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Field evaluation of a bent leg tillage implement in dry soil conditions

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Abstract: Tillage operations in dry soil conditions have increasingly been used in Iran in recent years. However, due to the recent droughts, the choice of suitable implements to reduce the clod and draught force is still under investigation. This study was aimed at determining the effect of the geometry of a bent leg tillage implement on the soil pulverisation and draught force in dry soil conditions. The treatments included three bent leg tillage depths (10, 15, and 20 cm) and three forward speeds (6, 9, and 12 $km \cdot h^{-1}$). The effect of the bent leg tillage implement on the clod mean weight diameter (*MWD*) and draught force was studied using a split plot experiment with three replications. The results showed that the tillage depth and forward speed affected the *MWD* and the draught force. Increasing the tillage depth from 10 to 20 cm increased the *MWD* and draught force by 24.9 and 35.1%, respectively. Increasing the forward speed from 6 to 12 $km \cdot h^{-1}$ decreased the *MWD* by 7.4% and increased the draught force by 40.0%. These findings show that the bent leg tillage technology has the potential to reduce the *MWD* and draught force at higher forward speeds. Therefore, a bent leg tillage implement can be suggested as a proper implement for tilling in dry land conditions.

Keywords: clod mean weight diameter; draught force; forward speed; tillage depth

Due to the recent droughts in Iran, the choice of the proper implements to reduce the clod and draught force in dry soil conditions is still under investigation. The soil moisture content has an important effect on the tillage quality (Solhjou et al. 2001; Arvidsson and Bölenius 2006). Previous studies have shown that the clod mean weight diameter (*MWD*) increased with a decreasing soil moisture content (Salar et al. 2013; Solhjou and Alavimanesh 2020). Also, increasing the tillage depth increased the *MWD* value (Yassen et al. 1992; Esehaghbeygi et al. 2020).

Conventional tillage uses a mouldboard plough + disc harrow, which can damage the soils and lands in Iran. Also, tilling with a mouldboard plough creates big clods in dry soil conditions which subsequently need a disc harrow to be used several times to break them down. Thus, the tillage intensity could

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be decreased in Iran (Hemmat 2009). No-till may not produce a suitable amount of crop production; therefore, some degree of soil disturbance is necessary (Sarikhani Khorami et al. 2018; Afzalinia et al. 2019). Reducing tillage by chisel plough has been suggested to be used in most provinces of Iran (Javadi et al. 2009). Previous studies have shown that the chisel plough is an alternative for the mouldboard plough in Iran (Esehaghbeygi 2009). Primary studies about reduced tillage implements have indicated the low penetration ability in dry and heavy soils and tyre slippage for medium power tractors due to high draught force requirements.

The factors previously identified in the literature influencing the draught force and soil disturbance include: soil conditions such as the texture, moisture, and structure; tool settings like the working depth, forward speed, and tool geometry (Godwin 2007; Godwin and O'Dogherty 2007; Solhjou et al. 2012; Salar and Karparwerfard 2017). One of the important factors which affects the draught force is the geometry of the tool, such as the rake angle. The rake angle affects the draught force, soil failure and mixing of soil layers (Godwin and Spoor 1977; Solhjou et al. 2012). Increasing the rake angle increases the draught force and reduces the cross-sectional area of the furrow (Godwin 2007; Solhjou et al. 2012). Adding a chamfer to the face of a vertical narrow tool decreased the draught force and lateral soil throw (Rosa and Wulfsohn 2008). Sharifat (1999) showed that a 45° triangular and elliptical face geometry had the lowest lateral soil movement and energy when compared to a blunt and a 90° triangular narrow tool. Also, Solhjou et al. (2013) showed that adding a chamfer to the face of a vertical narrow point opener decreased the lateral and forward soil movement, but increased the size of the furrow cross-sectional area and the opener's critical depth.

Another factor that affects the draught force is the forward speed. Increasing the forward speed increased draught force of three primary tillage implements: a mouldboard plough, chisel plough, and disc plough, where the maximum was exhibited by the mouldboard plough (Naderloo et al. 2009). The draught force of the subsoiler increased by increasing the forward speed (Askari et al. 2017). Also, increasing the forward speed increased the draught force of a chisel plough (Moeenifar et al. 2014; Al-Neama and Herlitzius 2017). Increasing the forward speed increased the draught force of implements due to creating higher acceleration to the soil particles during their translocation. Moreover, increasing the operating depth increased the draught force of the tools (Moeenifar et al. 2014; Esehaghbeygi et al. 2020). Thus, the tool geometry, operating depth and forward speed are the three important factors which highly affect the draught force of an implement. The ability to conduct tillage operations at more forward speeds is desirable to farmers for higher work rates and timelines; which result in reducing labour and machinery costs. However, tillage operations at high speed (more than 8 km·h^{-1}) often results in a significant higher demand of the draught force (Godwin and O'Dogherty 2007).

Solhjou et al. (2014) quantified the soil disturbance and soil translocation of a bent leg opener design in a soil bin. As shown in Figure 1, the bent leg opener includes a footed bent leg opener (bent leg opener with a foot component) and a footless bent leg opener (bent leg opener without a foot component). The design was based on the RT blade (Figure 1A) developed by a South African farmer (Solhjou et al. 2014; Barr et al. 2020), who scaled down the concept of bent leg subsoilers aiming to reduce the draught force and surface soil disturbance (Raoufat and Mashadi Mighani 1999; Esehaghbeygi et al. 2005). Solhjou et al. (2014) found that the bent leg opener without a foot and shank offset of 45 mm had the potential to increase the furrow cross-sectional area with less soil translocation and soil mixing (Figure 1B). This footless bent leg opener can be proper for no-till seeding. Barr et al. (2016) found that the footed bent leg opener can work at a for-

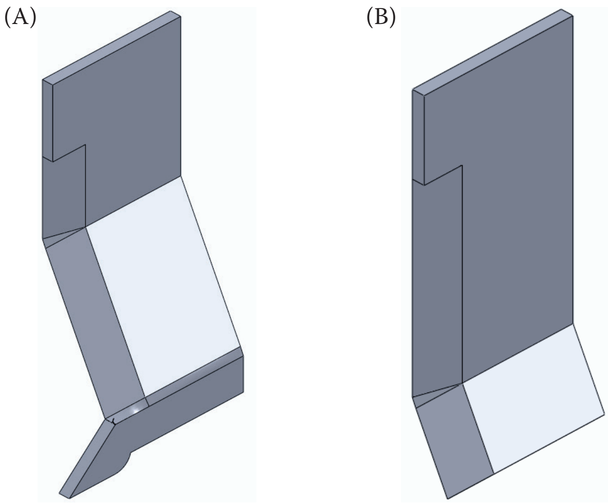

Figure 1. Bent leg openers (A) with a foot component and (B) without a foot component

Source: Solhjou et al. 2014

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ward speed of 16 km·h^{-1} with less draught force and lateral soil throw compared to the straight shank openers of 53 and 90° rake angles. The field evaluation of a footed bent leg opener in a seeding system showed that increasing the forward speed from 8 to 12 km·h^{-1} had no penalty to the wheat emergence. However, increasing the forward speed of seeders using a straight opener the reduced wheat emergence by 31% (Barr et al. 2019).

These results were only based on a footed bent leg opener and various levels of forward speeds. However, less information is available on a footless bent leg blade and the effects of the tillage depth and forward speed on its draught force and the clods in field conditions. Therefore, the objective of this study was to evaluate the effect of the tillage depth and forward speed on the soil pulverisation and draught force of a footless bent leg tillage implement in dry soil conditions. It was expected that the findings would highlight some implications for improving the performance of tillage practices in dry soil conditions.

MATERIAL AND METHODS

To determine the effect of the geometry of a bent leg tillage implement on the soil pulverisation and draught force, experiments were undertaken in a field near the Zarghan region of the Fars province, Iran. The soil texture was silty clay, 16.4% sand, 42.6% silt, and 41% clay. This study was a split plot design with three replications. The treatments included three tillage depths of 10 (d_1), 15 (d_2), and 20 cm (d_3) as the main plots and three forward speeds of 6 (v_1), 9 (v_2), and 12 km·h^{-1} (v_3) as the sub-plots.

The size of each plot was 3 × 50 m and the barley residue retained on the soil surface before the tillage was 1 970 kg·ha^{-1}. The soil bulk density before the tillage was 1.29 and 1.48 g·cm^{-3} (dry weight basis) in soil depths of 0–10 and 10–20 cm, respectively. The soil moisture content in the field was 4.4% (dry weight basis) for the soil depth of 0–20 cm when the treatments were applied in the field. The bent leg blade with a chamfered face was manufactured from 15 mm thick steel. The details of the bent leg blade are shown in Figure 2 and Table 1. Figure 3 shows the bent leg tillage implement with a lateral blade spacing of 17 cm that was used in this research.

The forward speed was obtained by dividing the distance of 20 m by the time of the tillage operating for this distance. The draught force of the bent leg tillage implement was measured according to the Regional Network for Agricultural Machinery (RNAM 1983) standard method using a drawbar dynamometer and two tractors (Figure 4). A 56 kW ITM-285 tractor was used to pull a 56 kW MF-285 (Iran Tractor Manufacturing Co., Iran) carrying the bent leg tillage implement. The draught was measured and recorded by a recording drawbar dynamometer

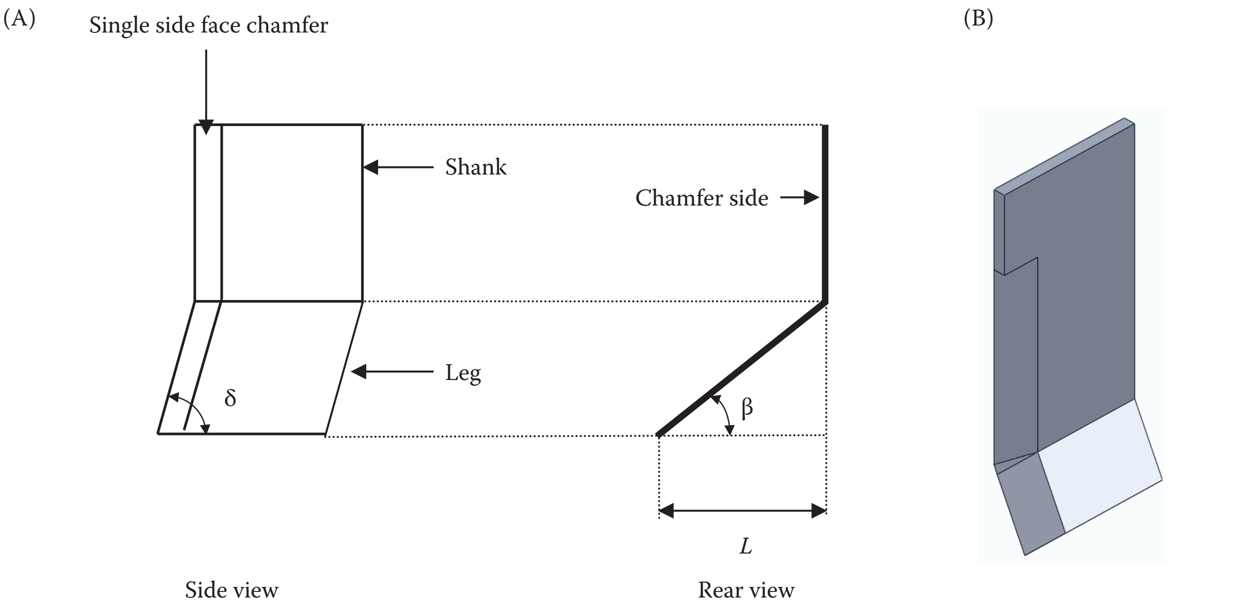

Figure 2. Bent leg blade: (A) geometry and (B) isometric view

L – shank lateral offset; β – side bend angle; δ – leg forward angle

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Table 1. Geometric parameters of the experimental bent leg blade

Blade	Shank offset *L* (mm)	Side bend angle β (°)	Leg forward angle δ (°)	Leg face condition
Bent leg	45	45	70	chamfered*

* Single side face chamfer of 17°

(DBBP-3t; Bongshin, South Korea) placed between the two tractors and the procedure recommended by the RNAM standard method for draught measurement was adopted (Figure 4). In both cases, the tractor forward speed was 6, 9, and 12 km·h^{-1} used as the forward speed treatments. The measurements were taken in two stages, firstly, when the bent leg tillage implement was engaged in the soil and, sec-

Figure 3. The bent leg tillage implement

Figure 4. Measuring the draught force with a drawbar dynamometer and two tractor method

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ondly, when the implement was raised by the hydraulic lift of the tractor. The net difference between the two measurements was the draught force needed to pull the bent leg tillage implement in the soil (Raoufat and Firouzi 1998; Esehaghbeygi et al. 2020).

The *MWD* was measured after the tillage operation. The soil samples were manually taken from a depth of 0–10 cm with special care to avoid soil clod break-up. A frame with a size of 0.5 × 0.5 m was used to surround the soil samples which were then air dried for 24 h. The dried soil samples were passed through 7 sieves with 6.35, 12.7, 38.1, 50.8, 76.2, 88.9, and 101.6 mm mesh openings. The mesh openings were chosen based on the clod diameters. The soil remaining on each sieve was weighed and Equation (1) was used to calculate the *MWD* for each soil sample (Salar et al. 2013; Solhjou and Alavimanesh 2020).

$$MWD \sum_{i=1}^{n} \frac{W_i}{W} \times D_i = \qquad (1)$$

where: *MWD* – clod mean weight diameter (mm); W_i – weight of the soil remaining between two adjacent sieves (kg); *W* – total weight of the soil sample (kg); D_i – mean diameter of two adjacent sieve meshes (mm).

All the statistical analyses were performed using SAS software (version 9.1) and Duncan's multiple range test (P = 0.05) was used to compare the means of the treatments.

RESULTS AND DISCUSSION

Clod mean weight diameter. As shown in Figure 5, increasing the tillage depth of the bent leg tillage implement increased the *MWD*. The lowest *MWD* value was obtained at a tillage depth of 10 cm with 12.4 mm and the highest was obtained at a tillage depth of 20 cm with 16.5 mm. Increasing the tillage depth from 10 to 20 cm increased the *MWD* by 24.9%. Other studies have also shown that the *MWD* value increased with an increasing tillage depth (Yassen et al. 1992; Solhjou et al. 2001; Esehaghbeygi et al. 2020). Increasing the tillage depth increased the *MWD* value due to the higher compaction in the deeper soil layers.

Increasing the forward speed decreased the *MWD* value (Figure 6). Increasing the forward speed from 6 to 12 km·h^{-1} decreased the *MWD* by 7.4%. Dehghani and Karparvarfard (2017) reported that increasing the forward speed decreased the *MWD* value. This is due to creating high acceleration to the soil particles during their translocation.

As shown in Figure 7, the lowest *MWD* value of 12 mm was obtained at a tillage depth of 10 cm and a forward speed of 12 km·h^{-1} (d_1v_3) and the highest *MWD* value of 16.6 mm was obtained at a tillage depth of 20 cm and a forward speed of 6 km·h^{-1} (d_3v_1) for the bent leg tillage implement. Therefore, increasing the forward speed and decreasing the operating depth reduced the *MWD* of the bent leg tillage implement. Also, the effect of the tillage depth on the *MWD* was greater than that of the forward speed of the bent leg tillage

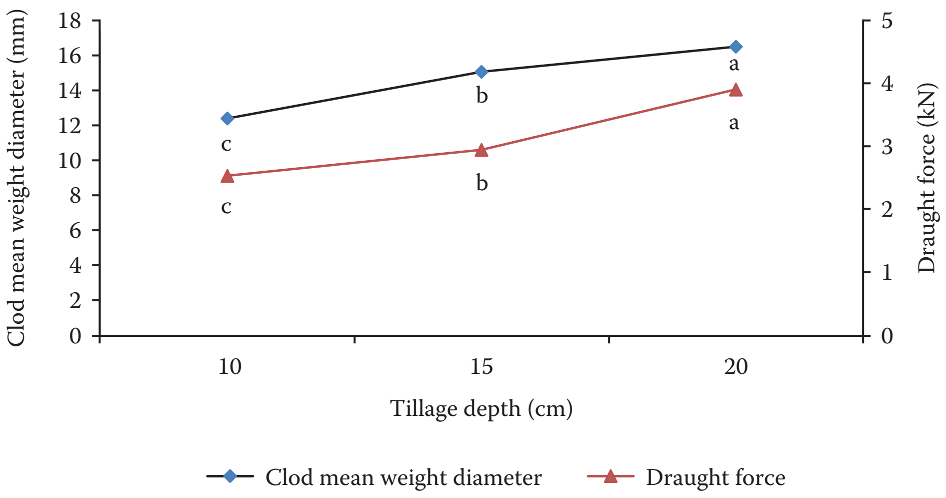

Figure 5. Effect of the tillage depth on the clod mean weight diameter and draught force

[a–c] significant differences at a probability level of 0.05 (P = 5%) based on Duncan's multiple range test

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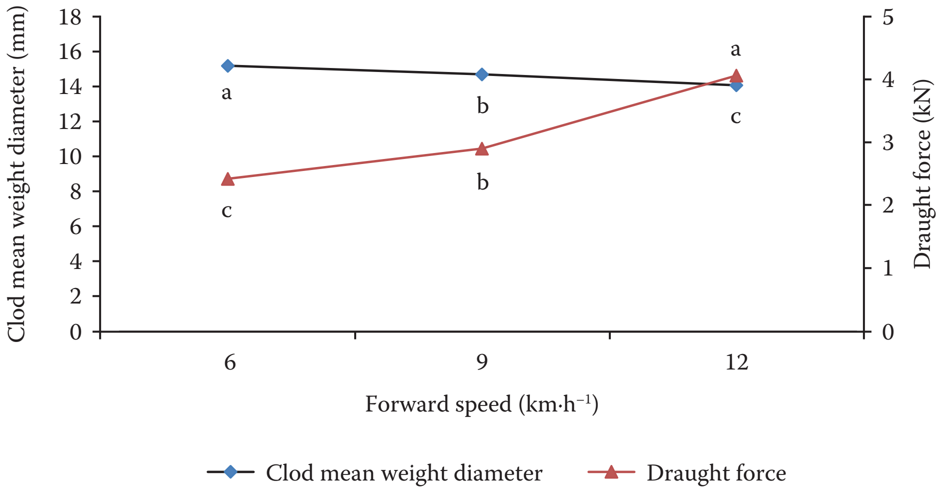

Figure 6. Effect of the forward speed on the clod mean weight diameter and draught force

[a–c] significant differences at a probability level of 0.05 (P = 5%) based on Duncan's multiple range test

implement. The bent leg tillage implement is able to reduce the number of clods in dry soil conditions. Reducing the *MWD* by the bent leg tillage implement was due to the geometry of the bent leg blade which is able to reduce the soil disturbance and mixing of the soil layers (Solhjou et al. 2014). Therefore, the bent leg tillage implement can be suggested as a proper implement for tilling in dry soil conditions.

Draught force. Increasing the tillage depth strongly increased the draught force of the bent leg tillage implement (Figure 5). The highest draught force was obtained at a tillage depth of 20 cm with 3.9 kN and the lowest draught force was obtained at a tillage depth of 10 cm with 2.5 kN. The draught force of the bent leg tillage implement at an operating depth of 20 cm increased by 35.1% compared to the draught force at an operating depth of 10 cm. Other studies have shown that the draught force increased with an increasing tillage depth (Godwin and O'Dogherty 2007; Naderloo et al. 2009; Moeenifar et al. 2014; Esehaghbeygi et al. 2020). Increasing the operating depth increased the draught force, which was due to increasing the soil compaction at deeper soil layer and, as a result, the friction force between the soil and blade increases.

As shown in Figure 6, increasing the forward speed significantly increased the draught force of the bent leg tillage implement. Increasing the forward speed from 6 to 12 km·h^{-1} increased the draught force

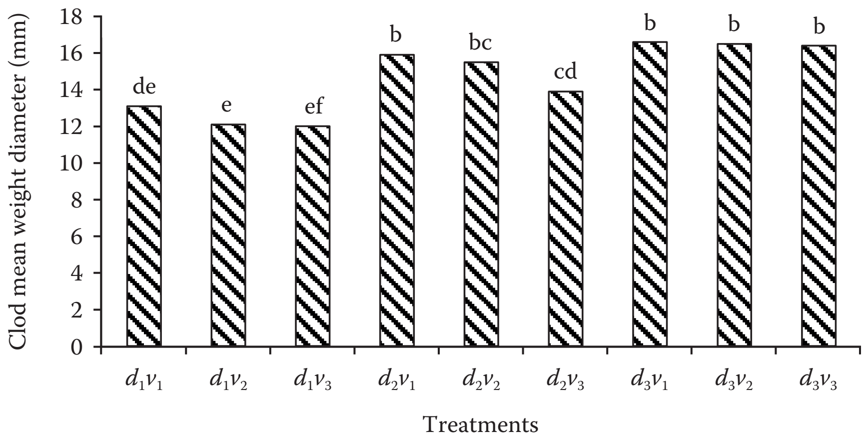

Figure 7. Interaction between the tillage depth and forward speed on the clod mean weight diameter

[a–f] significant differences at a probability level of 0.05 (P = 5%) based on Duncan's multiple range test; d_1 – tillage depth of 10 cm, d_2 – tillage depth of 15 cm, d_3 – tillage depth of 20 cm; v_1 – forward speed of 6 km·h^{-1}, v_2 – forward speed of 9 km·h^{-1}, v_3 – forward speed of 12 km·h^{-1}

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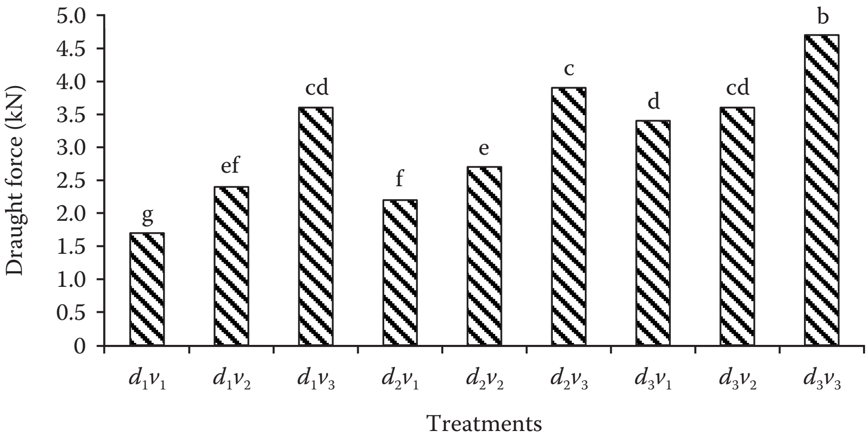

Figure 8. Interaction between the tillage depth and forward speed on the draught force

[a–g] significant differences at a probability level of 0.05 (P = 5%) based on Duncan's multiple range test; d_1 – tillage depth of 10 cm, d_2 – tillage depth of 15 cm, d_3 – tillage depth of 20 cm; v_1 – forward speed of 6 km·h^{-1}, v_2 – forward speed of 9 km·h^{-1}, v_3 – forward speed of 12 km·h^{-1}

by 40.4%. Previous studies have also shown that the draught force increased when increasing the forward speed (Godwin 2007; Barr et al. 2016; Dehghani and Karparvarfard 2017; Askari et al. 2021). Increasing the forward speed increased the draught force of the bent leg tillage implement, which was due to creating high acceleration to the soil particles during their translocation.

The interaction between the tillage depth and forward speed on the draught force of the bent leg tillage implements are shown in Figure 8. The lowest draught force of bent leg tillage implement with 1.7 kN was measured at a tillage depth of 10 cm and a forward speed of 6 km·h^{-1} (d_1v_1) and the highest draught force of 4.7 kN was measured at a tillage depth of 20 cm and a forward speed of 12 km·h^{-1} (d_3v_3). Therefore, decreasing the tillage depth and forward speed reduced the draught force of the bent leg tillage implement. This shows that the tillage depth and forward speed strongly affect the draught force. Decreasing the draught force of the bent leg tillage was due to the geometry of the bent leg blade which is able to reduce soil disturbance (Solhjou et al. 2014; Barr et al. 2020). Other studies have shown that the blade geometry affected the draught force of the tool (Raoufat and Firouzi 1998; Godwin 2007; Moeenifar et al. 2014; Mohammadi et al. 2020). The findings of this study show potential for the bent leg tillage technology to increase the forward speed during tillage operation by reducing the draught force; thus, improving the field capacity and also decreasing the fuel consumption which can decrease the environmental hazards due to less CO_2 emissions from the fuel consumption. Other researchers have reported that reducing the draught force decreased the fuel consumption of tractors (Fazeli et al. 2017; Mohammadi et al. 2020; Souri Damirchi Sofla et al. 2021).

CONCUSION

The tillage depth and forward speed affected the *MWD* and draught force of the bent leg tillage implement. Increasing the tillage depth from 10 to 20 cm strongly increased the *MWD* and draught force by 24.9 and 35.1%, respectively. However, increasing the forward speed from 6 to 12 km·h^{-1} significantly reduced the *MWD* by 7.4% and increased the draught force by 40.4%. The findings indicate the potential for the bent leg tillage technology to the increase forward speed during tillage operation by reducing the draught force and *MWD*; thus, improving the field capacity and also reducing the fuel consumption. Reducing the size of clods in the field by using the bent leg tillage implement can reduce the number of required secondary tillage operations in dry soil conditions and also reduce the tilling cost. The bent leg tillage implement can decrease the draught force; thus, it can be used when working with medium power tractors and also for working in small sized fields. Thus, the bent leg tillage implement can be suggested as a proper implement for tilling in dry soil conditions. As for the further progression of the work, it is recommended to examine the performance of the bent leg tillage implement on the crop yield under con-

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servation farming practices when compared to conventional tillage.

REFERENCES

Afzalinia S., Karami A., Rousta M.J. (2019): Effect of conservation tillage on soil properties, field capacity, fuel consumption, and wheat yield in the wheat-corn rotation. Agricultural Mechanization and Systems Research, 72: 163–178.

Al-Neama A.K.A., Herlitzius T. (2017): Draught forces prediction model for standard single tines by using principles of soil mechanics and soil profile evaluation. LANDTECHNIK, 72: 157–164.

Arvidsson J., Bölenius E. (2006): Effects of soil water content during primary tillage – Laser measurements of soil surface changes. Soil and Tillage Research, 90: 222–229.

Askari M., Shahgholi G., Abbaspour-Gilandeh Y. (2017): The effect of tine, wing, operating depth and speed on the draught requirement of subsoil tillage tines. Research in Agricultural Engineering, 63: 160–167.

Askari M., Shahgholi G., Abbaspour-Gilandeh Y. (2021): Field assessment of triaxial forces on single and double bentleg plows at various forward speeds. Agricultural Mechanization and Systems Research, 22: 1–18.

Barr J., Desbiolles J., Fielke J.M. (2016): Minimising soil disturbance and reaction forces for high speed sowing using bentleg furrow openers. Biosystems Engineering, 151: 53–64.

Barr J., Desbiolles J., Fielke J.M., Ucgul M. (2019): Development and field evaluation of a high-speed no-till seeding system. Soil & Tillage Research, 194: 104337.

Barr J., Desbiolles J., Ucgul M., Fielke J.M. (2020): Bentleg furrow opener performance analysis using the discrete element method. Biosystems Engineering, 189: 99–115.

Dehghani M., Karparvarfard S.H. (2017): Optimization of chisel tine operation used in combined tillage machine. Iranian Journal of Biosystems Engineering, 47: 651–658.

Esehaghbeygi A. (2009): Effect of using different tillage implements on the yield and yield components of irrigated Alvand winter wheat. Agricultural Science, 19: 333–341.

Esehaghbeygi A., Tabatabaeefar A., Keyhani A.R., Raoufat M.H. (2005): Depth and rake angle's influence on the draught force of an oblique blade subsoiler. Iran Agricultural Science, 36: 1045–1052.

Esehaghbeygi A., Abedi M., Razavi J., Hemmat A. (2020): Field evaluation of a vibrating dual bent-share cultivator. Research in Agricultural Engineering, 66: 123–130.

Fazeli S., Abbaspour-Gilandeh Y., Shahgoli G., Fazel-Niari Z. (2017): Effect of forward speed and tillage depth on fuel consumption and draft force of several types of cultivator blades. Agricultural Mechanization and Systems Research, 18: 71–88.

Godwin R.J. (2007): A review of the effect of implement geometry on soil failure and implement forces. Soil & Tillage Research, 97: 331–340.

Godwin R.J., Spoor G. (1977): Soil failure with narrow tine. Journal of Agricultural Engineering Research, 22: 213–228.

Godwin R.J., O'Dogherty M.J. (2007): Integrated soil tillage force prediction models. Journal of Terramechanics, 44: 3–14.

Hemmat A. (2009): Reduction in primary tillage depth and secondary tillage intensity for irrigated canola production in a loam soil in central Iran. Journal of Agricultural Science and Technology, 11: 275–288.

Javadi A., Rahmati M.H., Tabatabaeefar A. (2009): Sustainable tillage methods for irrigated wheat production in different regions of Iran. Soil & Tillage Research, 104: 143–149.

Moeenifar A., Mousavi-Seyedi S.R., Kalantari D. (2014): Influence of tillage depth, penetration angle and forward speed on the soil/thin-blade interaction force. Agricultural Engineering International: The CIGR Journal, 16: 69–74.

Mohammadi M., Karparvarfard S.H., Kamgar S., Rahmatian M. (2020): Optimization and evaluation of working conditions of new tillage blade for use in tillage tools. Journal of Agricultural Machinery, 10: 273–287.

Naderloo L., Alimadani R., Akram A., Javadikia P., Zeinali Khanghah H. (2009): Tillage depth and forward speed effects on draught of three primary tillage implements in clay loam soil. Journal of Food, Agriculture and Environment, 7: 382–385.

Raoufat M.H., Firouzi S. (1998): Field evaluation of a dual bentleg plow. Iran Agricultural Research, 17: 67–82.

Raoufat M.H., Mashadi Mighani H. (1999): Appropriate tine spacing of a double bentleg plow for better tillage and efficient performance. Iranian Journal of Agricultural Science, 30: 319–330.

Regional Network for Agricultural Machinery (1983): RNAM Test Codes and Procedures for Farm Machinery. Technical series No. 12, Bangkok, Regional Network for Agricultural Machinery: 297.

Rosa U.A., Wulfsohn D. (2008): Soil bin monorail for high-speed testing of narrow tillage tools. Biosystems Engineering, 99: 444–454.

Salar M.R., Esehaghbeygi A., Hemmat A. (2013): Soil loosening characteristics of a dual bent blade subsurface tillage implement. Soil & Tillage Research, 134: 17–24.

Salar M.R., Karparverfard S.H. (2017): Modeling and optimization of wing geometry effect on draught and vertical forces of winged chisel plow. Journal of Agricultural Machinery, 7: 468–479.

https://doi.org/10.17221/41/2022-RAE

Sarikhani Khorami S., Kazemeini S.A., Afzalinia S., Gathala M.K. (2018): Changes in soil properties and productivity under different tillage practices and wheat genotypes: A short-term study in Iran. Sustainability, 10: 3273.

Sharifat K. (1999): Soil translocation with tillage tools [PhD. Thesis]. Saskatoon, University of Saskatchewan.

Solhjou A., Loghavi M., Ahmadi H., Roozbeh M. (2001): The effect of moisture content and plowing depth on soil pulverization and reduction of secondary tillage. Journal of Agricultural Engineering Research, 2: 1–12.

Solhjou A., Fielke J.M., Desbiolles J. (2012): Soil translocation by narrow openers with various rake angles. Biosystems Engineering, 112: 65–73.

Solhjou A., Desbiolles J., Fielke J.M. (2013): Soil translocation by narrow openers with various blade face geometries. Biosystems Engineering, 114: 259–266.

Solhjou A., Fielke J.M., Desbiolles J., Saunders C. (2014): Soil translocation by narrow openers with various bent leg geometries. Biosystems Engineering, 127: 41–49.

Solhjou A., Alavimanesh S.M. (2020): Effect of soil moisture content, forward speed and bent leg blade spaces on soil pulverization. Agricultural Mechanization and Systems Research, 73: 83–92.

Souri Damirchi Sofla B., Karparvarfard S.H., Ranjbar Karim Abadi A., Azimi-Nejadian H., Moazni Kalat A. (2021): Evaluation of the effect of rake angle on the performance of a modified narrow blade. Journal of Agricultural Machinery, 11: 187–197.

Yassen H.A., Hassan H.M., Hammadi I.A. (1992): Effects of plowing depth using different plow type on some physical properties of soil. Agricultural Mechanization in Asia, Africa and Latin America, 23: 21–24.

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