American-Eurasian J. Agric. & Environ. Sci., 10 (5): 821-828, 2011
ISSN 1818-6769

Performance Evaluation of a Cup-Belt Potato Planter at Different Operation Conditions and Tuber Shapes

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Abstract: A field study was conducted to investigate the performance of an auto-feed cup-belt potato planter under different operation conditions with different tuber shapes. The operation conditions included in the study encompassed three forward ground speeds (1.8, 2.25 and 3.0 km/h), four ratios of forward speed to feeding mechanism speed (1.22, 1.39, 1.78 and 2.00) and two feeding gate heights (80 and 100 mm). The whole and cut tubers were utilized to provide different shapes of the tubers that relatively had the same size considering the tuber longest dimension. The performance of the planter was evaluated based on the coefficient of variation (CV), the multiple index (MULTI), the miss index (MISI), the quality of feed index (QFI) and the precision index (PREC). Results of the study revealed that the tuber shape was statistically found to have a significant effect on the CV and the QFI only. For whole and cut tubers, the CV and the MISI were proportional to the forward speed; however, inversely proportional to the gate height and speed ratio. The highest CV and MISI values of 68.4% and 16.42%, respectively, were observed for cut tubers at 3.0 km/h, 1.22 and 80 mm for ground speed, speed ratio and gate height, respectively. On the other hand, the QFI, in case of the whole and cut tubers, as well as MULTI, for cut tubers, were found to be, on the average, inversely proportional to the ground speed and proportional to the speed ratio and gate height. Lower MULTI values were found to generally associate with the cut tubers. The maximum MULTI of 7.76% was observed in the whole tuber data set at 1.8 km/h, 2.00 and 100 mm for ground speed, speed ratio and gate height, respectively. However, the maximum QFI value of 91.66% was associated with the cut tubers at 1.8, 1.78 and 100 mm for ground speed, speed ratio and gate height, respectively. In addition to the tuber shape, gate height and speed ratio showed a negligible effect on the CV of the accepted tuber spacing (PREC). The PREC was found to be proportional to the ground speed, where the value of this index increased from 14.89 to 19.81% as the ground speed increased from 1.8 to 3.0 km/h for the whole tubers at 1.22 and 80 mm for speed ratio and gate height, respectively.

Key words: Potato planter · Operation conditions · Performance evaluation · Tuber shape · Multiple index · Miss index · Quality of feed index · Precision index

INTRODUCTION

Potato is viewed as one of the most important vegetable crops in the world. In Saudi Arabia, a potato production development program was established in 1974 to study the possibilities of increasing the potato cultivated area and explore the problems that may hinder the spread of its cultivation. In 2010, the potato plantation reached over 17,665 ha in Saudi Arabia, with an annual production of about 444,138 tons [1]. Potato planting is considered as a very crucial and critical operation because it directly affects the yield and the farming cost, as the price of potato tubers mounts to about 60% of the total potato production cost [2].

The performance of several potato planters has been investigated by many researches and studies. Ghonimy and Rostom [2] found that potato yield reached up to 20.95 t/ha when a cup-belt prototype planter was used compared to 19.52 t/ha with a cup-chain prototype planter. They also stated that the automatic cup-feeding system exhibited the best performance compared to the automatic chain and the semi-automatic tray feeding systems. In addition, they concluded that higher coefficient of variation was found with auto-feed cup planter compared

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to planters with either single- or multi-feed belts. Wahby *et al.* [3] observed that a tested cup-feeding planter produced a lower in-row spacing compared to semi-automatic and finger-feed mechanism planters. Sieczka *et al.* [4] stated that the speed of planting of up to 6.7 km/h had no consistent effect on the average spacing or the uniformity of seed spacing distribution. Altuntas [5] reported that seed tuber distribution pattern in the row was disturbed when the tuber size and machine forward speed increased. In addition, the usage of cut tubers produced lower coefficient of variation of spacing and miss ratio compared to those found with the usage of whole tubers. Forward speed and release point on the metering mechanism were reported to affect tuber spacing distribution in the furrow [6]. Khairy [7] concluded that an increase in the forward speed caused an increase in the mean tuber distance in sandy soil, especially with forward speeds of higher than 3.6 km/h. Adjusting the planting speed coupled with the use of uniform shape seeds greatly contributed into the improvement of a potato planter performance [8]. The forward speed of a potato planter was observed by Wahby *et al.* [3] to have a significant effect on in-row spacing of potato tubers. Bader [9] related the potato yield to the forward speed of an automatic cup potato planter, where the highest yield of 7.05 t/ha was obtained when the planter was operated at a forward speed of 3.0 km/h. El-Sahrigi *et al.* [10] reported that planting cut tubers using cup cell at a metering belt speed of 0.6 m/s and a drop height of 10 cm produced a high seed space uniformity of 97.99%. On the contrary, a low space uniformity of 58.7% was achieved when planting whole seed tubers utilizing a spoon shaped cell at a metering speed of 0.8 m/s and a drop height of 30 cm. The planting speed was found by Ismail [11] to be proportional to the percentage of missed tubers and inversely proportional to the percentage of tuber doubles and spacing uniformity.

There are differences in size and shape of seed tubers not only among varieties, but also within a single variety [12]. Misener [13] found that the best uniformity of tuber spaces for different potato planters was recorded with whole tubers. To achieve optimum planter performance, Kepener *et al.* [14] recommended the selection of proper size and shape tubers that best fit a given shape of cell. They also reported that smooth tubers approaching spherical tuber shape are the best candidates to produce a high planting precision. Gruczek [15] observed that a higher planting precision can be achieved using exactly graded medium shaped tubers (4-5 cm) at a planter forward speed of 3.0 km/h. On the other hand, Buitenwerf *et al.* [16] showed that the regular shape of the tubers did not necessarily result in a higher planting accuracy. In Washington, 91% of potato fields were planted with cut seed pieces; however, only 9% were planted with whole (uncut) seed tubers [17]. The mean spacing and the standard deviation of the seed spacing are useful but do not thoroughly characterize the distribution of seed spacing for single seed planters. In addition to the standard deviation of the seed spacing, the multiple index, the miss index, the quality of feed index and the precision index should be all considered in the performance evaluation of a single seed planter [18].

In the Kingdom of Saudi Arabia, the cup-belt prototype is the most commonly used machine for potato planting. However, a lack of a thorough knowledge exists in the details of the factors affecting the operation efficiency of this machine under different operation conditions in the Kingdom. Therefore, the main goal of this study was to investigate the effects of forward speed, speed ratio (forward speed/feeding mechanism speed), feeding gate height and tuber shape on the performance of a cup-belt potato planter.

MATERIALS AND METHODS

The field experiments related to this study were conducted on a small size field (2000 m^2) at the educational farm of the College of Food and Agricultural Sciences, King Saud University, Riyadh, Saudi Arabia. The field soil was mainly sandy loam with a bulk density ranging from 1.60 to 1.65 g/cm^3. The field was prepared using moldboard plow, disc harrow and a roller. Experiments were conducted under three forward speeds (1.8, 2.25 and 3.0 km/h), four ratios of forward speed to feeding mechanism speed (1.22, 1.39, 1.78 and 2.00), two feeding gate heights (80 and 100 mm) and two tuber shapes (whole and cut). Different combinations of treatments were repeated three times (replicates), which required 144 test runs. Each test run was conducted on a course of 15 m. Factorial completely randomized design was adopted for the field experiment layout.

An automatic cup-belt potato planter, Fig. 1 (Model: TEKYATAGANLI, Turkey) mounted on a 74 kW Volvo tractor was the planter machine to be tested. The planter was equipped with a shoe type furrow opener and was specified to cover two rows at 64 cm spacing with a total machine weight of 550 kg. The rotational speed of the belt carrying the cups was adjustable and dependent on the selected speed ratio.

Fig. 1: Tested potato planter.

On the average, the dimensions of the used potato tubers (Hermes Variety) were 65±6 mm in length, 56±7 mm in width and 48±5 mm in thickness. To provide different shapes of relatively the same size, some tubers were cut into sizes approximately equal to the size of the whole ones considering the longest dimension. The size of the tubers, whole and cut, was maintained in the range of 35 to 55 mm, which was the range of tuber size recommended to be used with cup-belt potato planters [19].

Seed spacing measurements were performed at 5 m length on both rows in each plot. Soil was carefully removed from above the seeds and seed spacing was then measured using a measuring tape. Corresponding to the test speed ratios of 1.22, 1.39, 1.78 and 2.00, the theoretical seed tuber spacings were 20.0, 23.0, 29.0 and 33.5 cm, respectively.

Seed tuber spacing uniformity was evaluated in terms of the Coefficient of Variation (CV), multiple index (MULTI), miss index (MISI), quality of feed index (QFI) and precision index (PREC). These test criteria were selected according to the plant spacing measures of accuracy recommended by Kachman and Smith [18].

Multiple index (MULTI): Is the percentage of spacing that are less than or equal to half the theoretical spacing. The MULTI was calculated as follows:

$$MULTI,\% = \frac{N_1 \times 100}{N} \qquad (1)$$

Where:
N_1 is the number of spacing less or equal to half the theoretical spacing.
N is the total number of spacing.

Miss index (MISI): Is the percentage of spacing greater than 1.5 times the theoretical spacing. The MISI was calculated as follows:

$$MISI,\% = \frac{N_2 \times 100}{N} \qquad (2)$$

Where:
N_2 is the number of spacing greater than 1.5 times the theoretical spacing.

Quality of feed index (QFI): Is the percentage of spacing values that are more than half but not more than 1.5 times the theoretical spacing. This is a measure of how close the actual spacing value is to the theoretical spacing value. The QFI was calculated as follows:

$$QFI,\% = 100 - (MULTI + MISI) \qquad (3)$$

Precision index (PREC): Is a measure of the variability in spacing between seeds due to the drop of more than one seed at one time and no seed at another time. The precision is estimated by calculating the coefficient of variation of the actual seed spacing from accepted seed spacing. The distance between two adjacent tubers is acceptable as long as it is more than half and less than 1.5 the theoretical spacing [18]. Therefore, smaller values of PREC indicate better performance than larger ones.

RESULTS AND DISCUSSIONS

Coefficient of Variation (CV): The Coefficient of Variation (CV) of tuber spacing at the different operation conditions and tuber shapes was illustrated in Fig. 2.

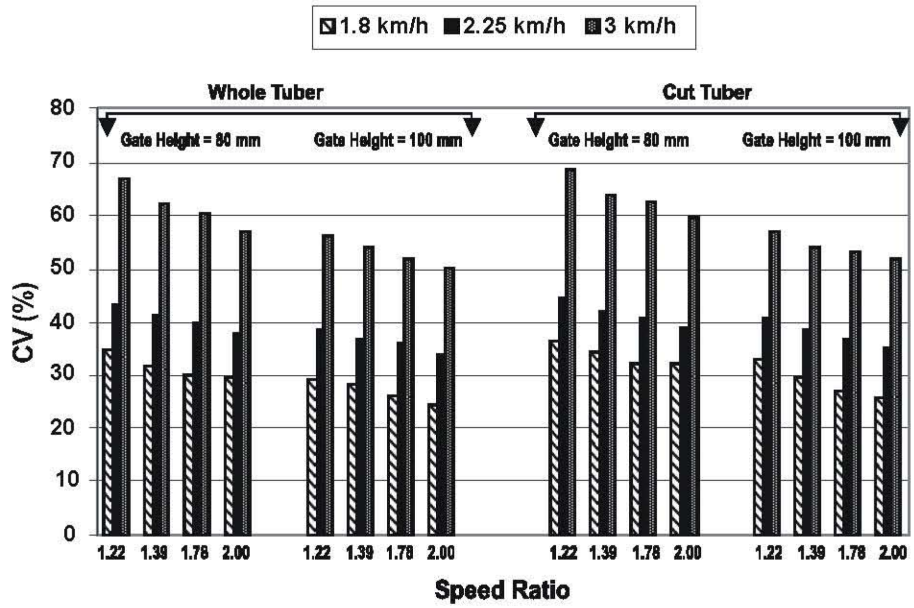

Fig. 2: CV of tuber spacing as affected by operation variables.

The statistical analysis indicated that the value of the CV was significantly affected by forward speed, speed ratio, feeding gate height and shape of tubers ($P< 0.01$). For the whole and cut tubers, the general trend shown in Fig. 2 suggests that the CV was proportional to the forward speed and inversely proportional to the speed ratio and feeding gate height. The highest CV values of 66.96% and 68.40% were observed for the whole and cut tubers, respectively, at a forward speed of 3.0 km/h, a speed ratio of 1.22 and 80 mm gate height. For whole and cut tubers, the lowest CV values of 24.39% and 25.66%, respectively, were found at a forward speed of 1.8 km/h, a speed ratio of 2.00 and a gate height of 100 mm. Referring to all of the test parameters, the CV of tuber spacing for the whole tubers was observed to be lower than that for the cut tubers. Therefore, the performance of the tested cup-belt potato planter can be said to be better when the whole tubers were used rather than using cut tubers.

For potato planters, the recommended CV for the acceptable seed tuber spacing uniformity should be less than 40% [20]. Therefore, the accepted CV values were observed when the cup-belt potato planter was operated at low forward speeds (≤ 2.25 km/h).

Multiple Index (MULTI): The effect of forward speed, speed ratio and feeding gate height as well as tuber shape on the MULTI is shown in Fig. 3. Results of the statistical analysis indicated that the forward speed and speed ratio effects on MULTI were statistically significant ($P< 0.01$). The general trend illustrated in Fig. 3 indicated that the MULTI, for whole and cut tubers, was proportional to the speed ratio; however, inversely proportional to the forward speed. For both gate heights and at nearly all speed ratios, lower MULTI values were observed, for the whole tubers, at a ground speed of 2.25 km/h. At a speed ratio of 1.78 and 100 mm feeding gate height, an increase in the forward speed from 1.8 to 3.0 km/h caused a drop in MULTI from 5.82% to 3.34% and from 4.78% to 3.21% for whole and cut tubers, respectively. This was attributed to the fact that, at low forward speed, some cups may have the chance to carry more than one tuber. In addition, higher values of MULTI were observed with whole tubers, as the uniform shape of the tubers could enhance the fitting of multiple units in one cup. The highest MULTI values of 7.76% and 5.55% for whole and cut tubers, respectively, were observed at a forward speed of 1.8 km/h, a speed ratio of 2.00 and a feeding gate height of 100 mm. Considering the MULTI measure, using cut tubers would result in a slightly better performance of the planter compared to its performance with whole tubers.

Miss Index (MISI): The results of MISI as affected by the forward speed, speed ratio and feeding gate height for whole and cut tubers were presented in Fig. 4. The statistical analysis indicated that the forward speed, height of feeding gate and speed ratio were significant factors affecting the MISI ($P< 0.01$). On the contrary, the tuber shape had no significant effects on the MISI. It was observed that the increase in the forward speed caused an increase in the percentage of missed tubers at all other

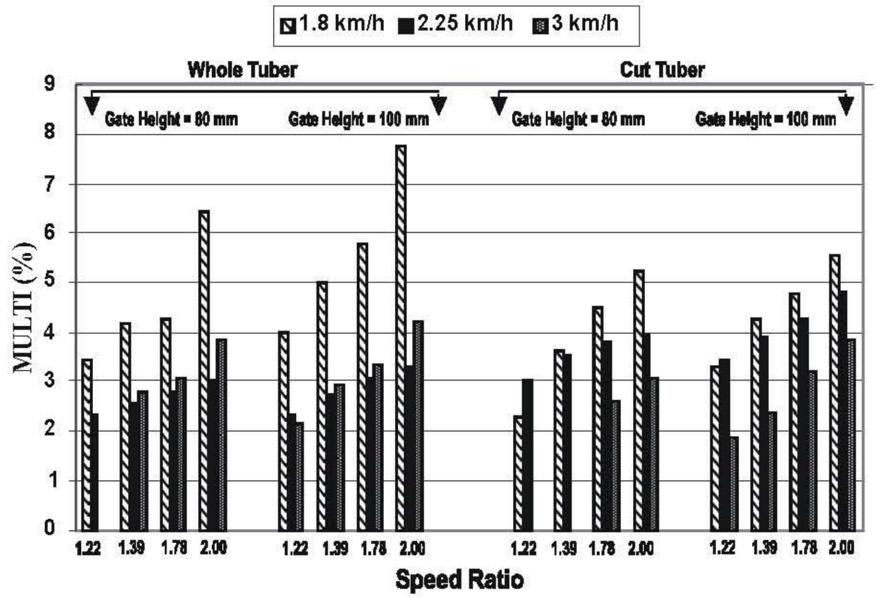

Fig. 3: Effect of the operation variables on the multiple index.

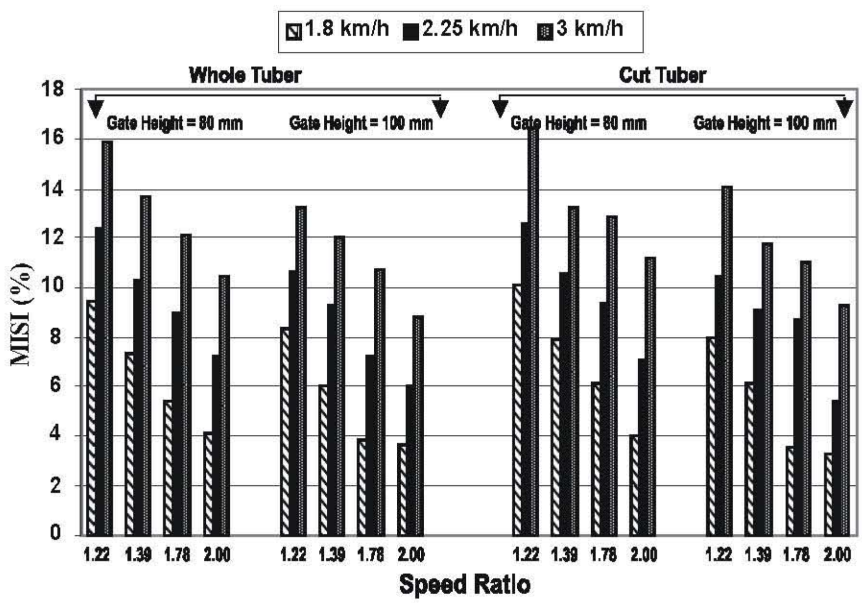

Fig. 4: Effect of the operation variables on the miss index.

operating variables. That was attributed to the increase of machine vibration as the forward speed increased causing some tubers to fall from the cups back into the hopper. The MISI was found to decrease with increasing speed ratio and gate height. The highest values of the MISI of 15.98% and 16.42% for whole and cut tubers, respectively, were observed at the forward speed of 3.0 km/h, the speed ratio of 1.22 and the gate height of 80 mm. The lowest values, however, of 3.68% and 3.21% for whole and cut tubers, respectively, were recorded at the forward speed of 1.8 km/h, the speed ratio of 2.00 and the gate height of 100 mm. Based on the percentage of missed tubers, the performance of the tested cup-belt planter was a little better with the whole tubers than with the cut ones.

Quality of Feed Index (QFI): The effects of the forward speed, speed ratio and feeding gate height on the QFI for whole and cut tubers were illustrated in Fig. 5. Results from statistical analysis indicated that the forward speed, speed ratio, feeding gate height and tuber shape effects

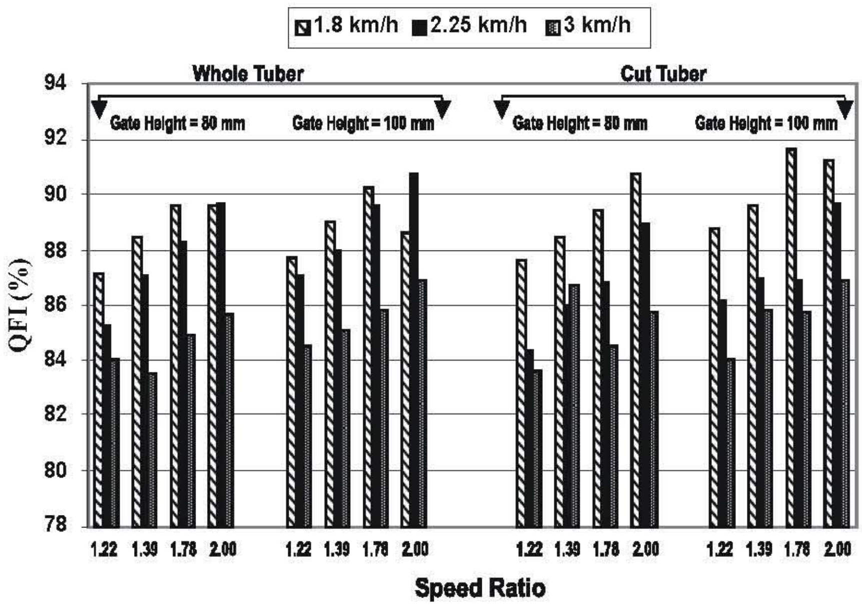

Fig. 5: Effect of the operation variables on the quality of feed index.

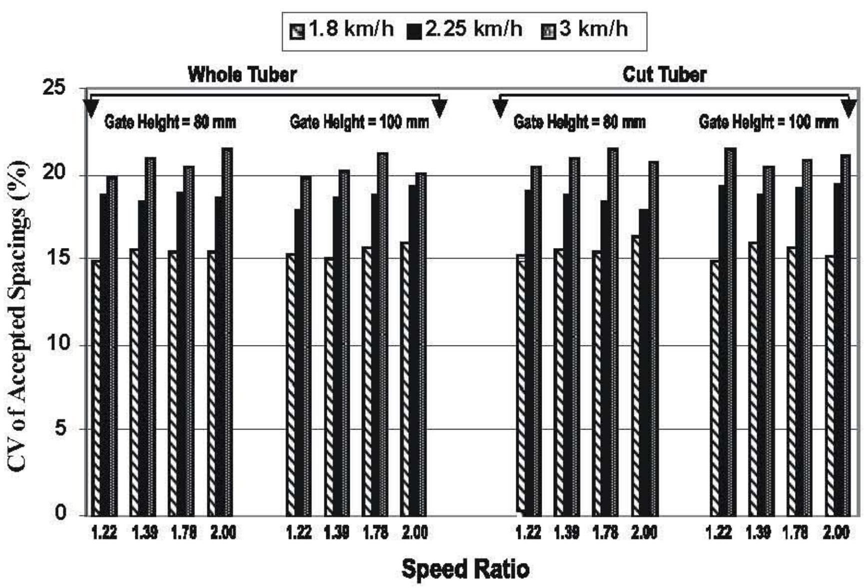

Fig. 6: Effect of the operation variables on the precision index.

on the QFI were statistically significant (P< 0.01). As a general trend shown in Fig. 5, the values of QFI were inversely proportional to the forward speed and proportional to the gate height and speed ratio for both, whole and cut tubers. For whole tubers, the highest value of QFI was 90.76% at the forward speed of 2.25 km/h, the speed ratio of 2.00 and the gate height of 100 mm. However, for cut tubers, the highest value of 91.66% was observed at the forward speed of 1.8 km/h, the speed ratio of 1.78 and the gate height of 100 mm. Except for the speed ratio of 1.39 and a gate height of 80 mm for cut tubers, the lowest values of QFI were recorded at the forward speed of 3.0 km/h at all levels of other test parameters. Operating at a lower forward speed and higher speed ratio resulted in a better performance represented by higher values of QFI.

Precision Index (PREC): The PREC, represented by the CV of the accepted seed tuber spacing, as affected by the forward speed, speed ratio and feeding gate height for whole and cut tubers is shown in Fig. 6. Statistical analysis results indicated that, among the test parameters, only the forward speed significantly affected the PREC ($P< 0.01$). The CV of the accepted spacing (PREC) was found to be proportional to the forward speed. At all levels of other test parameters, the most uniform seed tuber spacing was observed at the lowest forward speed of 1.8 km/h. Therefore, the performance of the tested planter can be improved by operating it at lower forward speeds, where lower CV of accepted spacing (lower PREC) is achieved (Fig. 6).

CONCLUSION

A cup-belt potato planter was field tested at different operation conditions and with different tuber shapes. The specific conclusions of the study include the following:

- The increase in the forward speed caused an increase in the CV, MISI and PREC (CV of the accepted seed tuber spacing) and a decrease in the MULTI and QFI.
- For whole and cut tubers and at both gate heights, better planter performance (lower CV values) was achieved at higher speed ratios (high values of seed spacing) and lower ground speeds. The gate height of 100 mm produced lower CV values.
- Among all other test parameters, the PREC was affected only by the machine forward speed.
- Statistical analysis indicated that the tuber shape produced a significant effect on the CV and the QFI. In general, the shape of the tubers exhibited a slight effect on the remaining indexes, hence on the performance of the tested planter.

ACKNOWLEDGMENT

This project was supported by King Saud University, Deanship of Scientific Research, College of Food and Agriculture Sciences, Research Center.

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