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Evaluation of Some Operational Parameters of a Vacuum Single-Seed Planter in Maize Sowing

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ABSTRACT

The objective of the study was to evaluate the performance of a vacuum single-seed planter in field conditions to optimize some operating parameters in maize production. Three forward speed of the tractor (4.0, 5.4 and 7.9 km h^{-1}) and five target seed spacing (102, 147, 195, 247 and 309 mm) were evaluated by examining the mean seed spacing, coefficient of precision in spacing, miss index, multiple index, quality of feed index, sowing depth, deviation from the row (inter-row spacing), mean emergence time, emergence rate index and percentage emergence. The point dropped in a furrow of seed, depth of seed placement, emergence rate and three indices of uniformity in seed spacing and precision coefficients of sowing quality were determined. The planter performed the best performance at the lowest forward speed and the highest target seed spacing. However, the deviation of seeds from the intended point in intra-row spacing was significantly affected only by the forward speed (P<0.001). Improvement in the larger seed spacing was due to the lower variation. Increasing the forward speed resulted in a shallower sowing depth. The desired planting depth was also obtained at 4.0 km h^{-1} in all plots. Increasing target seed spacing increased the emergence percent by about 35% while increasing forward speed decreased the emergence percent by 10%. Sowing at 4.0 km h^{-1} resulted in the lowest miss, multiple and precision indices (5.1% 2.9%, and 15.3%, respectively), and a quality of feed index as high as 92% was obtained in similar conditions. The results indicated that, with single-seed planters, success may be achieved in a conventional tillage maize production system at a target seed spacing of more than 102 mm and tractor forward speeds of less than 7.9 km h^{-1}, and thus satisfying farmers who carry out maize sowing by conventional tillage.

Keywords: Plant spacing, Tractor forward speed, Sowing depth, Deviation from a row, Sowing uniformity

1. Introduction

The aim of sowing is to dropped seeds at an asked seed spacing (intra-row spacing), inter-row spacing and target seed depth. This process is one of the most major missions that growers take upon oneself. Therefore, a planter should place seeds in an environment for reliable germination and emergence.

Intra-row spacing (plant spacing), inter-row spacing (deviation from row), sowing depth and percentage emergence are the most known features used by growers to measure planter performance. One of the reasons for reduced yield is irregular seed germination (Nafziger 1996). Therefore, uniform seed spacing, inter-row spacing, and sowing depth result in better sprouting and emergence and increase output by decreasing competition among plants for existing moisture, light and nutrients (Griepentrog 1998; Karayel & Özmerzi 2002).

Various factors such as seed metering unit, furrow opener, tractor forward speed, seed quality, and soil conditions affect seed distribution in soil. However, producers have a trend towards both higher plant distribution uniformity and faster planter forward speeds.

In the present, the yield has been increased by reducing the variation of plant spacing within rows. Kachman & Smith (1995) reported that the mean plant spacing and the standard deviation of plant spacing are beneficial for precision planters. However, they reported that these parameters do not entirely describe the distribution of plant spacing. In addition to the standard deviation of the row spacing and the mean, the uniformity indicators (The multiple index, the miss index, the quality of feed index and coefficient of precision) of the plant spacing should also be considered. This is because the space between seeds within a furrow is affected by several parameters including multiple seeds drop or single-seed drop failure, drop failure of a seed, failure in germination and displacement of seeds in the furrow. Nafziger (1996) reported that multiple seeds drop (Multiple index) may increase yields by 6%, however, losses in seed drop failure (miss index) may decrease yields by about 7%.

Nielsen (1995) reported that the loss of yield is at least 78 kg per hectare due to the increase in speed in the range of 1.8 to 3.1 m s^{-1} forward speed. Nielsen (1995) also determined that forward speed significantly affects the variation in plant spacing. Panning et al. (2000) evaluated the performance of a planter designed for row crops and two sugar beet planters in laboratory and field conditions. They reported that with increasing forward speed, the precision coefficient did not change for a planter and decreased for another. However, in field tests, they found the most uniform seed distribution for each planter at the lowest forward speed (3.2 km h^{-1}). As the forward speed increased from 3.2 to 8.0 km h^{-1}, plant distribution uniformity decreased for all planters. They reported that the field and laboratory test results were not alike and laboratory test results could not be used in practice.

It is a concern for maize growers that the plant emergence time is nonuniform. Nafziger (1996) reported that nonuniform plant emergence time reduces yield in maize. However, Nafziger (1996) suggested that the yield loss would not exceed 3% if plant emergences were completed in shorter than two weeks. Erbach (1982) developed the Emergence Rate Index (ERI) to evaluate maize and soybean plant stands. The ERI is an indication of how rapid and uniform germination of seeds from the soil. He reported that the ERI ranged from 4.9% to 12.7% for soybean and 4.9% to 11.0% for maize.

Singh et al. (2005) reported that seed distribution uniformity is affected when the seed metering unit fails to drop a seed or drops multiple seeds. Therefore, to achieve accurate seed spacing, on needs to optimize different parameters that affect seed placement such as tractor forward speed for appropriate planter performance and target seed spacing to regulate seed spacing. Problems due to seed plate operational speed, furrow openers and planter speed range from insufficient seed placement in the target seed spacing to the incorrect seed placement depth, which are problems that may contribute to reducing the emergence rate of maize, and finally, its yield. Additionally, some physical properties such as shape, size, and weight of the seeds, operation parameters such as the forward speed of the tractor and tillage system are among the important factors that affect planter performance and sowing quality (Ivancan et al. 2004; Staggenborg et al. 2004). The specific objective of this study was to evaluate the influence of different tractor forward speeds and target seed spacings on maize plant spacing variation, sowing depth, deviation from the row of plants, mean emergence time (MET), ERI, and percentage emergence (PE).

2. Materials and Methods

The field experiment was conducted on a research area in Erzurum province in Turkey in the growing season of 2014. The soil properties of the research area are given in Table 1. In the experiments used maize (Zea mays) seeds, with 326 g of thousand-grain weight, 74% of sphericity, 0.9 g cm^{-3} of bulk density and 7.5 mm of geometric mean diameter. A vacuum single-seed planter was used in the sowing operation, with air suction, four-rows and 70 cm each of row spacing. The planter was composed of shoe furrow openers and 30-holes (each of hole diameter 5.0 mm) metering plates (Figure 1). The seeds were sowed at 60 mm of sowing depth determined as the most suitable value for maize by Özmerzi et al. (2002). The ability to hold the vacuum plate of the seeds was driven by tractor PTO. The negative air pressure generated by the fan was used 8.8 kPa suggested by Önal (2011) for maize. The hole diameters of the seed metering plate were determined depending on the geometric mean diameter of maize seeds. The geometric mean diameter of the seeds was calculated by Equation (1). The geometric mean diameter was measured from 100 samples randomly selected from each kernel (Mohsenin 1986).

$$d = (lwt)^{1/3} \qquad (1)$$

In this Equation, d is the geometric mean diameter, and l, w, and t are the length, width, and thickness, respectively.

Table 1- Physical soil properties for the 0 to 0.15 m depth range in the experiment area

Physical property	***Value***
Moisture content (% d.b.)	23.86
Bulk density (g cm^{-3})	0.93
Porosity (%)	64.90
Penetration resistance (MPa)	0.64
MWD* (%)	15.67
Roughness (%)	3.16
Sand (%)	38.7
Clay (%)	37.8
Silt (%)	23.5
Texture class	Clay loam

*MWD; Mean weight diameter of soil aggregates

The experimental setup was a complete factorial design (3x5) with three repetitions. For optimization of the operational factors affecting the performance of the vacuum planter, the experiment field was divided into 45 plots, including five target seed spacings (102, 147, 195, 247 and 309 mm), three tractor forward speeds (4.0, 5.4 and 7.9 km h^{-1}), and three replicates. The plots were 40 m in length and 3 m in width. All plots in the field were uniform in terms of physical soil properties. A space between the plots was allowed for turning the tractor into and out of the plot. The plots were treated by conventional tillage. The soil was tilled by a moldboard plow and a disc harrow combined by a float, consecutively. The tillage depth was set at 250 mm considering previous studies carried out by Peterson et al. (1983), Raoufat & Mahmoodieh (2005), Stipesevic et al. (2009) and Topakci et al. (2011). The experiment area had been also processed in the previous year. The initial moisture content of the soil was measured at a soil depth of 20 cm by a TDR 300 device (Time Domain Reflectometry). The moisture content was about 28%.

Figure 1- Single-seed planter (a), Sowing (b) and plant emergences (c)

The practical spacing between plants within a row ranges between 100 and 300 mm for maize as a fraction of inter-row spacing (Heege & Billot 1999). Target seed spacings were determined based on different chain drive ratios of a planter, following the values used in practice. The forward speeds were determined using different gear stages of the tractor. The determination of the forward speed was carried out by measuring time at a distance of 30 meters in the experiment area.

To carry out measures of intra-row spacing (plant spacing), inter-row spacing (deviation from rows) and sowing depth, the sub–plots with lengths of 15 m were established in the four rows at the center of each treatment (Staggenborg et al. 2004). The sub-plots were determined considering the center of the 45 main plots. The measurements of intra-row spacing, deviation from rows and sowing depth were performed on three rows randomly selected from each plot. As a result of these measurements, sowing quality values were determined considering the spacing between plants, deviation from rows of plants, sowing depth, and the variation coefficient values of plant spacing and sowing depth. The seed spacings were analyzed using the performance indices of multiple index, miss index, quality of feed index, and precision which were described by Kachman & Smith (1995).

Intra-row seed distribution was characterized using the mean plant spacing and the coefficient of variation in plant spacing. The intra-row spacing was determined by measurement of 100 consecutive plant spacing in each of the sub-plots, previously also used by Staggenborg et al. (2004) (Figure 2a). The distances between consecutive plants were measured 16 days after sowing for each plot. Using these values of measurement, the mean ($\bar{x}$) spacing between plants, the standard deviation (s) of intra-row spacing of plants and the variation coefficient of intra-row spacing (CV) were computed by Equations 2, 3 and 4, respectively (Kachman & Smith, 1995). In computing the coefficient of variation, those which were double or more than the theoretical spacing between plants from the measured values were not taken into consideration (ISO 1984).

$$\bar{x} = \sum_{i=1}^{N} \frac{x_i}{N} \tag{2}$$

$$s = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \bar{x})^2}{N-1}} \tag{3}$$

$$CV = \frac{s}{\bar{x}} \tag{4}$$

Where; x_i is the spacing between two consecutive plants, and N is the total plant spacings measured.

After sowing, the amounts of deviation from the row axis of plants were measured to determine the inter-row distribution uniformity of the plants. A rope was tied up between two iron bars on each row of the sub-plots to measure the amounts of deviation from the row of the plants. The mean deviation amount was determined by measuring the distance of the plants from the right and left to the rope (Figure 2c). The measurements were carried out for 75 plants randomly selected from the rows for each repetition. However, the plant depth below the soil surface was measured to determine the depth at which the seed dropped. After the plant's germination was completed, it was dug out from the soil. Sowing depth was carried out by measuring the mesocotyl length of the plant reported by Özmerzi & Keskin (1983). The mesocotyl lengths were measured for 75 maize plants in each repetition (Figure 2b). Depending on these measurements, the mean ($\bar{x}$) sowing depths of the plants were calculated. After then, the coefficient of variation of sowing depth was computed by the Equation (4).

Figure 2- Measurements of intra-row spacing (a), sowing depth (b) and deviation from the row (c)

The measurement methods described by Kachman & Smith (1995) were used to evaluate the performance of the single-seed unit. These were multiple index, miss index, quality of feed index and coefficient of precision (MULT, MISS, QFI and PREC, respectively). The multiple index is the spacing percent between consecutive plants in a row, equal to or fewer than half of the target seed spacing (Z) ($MULT \leq 0.5Z$). The miss index is the spacing percent greater than 1.5 times the target seed spacing ($MISS > 1.5Z$). The quality of feed index is the plant spacing percent that is greater than 0.5 times but not greater than 1.5 times the target seed spacing ($0.5Z<QFI\leq 1.5Z$). In the sowing process, the lower the miss and multiple indices are, the better is the sowing quality. The precision coefficient index is the variation coefficient of seed or plant spacing in a row (Kachman & Smith 1995; Singh et al. 2005). The limit values of these indices are shown in Table 2 (Önal 2011; Yazgı & Degirmencioglu, 2014).

Table 2- Performance criteria to evaluate sowing quality in single-seed sowing

QFI (%) [*]	*MISS (%)*	*MULT (%)*	*Performance of planter*
>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 – ≤10.0	≥4.8 – ≤7.7	Moderate
<82.3	>10	>7.7	Insufficient

*QFI; quality of feed index, MISS; miss index, MULT; multiple index

The SPSS package program was used for the statistical analysis of the data. The data were evaluated by analysis of variance (ANOVA) to determine the effects of target seed spacings and tractor forward speeds on the sowing quality and performance of the single-seed planter. Additionally, Duncan multiple comparison (Post-Hoc) tests were used to determine the significant differences and similarities, according to the significance levels of 0.01 and 0.05, between the groups in the experiments.

3. Results and Discussion

From the data analyzed, it was found that the effect of seed spacing on MISS, MULT, QFI, and MSS / TSS ratio was statistically significant and the effect on DTP was also insignificant (Table 3). Each mean seed spacing (MSS) was higher than the target seed spacing (TSS) to which it belonged, whereas, MSS/TSS ratio decreased with increasing target seed spacing. Although the drift and rolling of the seeds in the furrow are generally close to each other in all TSSs, this result can be explained by the decrease of variation in intra-row seed spacing due to the increase of TSS. The MSS closest to the TSS was obtained at the 247 and 309-mm intra-row target seed spacings. However, as TSS decreased, the seed distribution deteriorated. This was because the MSS / TSS ratios became distant from 1.0. There was little MISS (≤8%) and MULT (≤5%) in any seed spacing except the 102 mm target intra-row seed spacing. The sowing performance at the 247 and 309-mm target seed spacings of the vacuum single-seed planter was better than other seed spacings. When the performance of the planter was compared with the limit values of the performance criteria given in Table 2; sowing quality was considered "insufficient" at 102 mm TSS, "moderate" at 147 and 195 mm and "good" at 247 and 309 mm.

PREC decreased as the intra-row plant spacing uniformity increased, with increased target seed spacing. The best PREC was obtained at the 247 and 309-mm spacings. The PREC values at all spacings were <29% (the highest acceptable limit for field trials reported by Kachman & Smith (1995) and considered acceptable precision for the vacuum single-seed planter. Bracy et al. (1999) reported that MISS, MULT, and QFI were affected by variation in seed spacing of a vacuum planter. Seeds at all target seed spacings except 147 mm fell away by about 42-45 mm from the intended point. However, there was no also statistical difference between the deviation from the intended point (34 mm) at 147 mm TSS and other DTP values. Wanjura & Hudspeth (1969) reported that trajectories of falling seed varied and caused the targeted fall point to vary by 25 mm. Bracy et al. (1999) reported that, if the loss in uniformity is at the seed release point or is an effect of seed bounce, the absolute variability would be relatively constant over seed spacing, and precision would be greater at wider spacings.

Table 3- Sowing uniformity in different target seed spacings

TSS (mm)	*Measures⁺*						
	MSS (mm)	*DTP (mm)*	*MSS /TSS*	*MISS (%)*	*MULT (%)*	*QFI (%)*	*PREC (%)*
102	122	45	1.20 a	18.0 a^x	6.8 a	75.3 c	23.1
147	154	34	1.05 b	7.6 b	4.1 b	88.3 b	19.0
195	200	42	1.03 b	7.0 b	3.5 b	89.5 b	16.4
247	252	42	1.02 b	4.9 b	2.2 c	93.0 ab	13.2
309	315	45	1.02 b	4.4 b	1.3 c	94.3 a	12.5
Significance		NS	0.000	0.000**	0.000	0.000	
Significance$_{(FS\ x\ TSS)}$ ^{z}		NS	NS	0.043*	0.023	0.015	

⁺ TSS; target seed spacing, MSS; mean seed spacing, MSS/TSS; the ratio of mean seed spacing to target spacing, DTP; mean deviation from the intended point at intra-row seed spacing, MISS; miss index, MULT; multiple index, QFI; quality of feed index, PREC; precision (variation of the spacings within target range), ^{x} ; In each group, the differences between the means followed by the same letter are insignificant at the 95% probability level, NS ,*,**; Nonsignificant at P≤0.05, significant at P≤0.05 and 0.001, respectively, ^{z} FS x TSS; interaction of tractor forward speed and target seed spacing

All measures of sowing uniformity and precision of the vacuum single-seed planter were affected by the tractor forward speed (Table 4). The DTP increased as the tractor forward speed increased. MISS ranged from 11.5% for the highest forward speed to 5.1% for the smallest forward speed. MULT seed drops were significantly lower at the 4.0 and 5.4 km h^{-1} forward speeds than at the 7.9 km h^{-1} forward speed. QFI was the greatest (>90%) at the 4.0 km h^{-1} forward speed. However, compared to the limit values in Table 2, the performance of the single-seed planter was sufficient for all forward speeds. PREC increased as the tractor forward speed increased. However, PREC decreased with increasing seed spacing at each forward speed (Figure 3). The loss of sowing uniformity of the single-seed planter was probably caused by a combination of target seed spacing and forward speed factors. The forward speed and TSS interaction found statistically significant and supported this result (Table 3 and 4). And also, since the transmission of motion was achieved with a sprocket, narrower seed spacing required a higher plate operational speed. Therefore, the high plate speed required to achieve the narrower seed spacings resulted in higher MISS and MULT. Wanjura & Hudspeth (1969) in determining the seed distribution efficiency of the vacuum wheels, the most different results found at lower vacuum pressures and higher wheel speeds.

Table 4- Sowing uniformity at different tractor forward speeds

Tractor forward speed (km h^{-1})	*Measures⁺*					
	DTP (mm)	*MSS /TSS*	*MISS (%)*	*MULT (%)*	*QFI (%)*	*PREC (%)*
4.0	33 c	1.01 b	5.1 c^x	2.9 b	92 a	15.3
5.4	42 b	1.07 ab	8.5 b	3.3 b	88 b	16.7
7.9	50 a	1.10 a	11.5 a	4.5 a	84 c	18.5
Significance	0.000	0.019*	0.000***	0.002**	0.000	
Significance$_{(FS\ x\ TSS)}$^{z}	NS	NS	0.043	0.023	0.015	

⁺ DTP; mean deviation from the intended point at intra-row seed spacing, MISS; miss index, MULT; multiple index, QFI; quality of feed index, PREC; precision (variation of the spacings within target range), ^{x}; In each group, the differences between the means followed by the same letter are insignificant at the 95% probability level, NS ,*,**, ***; Nonsignificant at P≤0.05, significant at P≤0.05, 0.01 and 0.001, respectively, ^{z} FS x TSS; interaction of tractor forward speed and target seed spacing

The effect of target seed spacing on MET, ERI, and PE was statistically significant (Table 5). However, the MET value obtained from only the largest TSS was significantly different from the others, while it was significant the difference between any two values of ERI depending on the TSS. As an expected result, the ERI decreased as the target seed spacing increased. There were no significant differences between 147 to 195 mm, between 147 to 247 mm and between 247 to 309 mm, while the values of PE obtained from the 102 mm seed spacing were significantly different from the others. In general, PE increased as TSS increased. The increase rate was about 35%. The highest emergence percentage (94.5%) depending on target intra-row seed spacing in the study was obtained from the 309 mm seed spacing. PE values can be influenced by the variation of sowing depth and miss index. Kuş (2014) reported that with the increase of deviation from the row, the seeds remained at the furrow edge without dropped to the targeted depth and disrupted the sowing depth. In this case, the seed may not be in contact with moisture and the germination rate may decrease. However, sowing depth values in the current study were not statistically different from each other. Therefore, the increase of PE values depending on the increase of TSS values was related to the decrease of the misses in these spacings. This means that the lower plate peripheral speeds required to achieve the greater seed spacings could have resulted in fewer misses in the rate of holding of seeds to the holes of the single-seed metering plate. However, the results obtained from this study on the misses were similar to those of the study conducted by Barut & Özmerzi (2004).

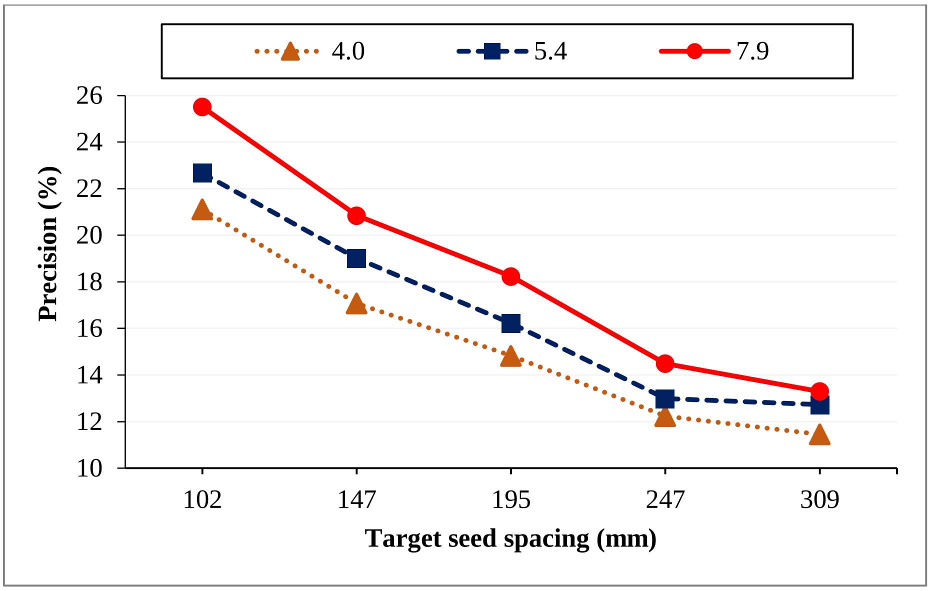

Figure 3- The precision of intra-row plant spacing depending on forward speed

Table 5- Results related to plant emergence depending on target seed spacings

TSS (mm)	*Measures*⁺					
	CV (%)	*Mean Sowing Depth (mm)*	*Mean deviation from row (mm)*	*MET (%)*	*ERI (%)*	*PE (%)*
102	12.0	52.1	9.1 a[x]	13.7 a	0.62 a	70.2 d
147	12.2	53.2	8.5 a	13.6 a	0.48 b	87.6 bc
195	12.2	52.3	7.6 ab	13.7 a	0.36 c	84.8 c
247	12.1	54.5	6.8 b	13.7 a	0.29 d	92.3 ab
309	12.6	53.2	6.7 b	13.4 b	0.23 e	94.5 a
Significance		NS	0.011*	0.000**	0.000	0.000
Significance$_{(FS\ x\ TSS)}$ [z]		NS	NS	0.000	NS	0.033

[+] TSS; target seed spacing, CV; coefficient of variation of sowing depth, MET; mean emergence time, ERI; emergence rate index, PE; percent emergence, [x]; In each group, the differences between the means followed by the same letter are insignificant at the 95% probability level, NS, *,**,***; Nonsignificant at P≤0.05, significant at P≤0.05 and 0.001, respectively, [z] FS x TSS; interaction of tractor forward speed and target seed spacing

The sowing depth, deviation from the row (inter-row spacing), MET, and PE were affected by increasing the tractor forward speed, while ERI was not affected (Table 6). With the increase in the forward speed, the mean sowing depth decreased and the variation coefficient of the sowing depth increased. However, mean sowing depth values obtained only at 4.0 and 7.9 km h^{-1} forward speeds were statistically different from each other. The deviation from the row of the plants also increased significantly as increased the forward speed. The deviation values were statistically different from each other. The mean deviation from the row of the plants at the smallest forward speed was 4.4 mm, while this value increased by 240% by doubling the forward speed. According to these results, the increase in the forward speed increased the displacement of seeds in the furrow. The displacement occurred as bouncing or dragging. This situation caused the seed to remain on the edge of furrow without falling to the target depth. It was concluded that the seed, which did not fall to the target depth, both increased the amount of deviation in plant germination and decreased the sowing depth.

The effect of the 7.9 km h^{-1} forward speed on MET and PE was significant in comparison to the 4.0 and 5.4 km h^{-1} forward speeds. However, there was no significant difference between 4.0 and 5.4 km h^{-1}. Increasing forward speed decreased the MET about 2.2% and PE values 10.0% also. It is thought that the decrease in PE with the increase in the forward speed was due to the increase of MISS and the decrease of ERI. It was assumed that the decrease in the MET with increasing of the forward speed was also caused by decreasing the mean sowing depth. Additionally, the effect of the forward speed on ERI was insignificant.

Table 6- Results related to plant emergence depending on tractor forward speeds

			Measures+			
Tractor forward speed (km h⁻¹)	*CV (%)*	*Mean Sowing Depth (mm)*	*Mean deviation from the row (mm)*	*MET (%)*	*ERI (%)*	*PE (%)*
4.0	11.5	55.0 b	4.4 c[x]	3.7 a	0.40	90.0 a
5.4	12.3	53.0 ab	8.2 b	3.6 a	0.39	86.8 a
7.9	12.8	51.2 a	10.6 a	3.4 b	0.38	81.0 b
Significance		0.003**	0.000***	0.000	NS	0.001
Significance$_{(FS \times TSS)}$ [z]		NS	NS	0.000	NS	0.033*

+CV; coefficient of variation of sowing depth, MET; mean emergence time, ERI; emergence rate index, PE; percent emergence, [x] In each group, the differences between the means followed by the same letter are insignificant at the 95% probability level, NS ,*,**, ***; Nonsignificant at P≤0.05, significant at P≤0.05, 0.01 and 0.001, respectively, [z] FS x TSS: interaction of tractor forward speed and target seed spacing.

4. Conclusions

The seed distribution uniformity of the vacuum single-seed planter was affected by both the seed spacing and the forward speed of the tractor. The uniformity (expressed as a percentage of target seed spacing) increased by increasing the seed spacing. Nonuniformity probably occurred due to the higher plate speeds and decreased seed spacing. However, it was assumed to occur as a result of the combination of tractor forward speed and seed spacing. Because the effect of forward speed and seed spacing interaction on MISS, MULT, and QFI was found significant.

Improvement of seed distribution, in addition to dropping the seed to the intended point in the intra-row spacing, it is possible by moving the seed down in the furrow and dropping to the target point. Bouncing and rolling in the furrow of the seed disrupts the seed spacing uniformity, and failure to fall to the bottom of the furrow also disrupts the sowing depth uniformity. The performance of the planter was sufficient for all of the others except 102 mm TSS. However, although increasing the forward speed of the tractor reduces planter performance, the primary detriment of higher tractor forward speeds is the risk of increasing the amount of deviation from the rows of plants and decreasing the seed depth uniformity. These results were supported in the study by the variation coefficient and the data of deviation from rows. This shows that the target seed spacing and tractor forward speed must be correctly selected to achieve desired planter performance.

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