet and Jonsson, 1992). Uniform seed spacing and depth result in better germination and emergence and increase yield by minimizing competition between plants for available light, water, and nutrients. It can be concluded that the precision seed drill had better performance compared to the conventional drill and the method developed in this study can be used to design roller type metering devices for different kinds of seeds.

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