

AFFECTING EACH OF RIDGER FURROW OPENER PARAMETERS AND PLANTING METHODS ON WATER USE EFFICIENCY AND SUGAR BEET YIELD

S. A. MAREY^{1,2}

¹*King Saud University, Sciences, Technology and Innovation Unit, Rector's for Graduate Studies & Scientific Research, Riyadh 11451, Saudi Arabia*

²*Agricultural Engineering Research Institute (AENRI), ARC, Giza, Egypt*

Abstract

MAREY, S. A., 2015. Affecting each of ridger furrow opener parameters and planting methods on water use efficiency and sugar beet yield. *Bulg. J. Agric. Sci.*, 21: 1304–1311

Design parameters of the ridger furrow opener directly affecting the furrow profile characteristics and the amount of applied water. Furrow-bed irrigation technique is usually used for water conservation, efficient fertilizer use and many other benefits. This study is to evaluate the impact of design parameters of the ridger furrow opener and planting methods on sugar beet yield and water use efficiency. Therefore, field experiments are conducted to (i) investigate the effects of share rake angles (20°, 25° and 30°), opener wing angles (35° and 45°) and wing shape configurations (straight and curved) on the furrow profile characteristics, transverse scattering, draft force, and (ii) evaluate planting methods (i.e. ridges with 50 cm rows spacing and pair of rows on bed with 30, 35 and 40 cm rows spacing), the wing shape and angles on the emergence, sugar percentage, root and sugar yield, applied water and water use efficiency. The results showed that the curved shape and the wing angle of 45° produced wider furrows than those produced by the straight shape and 35° wing angle. Minimum transverse scattering is associated with the curved wing, wing angle of 35° and share rake angle of 20°. Increasing the share rake and wing angles increased the required draft force. The highest average values of root and sugar yields have been achieved at beet planting in beds with 30 cm rows spacing flowed by beds with 35 and 40 cm rows spacing, respectively. The lowest value of the water use efficiency is achieved at planting on ridges compared to the other planting methods. The maximum emergence percentage, root and sugar yields, sugar percentage and water use efficiency are associated with a wing angle of 45° and the curved wing shape.

Key words: sugar beet; power requirements; root yield; furrow profile; applied water, bed planting, water applied

Introduction

Optimum population of plants on well-spaced rows has been found to produce good yield and quality in most of the arable crops. Good plant stand gives a complete occupation of the available space; and plant can receive light from all sides, i.e., complete light interception, (Zahoor et al., 2010). Scott and Jaggard (1978) found close relationship between solar radiation intercepted by a sugar beet crop and the yield. Egypt is considered as a country of water scarcity due to the low precipitation, high evaporation and temporal and spatial distribution of rainfall; and the land resources are limited

(Abo-Shady et al., 2010). In such regions, bed planting is one of the most renowned techniques used for saving water, efficient fertilizer use and many other benefits. Bed planting technique has been tested for several crops; it significantly improved the relationship of soil-water, nutrient, and the root growth of plants (Ren et al., 2013). Chaudhry et al. (1994) reported that furrow bed system saved about 25-53% of water and increased the yield of cotton crop by 6-52% as compared to basin system. In addition to the water saving, bed planting also improves the efficiency of fertilizer, reduces weed infestation and reduces seed rate without sacrificing yield. Irrigation water consumption in ridge and furrow planting

depends mainly on the wide of furrow and the furrow profile as well (Hu et al., 1997). The design parameters of the furrow opener such as the share rake angle and wing shape and angle strongly affect the shape of the ridge profile. In addition, one of the most important parameters strongly affect the required draft force is the share rake angle. For better penetration of soil, the rake angle of the share should be $\geq 25^\circ$ to the ground (Abd El-Tawwab et al., 2007). However, Zhang and Araya (2001) reported that the draft force of a mold board plough had increased steeply when rake angle was more than 30° . The rake angle of the furrow opener that gave a minimum specific draft for a lateritic sandy clay loam soil was 28° (Mathur and Pandey, 1992); while, Vashney and Patel (1988) reported that the minimum draft required for a cultivator shovel at different levels of soil moisture in a light soil was associated with 30° share rake angle. Varshney et al. (2006) investigated the effect of share rake angle for mould board plows and sweep on draft force under clay soil. They reported that the minimum specific draft was found with rake angles ranged from 25° to 29° for the sweep plow at soil moisture content of 21%. The sweep angle also affects the draft requirement and the furrow profile; increasing share sweep angle increased the draft force (Fielke, 1988). In Egypt, sugar beet crop is grown on raised planting beds to facilitate furrow

irrigation. The common arrangement of rows is a single row centered on beds 60 cm apart.

Therefore, the objectives of the current study were to: (i) Study the effect of some design parameters of furrow openers (e.g., share rake angle, wing angle and wing shape) on the furrow profile, seeds transverse scattering, and draft force requirements. (ii) Study the effect of planting methods (i.e., ridges and bed planting with different row-row spaces) on emergency, sugar parentage, root and sugar yield and water use efficiency.

Materials and Methods

Experimental design

Two field experiments are conducted in a private farm at Kafer Elsheikh governorate, Egypt, ($31^\circ 8' N$, $30^\circ 41' E$) in 1.75 hectare during agricultural season of 2011/2012. The field soil was mainly clay loam with average bulk density 1.31 and 1.44 g.cm^{-3} . Soil was prepared using chisel plough (7 shanks) two passes, disc harrow, and LASER leveling with 0.5% slop. The first experiment is to evaluate the impact of some design parameters of furrow openers in a ridging unit on furrow profile, seeds transverse scattering, and power requirements. These parameters are the share rake angles (20° , 25° , and 30°), wing angle (35° and 45°), and wing shape (straight and curved) (Figure 1). The angels of penetration were varied by inserting wedges between rear gang of ridger frame and upper part of shank. Experimental treatments are laid out in split-split plot design with three rake angles as the main treatments, two opener's wing angles as the sub treatment and two wing shapes as the sub-sub treatment. These experiments were conducted in ridges of 50 cm apart with the planter forward speed of 3.5 km h^{-1} and 15 cm ridging depth.

The second experiments were to evaluate four planting methods (ridges with 50 cm row space and beds having pair of rows on bed with 30, 35 and 40 cm distance between rows (Figure 2), two wing shapes (straight and curved), and two wing angles (35° and 45°). This is to evaluate these parameters on emergence, sugar percentage, root and sugar yields, applied water and water use efficiency. The experimental

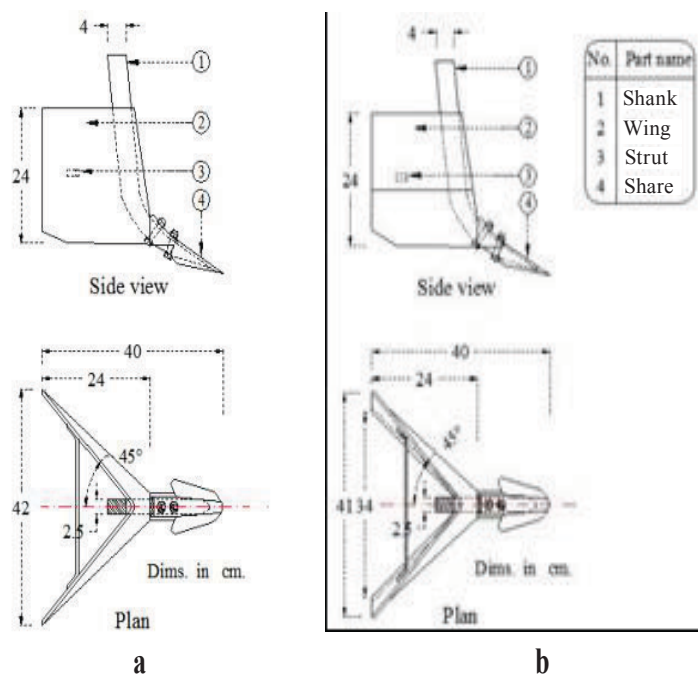


Fig. 1. Straight opener wing (a) and curved wing (b)

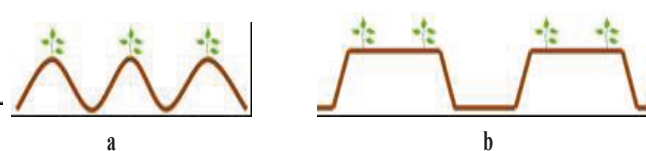


Fig. 2. Planting sugar beet on ridges (a) and beds (b)

plots were arranged in split-split plot design. The main plot was for the planting methods, the sub plot was for the wing angles and sub-sub plot was for the wing shape. In all experiments, different combinations of treatments were repeated three times (replicates). In the available conventional planters (e.g., GasparDO Seminatrici SPA (Figure 2a), the minimum distance between each two furrow openers is 60 cm. It is well known that reducing the distances between rows would increase the number of plants per unit area. Accordingly, GasparDO Seminatrici SPA planter was modified at the workshop of Delta sugar Co., (Kafer Elsheikh Factory). Several pre trails have been made to adjust a relatively low distance between the ridges of the planter. The minimum distance obtained is 50 cm.

This modification accomplished by fixing a steel beam (i.e., toolbar, 15 x 15 cm cross sectional area, and 0.7 cm thickness) in the front of the planter (Figure 2b). The ridger furrow openers were attached with this beam instead of the main planter frame in the conventional design. Three square tubes, each with cross sectional area of 8 x 8 cm and 0.6 cm thick, are welded and used to fix the hitch points with the beam (Figure 3b). The modified toolbar can be simply fixed to the planter and makes it available to be used for other crops by separating this unit when needed. In addition, curved wing shape was designed fabricated (Figure 1b) to compare with the conventional wing shape (i.e., straight). The arrangement of rows has been done by removing the ridger furrow opener between each two adjacent planting units. Seeds of sugar beet cultivar (MultigerM Montbuanco) are sowed in 13th September 2011 and the crop harvesting has done in 17th April 2012. Fertilizers were added according to the technical recommendation of the Ministry of Agriculture at N rates of 214 kg, 36 kg P₂O₅ and 238 kg K₂SO₄ per hectare. Nitrogen fertilizer was applied in two equal doses before the first and the second irrigations. Phosphorus broadcasted

before planting as Super Phosphate (15.5% P₂O₅). Potassium applied by topdressing in one application of Potassium Sulphate (48% K₂O) before the first irrigation. Furrow irrigation of sugar beet is used and controlled by the siphon method FAO (1974) and irrigation water was applied every 21 days (Irrigation intervals).

Experimental measurements

During executing these experiments the following indicators have been measured:

(i) Furrow profile characteristics are measured using a profile meter that was designed according to Römken et al. (1986) and Wagner and Yi ming (1991). This meter is a row of probes holed in a horizontal rectangular steel bar, spaced at 5 cm intervals; the props designed to slide up and down through the holes of the bar to make their tips just to touch the soil surface. Accordingly, the pines positions were recorded manually, and then characteristics of each furrow profile were determined.

(ii) The transverse scattering of seeds placement is determined statistically by estimating the standard deviation of the distances between each seed and the row centerline. Thus, the slandered deviation (Std, cm) is given by:

$$Std = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (X_i - X')^2}, \quad (1)$$

where X is the distance between the seed and the row centerline in cm, n is the number of observations and x is the mean distance.

(iii) Draft requirements:

a. Determination of rolling resistance RR:

Rolling resistance of both operating tractor and planter in lifted position was determined (at no load) by dynamometer method at planting speed. Ten reading were recorded in each case and the mathematical mean was calculated.

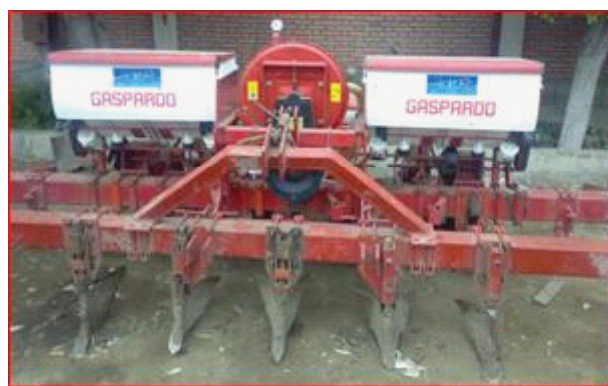


Fig. 3. Photo of the planter before modification (a) and after modification (b)

b. Determination of the net draft:

The hydraulic dynamometer was fixed between the 1st tractor and the 2nd tractor during different treatments, when recording the pull required for moving the operating tractor and the planter in planting operation position. The net draft (D) is determined according the following formula:

$$D = P - RR, \quad (2)$$

where: P = drawbar pull, kN;

(iv) The emergence percentage ($G_{p,\%}$) is recorded by accounting the number of plants (P) and the number of delivered seeds (S) for each treatment. This performed for the 2 central rows of each treatment and after 25 days from planting. Accordingly, G_p was calculated as:

$$G_p = P/S \times 100 \quad (3)$$

(v) The amount of applied water (IW, $m^3 ha^{-1}$) for each treatment was measured by using a siphon tubes. Siphon tubes, 2 m length and 50 mm diameter, were calibrated by checking the time required to fill a container of known volume to calculate the flow rate of the tubes. The inflow rate was constant during the irrigation periods of the treatments. Water use efficiency (WUE, $Mg m^{-3}$) was calculated according to Jensen (1983) as:

$$WUE = Y/IW, \quad (4)$$

where Y is the root yield, in $Mg ha^{-1}$, was estimated for the central three ridges of each plot .

(vi) The sugar yield ($Mg ha^{-1}$) estimated as the percentage of sucrose multiplied by root yield (Y). The percentage of sucrose estimated for the fresh harvested roots using an Au-

tomatic Sugar Polarimeter as described by McGinnus, (1982) at Delta Sugar Co. Ltd. , (El-Hammol, Kafr El-Sheikh Governorate, Egypt).

Results and Discussion

Effect of share rake angle, wing shape and wing angle on: Characteristics of furrow profile

The furrow profile at different share rake angles and wing angles as well as wing shape was illustrated in Figures 4 and 5. The general trend of furrow profiles, shown in Figures 3 and 4, indicated that the furrow depth was proportional to the share rake angle. The highest furrow depth associated with the rake angle of 30° . This trend was due to the increase of the share penetration into the soil by increasing the share rake angle. These results agree with those reported by Varshney et al. (2006) and Abd El-tawwab et al. (2007). For all rake and wing angles used in this study, the edge of the bed and the depth of furrow performed by the curved wing were higher than those performed by the straight wing. This may attributed to the collapse the soil inside furrows performed by the straight wings immediately after it formed. Increasing wing angle tends to increase the furrow width due to increase the soil cross-sectional area that moves in the front of the share having a wing angle of 45° compared to wing angle of 35° for all the share rake angles and wing shapes.

Seeds transverse scattering

Standard deviation tells the dispersion of seeds from the optimum location (i.e., the row centerline). The standard deviation at different share rake angles, wing angles and wing

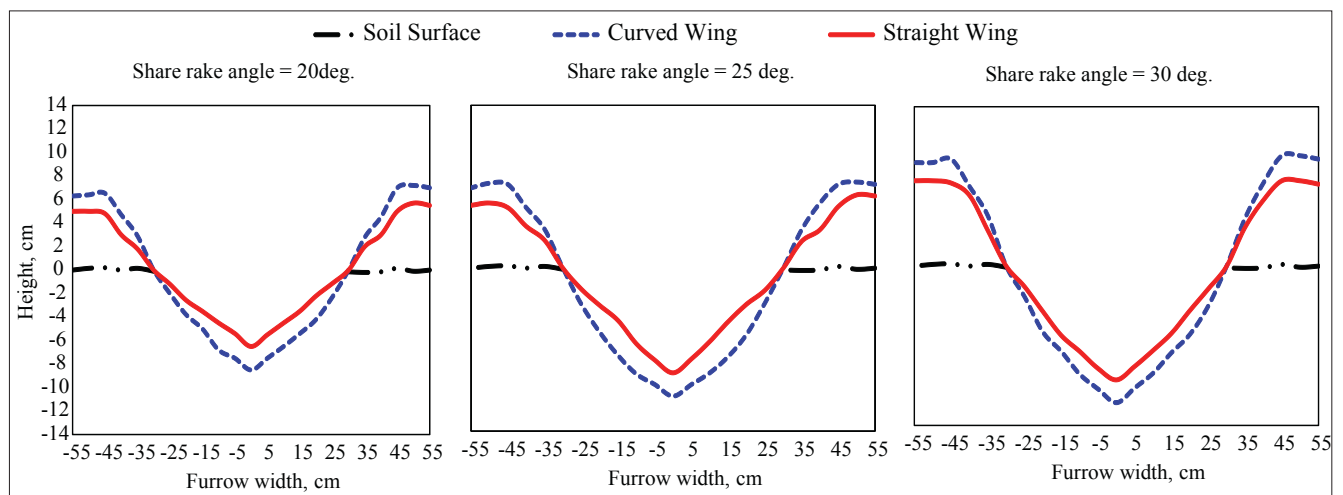


Fig. 4. Furrow profile as influenced by share rake angle and wing shape for wing angle of 45°

shapes are presented in Figure 5. At given wing angles and shape, the standard deviation was observed to increase with increasing share rake angle. For example, a decrease in the share rake angle from 30 to 20 caused a drop in the standard deviation from 2.9 to 2.04 cm at a wing angle of 35° and straight wing shape. This attributed to increase the soil movement and machine vibration as affected by increasing the share rake angle; this makes the seed to move with the soil away from the ridge centerline. For all share rake angles and both wing shapes, the maximum standard deviation occurred when the wing angle was 45°; and the minimum standard deviation could be achieved when the wing angle was 35°. Also, the lower values of the standard deviation were recorded with the curved wing compared to the straight wing for all wing and rake angles.

Draft force requirements

The planting draft force affected by the different parameters considered is shown in Figure 6. The minimum net draft was found to be associated with the rake angle of 20° at the different wing shapes and angles. Increasing the rake angle to 30° was observed to increase the required net draft force. These results were in agreement with those obtained by Abd El-tawwab et al. (2007). Increasing wing angle tends to increase the draft force due to the increase of the moving soil area in the front of furrow opener and the resistance force as well. From Figure 6 the highest values of the net draft force were recorded with the curved wing compared to the straight wing at all rake and wing angles due to increasing the frictional surface area of the curved wing compared to the straight wing.

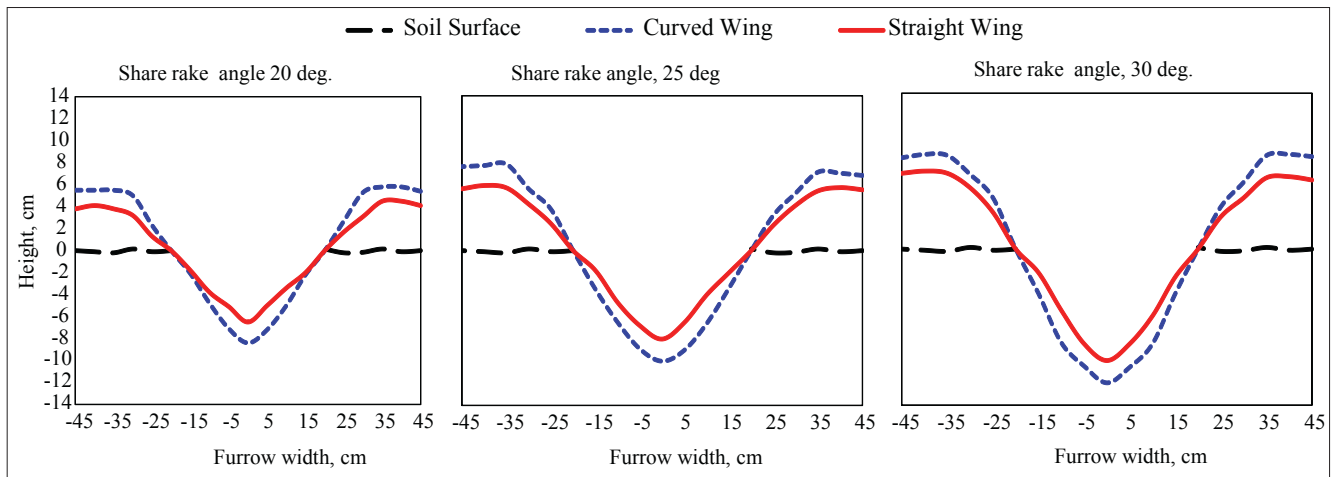


Fig. 5. Furrow profile as influenced by share rake angle and wing shape for wing angle of 35°

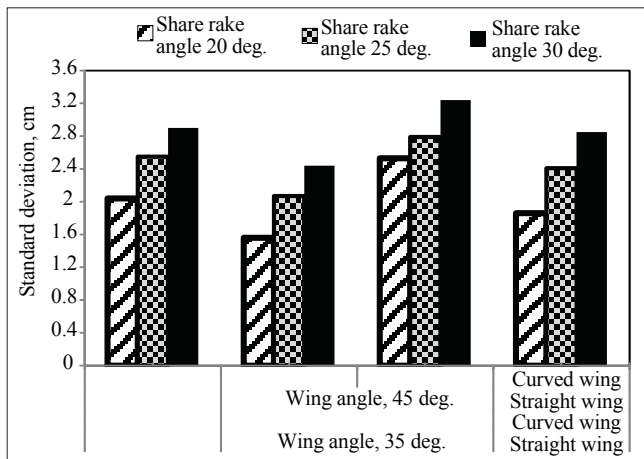


Fig. 6. Effect of share rake angle, wing angle and wing shape on standard deviation of seeds scattering, cm

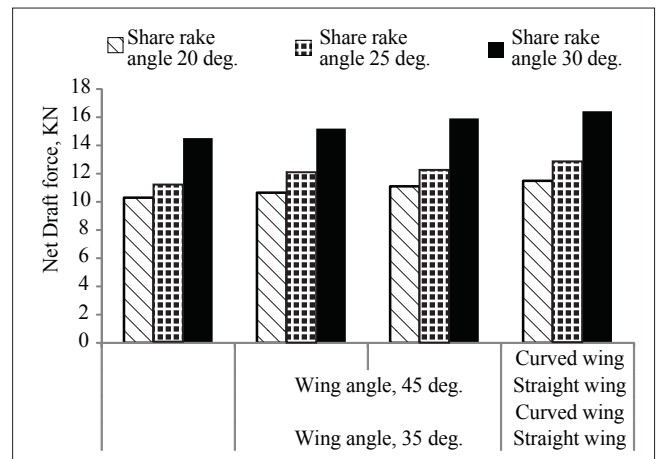


Fig. 7. Effect of share rake angle, wing angle and wing shape on net draft force, kN.

Effects of planting methods, wing shape and wing angle on: Emergence percentage

The statistical analysis indicated that the planting methods had no significant effect on the emergence percentage (Table 1). However, the germination percentage varied significantly ($P < 0.01$) under different wing angles and shapes (Table 1). The average emergence percentages under different planting methods, wing shapes, and angles are presented in Table 2. Wing angle of 45° gave a higher emergence (89.22 %) as compared to 35° wing angle (87.81%). A wider furrow increases the water flow; therefore water could not reach at ridge top which produced a warm bed area that enhances the germination percentage. The curved wing produced a higher germination

percentage than the straight wing (Table 2). This may be attributed to collapse of soil inside the furrow which impedes the water flow and increases its level inside the furrow.

Root yield

Planting methods showed a highly significant effect ($P < 0.01$) on the root yield (Table 1). Sugar beet planted in beds with 30 cm rows spacing produced maximum mean root yield (75.57 Mg ha^{-1}) followed by beds with 35 cm rows spacing (71.45 Mg ha^{-1}). On the other hand, the results of LSD test indicated that the differences between planting sugar beet in ridges and planting on beds with 40 cm rows spacing was not significant (Table 2). Previous studies focused on three agro-

Table 1
Two way analysis of variance for different sugar beet parameters

SOV	Seed emergence, %	Root. yield, Mg ha^{-1}	Sugar percentage, %	Sugar yield, Mg ha^{-1}	Applied water, $\text{m}^3 \cdot \text{ha}^{-1}$	Water use efficiency, Mg m^{-3}
F- value						
Planting method (M)	2.76 ^{NS}	51.98**	26.80**	37.72**	76.98**	386.96**
Wing angle (A)	50.13**	3.13 ^{NS}	24.91**	7.60*	111.36**	767.41**
Wing shap (S)	30.62**	6.87*	9.78**	5.60*	181.41**	1216.15**
M * A	0.68 ^{NS}	0.11 ^{NS}	0.031 ^{NS}	0.04 ^{NS}	0.44 ^{NS}	15.06**
M* S	2.81 ^{NS}	0.07 ^{NS}	0.18 ^{NS}	0 ^{NS}	0.34 ^{NS}	13.41**
S * A	0.99 ^{NS}	0.06 ^{NS}	0.6 ^{NS}	0.17 ^{NS}	0.81 ^{NS}	76.87**
M * A *S	0.7 ^{NS}	0.07 ^{NS}	0.04 ^{NS}	0.03 ^{NS}	1.37 ^{NS}	11.43**

* $p < 0.05$

** $p < 0.01$,

NS is not significant

Table 2
Mean values of sugar beet parameters as affected by planting methods, wing shape and angle

Planting methods	Seed Emerg., %	Root yield, Mg ha^{-1}	Sugar Perce. , %	Sugar yield, Mg ha^{-1}	Water appl., $\text{m}^3 \text{ ha}^{-1}$	Water use effici. , Mg m^{-3}
Beds with 40 cm rows spacing	88.8 a*	68.98 a	18.92 a	12.98 a	7267.9 a	9.75 a
Beds with 35 cm rows spacing	88.42 a	71.45 b	18.83 a	13.40 a	7455.3 a	9.80 a
Beds with 30 cm rows spacing	88.76 a	75.57 c	18.79 a	14.13 b	7663.6 a	10.16 b
ridges 50 cm a part	88.1 a	69.29 a	17.02 b	11.74 c	9716.4 b	7.26 c
LSD 0.05	1.296	1.458	0.613	0.565	452.46	0.234
Wing Angle, degree						
35	87.81 a	70.75 a	17.950 a	12.62 a	8710.5 a	8.303 a
45	89.22 b	71.90 a	18.83 b	13.5 b	7341.1 b	10.18 b
LSD 0.05	0.418	1.421	0.359	0.679	249.54	0.143
Wing Shape						
Straight	87.967 a	70.475 a	18.115 a	12.68 a	8899.7 a	8.303 a
Curved	89.067 b	72.175 b	18.667 a	13.44b	7151.9 b	10.18 b
LSD 0.05	1.071	0.7006	0.598	0.3868	470.93	0.1623

*The values with the same letters are not significant

nomic factors affecting the sugar beet yield (i.e., row spacing, hill spacing and plant population). In the current study, the hill spacing was maintained constant and the rows spacing was varied; this produced different plant population. Accordingly, plants population in beds was more than those in ridges. The same findings are obtained by Zahoor et al. (2010). Considering the effect of wing shape on the root yield, the statistical analysis shows that the root yield was significantly affected by wing shape ($P < 0.05$). It is evident from Table 2 that the curved wing was associated with the high value of root yield ($72.175 \text{ Mg ha}^{-1}$) compared to the straight wing ($70.745 \text{ Mg ha}^{-1}$). This was attributed to increase the number of plant per unit area as a result of increasing the emergence percentage. The wing angle had no significant effect on the root yield (Table 1).

Sugar percentage and yield

Sugar percentage was highly significantly ($P < 0.01$) affected by planting methods (Table 1). The planting of sugar beet on ridges, 50 cm apart, was associated with low percentage of sugar compared to the other planting methods. This may attributed to the increase of the moisture content of the soil in the root area as affected by the presence of water on both sides of the ridge. On the other hand, for sugar beets planted on beds with different rows spacing there is no significant difference in sugar percentage between the different rows spacing on beds. The planting methods had a highly significant effect on sugar yield (Table 1). Sugar beet planted on beds with 30 cm rows spacing produced highest sugar yield (14.13 Mg ha^{-1}); while, the lowest sugar yield (11.74 Mg ha^{-1}) was associated with beets planted in ridges. There is no significant effect of beets planted on beds with 35 and 40 cm rows spacing on sugar yield. In general, the wing shape and angle had a significant effect ($P < 0.05$) on the sugar yield (Table 1). The use of the curved wing and wing angle of 45° significantly increased the sugar percentage and yield compared to the straight wing and wing angle of 35° .

Water applied

The results of applied water to the sugar beet as affected by the planting methods, wing shape and wing angle were presented in Table 2. The statistical analysis indicated that the applied water was highly significantly affected by the planting methods, wing shape and angles. Planting beet on ridges resulted in a higher amount of irrigation water applied compared to planting beet on beds. This due to the fact that the number of furrow in case of ridges was more than that in case of beds which requires more water to fill. The same findings were reported by Chaudhry et al. (1994). LSD

test shows that there were no significant differences between the amounts of water applied to the beds with different row spaces (Table 2). Using the curved wing and wing angle of 45° led to decrease the amount of water applied compared with the straight wing and 35° wing angle because the furrows profiles produced by the curve wing and 45° wing angle were wider than that produced by the straight wing and 35° wing angle.

Water use efficiency (WUE)

Water use efficiency was high significantly affected by the planting methods, wing angle and shape. Planting the beet on beds with 30 cm distance between rows induced higher water use efficiency than the other planting methods. On the other hands, the planting of sugar beet on ridges was associated with low values of water use efficiency compared to planting on beds. Data presented in Table 2 shows that the water use efficiency for the beet planted on beds was not significantly affected by changing the space between rows from 35 cm to 40 cm. The maximum values of water use efficiency were associated with the curved wing and the wing angle of 45° compared to straight wing and wing angle of 30° . This may attributed to increasing the root yield and decreasing the amount of applied water.

Conclusions

Based on the results obtained from this study, specific conclusions could be summarized as follows:

- The curved wing angle of 45° wing angle and rake angle of 30° resulted in a wide furrow profile than the other parameters tested in this study.
- The minimum transverse scattering (std, 1.6 cm) is associated with the share rake angle of 20° , wing angle of 35° and curved wing shape.
- Increasing the share rake angle from 20 to 30° and wing angle from 35 to 45° resulted in an increase in mean values of net draft force requirement by 42 and 8.2%, respectively.
- The planting methods have highly significant effects on the sugar percentage, sugar and root yields, amount of applied water, and water use efficiency.
- The highest values of the emergence percentage (89.22%), root and sugar yield (71.90 and 13.5 Mg ha^{-1} , respectively), sugar percentage (18.83%), and water use efficiency (10.18 Mg m^{-3}) were achieved with the wing angle of 45° compared to the wing angle of 35° .
- Curved wing gives an increase in the emergence percentage, sugar percentage, sugar and root yields, and water use efficiency; while decreased the amount of irrigation water applied.

Acknowledgements

The author offers sincere thanks and appreciation to the Deanship of Scientific Research and the Agricultural Research Center in the College of Food and Agricultural Sciences, King Saud University, Saudi Arabia for supporting this research effort.

References

- Abd El-Tawwab, I. M., M. E. Badaway and S. El-Khawaga**, 2007. Developing and performance evaluation of a locally fabricated sugar beet planter. *Misr J. Ag. Eng.*, **24** (4): 648-665.
- Abo-Shady, K. A., M. Samia, E. E. Hilal, M. and M. F. Ibrahim**, 2010. Yield and quality of sugar beet crop as affected by irrigation interval, cultivars and potassium fertilization in north delta. *J. Agric. Res. Kafer El-Sheikh Univ.*, **36**(4): 361-376.
- Chaudhry, M. R., M. A Gill, M. S Arshed and M. Arif**, 1994. Surface water application techniques for cotton crop to alleviate water logging and salinity. *Sarhad J. Agric.*, **19**: 461-467.
- FAO**, 1974. The euphrates pilot irrigation project. Methods of Soil Analysis, Gadeb Soil Laboratory, a Laboratory Manual. *Food and Agriculture Organization*, Rome, Italy.
- Fielke, J. M.**, 1988. The Influence on Tillage of Share Wing Geometry in a Sandy Loam Soil. Conference on Agricultural Engineering 1988: An Australasian Conference to Celebrate the Australian Bicentennial; Preprints of Papers. Barton, *ACT: Institution of Engineers*, Australia, pp. 73-77.
- Hu, X., T. Shiheng and W. Lixiang**, 1997. Research on ridge and furrow planting of proso in semi arid and Drought inclined Areas; Agricultural Research in the Arid Areas 01.
- Jensen, M. E.**, 1983. Design and Operation of Farm Irrigation Systems. *American Society of Agricultural and Biological Engineers*, St. Joseph, Michigan, USA, DOI:10.13031/2013.23684.
- Mathur, S. M. and K. P. Pandey**, 1992. Influence of System Parameters on Performance of Reversible Hoe Type Furrow Opener for Animal Drawn Seed and Fertilizer Drills. Proceeding of the International Agricultural Engineering Conference, November 17-23, 1991, *Asian Institute of Technology*, Bangkok, Thailand, pp. 143-150.
- McGinnus, R. A.**, 1982. Sugar Beet Technology. 3rd ed., *Sugar Beet Development Foundation*, Fot. Collinos., Co, USA, pp. 119-153.
- Ren, X., J. Zhikuanb, C. Xiaolic, H. Juandand H. Qingfang**, 2013. Effect of ridge and furrow planting of rainfall harvesting on soil available nutrient distribution and root growth of summer corn under simulated rainfall conditions. *Trans Chinese Soc. Agric. Eng.*, **23**: 94-99.
- Römken, M. J. M., S. Singarayay and C. J. Gantzer**, 1986. An automated non-contact surface profile Meter. *Soil Tillage Res.*, **6**: 193-202.
- Scott, R. K. and K. W Jaggard**, 1978. How the crop grows, from seed to sugar. *British Sugar Beet Rev.*, **46** (4): 19-22.
- Varshney, A. C. and K. V. Patel**, 1988. Effect of cutting angle of shovel on unit draft and rake. *Indian J. of Agricultural Sciences*, **58** (12): 932-934.
- Varshney, A. C., R. K. Naik, S. M. Nandy, G. S. Prajapati and S. N. Ararang**, 2006. Determination of penetration of soil working tools in clay soil. *Indian Journal of Agricultural Sciences*, **76** (1): 66-67.
- Zahoor, A., P. Shah, K. M. Kakar, H. El-Sharkawi, P. B. S. Gama, E. A. Khan, T. Honna and S. Yamamoto**, 2010. Sugar beet (*Beta vulgaris* L.) response to different planting methods and row geometries II: Effect on plant growth and quality. *J. of Food, Agriculture & Environment*, **8** (2): 785-791.
- Zhang, C. and K. Araya**, 2001. A three stage soil layer mixing plough for the improvement of meadow soil, Part II. Soil bin experiments. *J. of Agricultural Engineering Research*, **78** (4): 359-367.
- Wagner, L. E. and Y. Yiming**, 1991. Digitization of Profile Meter Photographs. *Trans. of the ASAE*, **34** (2), 412-416.

Received September, 29, 2014; accepted for printing October, 5, 2015