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PARAPLOUGH AND MOULDBOARD PLOW PERFORMANCE EVALUATION FOR SEEDBED PREPARATION AND SUPPORTING CONSERVATION TILLAGE

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The final yield of agricultural products depends on the effective factors during the growing season of plants, especially the size of soil aggregates and proper size distribution of aggregates. Therefore, it is very important to select appropriate tillage implement and to provide a suitable seedbed in terms of aggregate size with the least energy consumption. It is a new idea to use paraplough and winged-paraplough as tools for seedbed preparation. To measure and determine the factors affecting the mean weight diameter (MWD) of aggregates and percentage of crop residues on the soil surface, a series of field trials were performed in a randomized complete block design (RCBD) with five replications. The trials were conducted at three forward speeds of 2, 5 and 7 km·h^{-1} and three operating depths of 0–10; 0–20; 0–30 cm using the mouldboard plough and the paraplough with different wing configurations (without wings, with forward wings, with backward wings). The main impacts of implemented type, forward speed and operating depth and their mutual binary effects were significant at P <1% for both the MWD of aggregates and percentage of remaining residue. The highest MWD of aggregates was related to mouldboard plough (5.59 mm) and the lowest value was related to paraplough with backward wings (2.9 mm). It was found that the winged paraplough created a good pulverization in the soil and sustained a high percentage of crop residues on the soil surface. This issue can be very useful and important in the conservation tillage and the conservation of soil resources, especially in the water deficient areas where the soil is prone to erosion.

Keywords: mean weight diameter; crop residues; aggregates; forward speed; operating depth

The final yield of agricultural products depends on the effective factors during the growing season. The physical condition of soil is one of the factors playing a significant role in the crop growth and yield (Aluko and Koolen, 2000). The soil physical properties are directly affected by the tillage operations. Therefore, appropriate selection of the type of tillage operations and their proper performance determine the physical properties of soil (Liebig et al., 2004) and help to prevent land degradation and to maintain and improve the physical, chemical and biological properties of the soil. Tillage is considered one of the basic field operations in agriculture due to its effects on the physical soil properties and, consequently, on the crop production (Boydas and Turgut, 2007), which aims to create a suitable environment for the plant growth and to increase crop yield (Chichongue et al., 2020). The size of aggregates is one of the important soil properties (Chichongue et al., 2020). The size distribution of aggregates plays a significant role in the environmental effects of erosion, porosity and other soil characteristics and the plant growth and yield (Díaz-Zorita et al., 2007). A good bed for seed is generally attributed to a soil that is softer and more stable around the seed. By creating a suitable structure for aggregates, it is possible to improve water infiltration into the soil and ensure a favourable effect on the plant growth and its yield (Abbaspour-Gilandeh and Sedghi, 2015).

Boydas and Turgut (2007) investigated the effect of different tillage implements at different operating speeds on the physical properties of loamy soil. The MWD of aggregates significantly correlated with the tillage implement type. They concluded that the soil pulverization was strongly decreased with the increment of operating speed of implements. The smallest clod size using different tillage implements was also observed at 14–20 cm depth range. Barzegar et al. (2004) conducted a study on the effect of interaction between tillage methods and soil moisture content and its impacts on the size distribution of aggregates for seedbed preparation in two soil textures in the southwest of Iran (Khuzestan). The results showed that the size distribution of aggregates was changed with variation of the soil moisture content under the influence of different tillage systems. Salar et al. (2013) investigated the behaviour of three types of subsoiler and chisel blades in deep conservation tillage. It was found that the smallest MWD was obtained when the forward wing bent blade with a rake angle of 7.5° and a bend angle of 10° was used. The MWD of dual bent wings was significantly smaller in contrast to the chisel results. The soil moisture content had a significant effect on the MWD and remaining of crop residues on the soil surface when ploughing with chisel. Dal Ferro et al. (2014) studied the effects of conventional tillage and non-tillage methods based on the soil structure of maize

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farm over a two-year period. The pore size distribution and size of aggregates at 0–40 cm depth range were evaluated. The short-term effects of conventional tillage showed that fine aggregates were created at the soil depth of 54–250 mm and the size of soil pores at that depth ranged from 0.5 to 50 µm. Abbaspour- Gilandeh and Sedgi (2015) conducted a series of field tests and predicted influential factor on soil MWD using fuzzy method, observing that the highest amount of MWD of soil aggregate was observed at layer depth of 20–25 cm at 18–20% moisture content. The amount of MWD of soil aggregate increased with the increasing soil sampling depth. The interaction of moisture content and the forward speed showed that the highest MWD was observed at forward speed of 8–8.5 km·h^{-1} and the moisture content of 20–26%. With increasing forward speed, the amount of MWD of soil aggregate increased at high moisture content, while no clear trend was observed at lower moisture contents. The lowest amount of MWD of soil aggregate was observed at lower moisture content and lower forward speed. In terms of MWD, Askari et al. (2018) reported that soil fragmentation of forward bent-winged tine was significantly higher in contrast to the backward one. The conventional winged tine transferred soil from depth to the surface in clods, but the bent-winged tool cut the soil in layers at depth and moved it vertically as it moved forward; therefore, the soil disintegrated into smaller clods. By adding conventional wings (backward and forward bent wings to the subsoiler), the MWD decreased by 4, 36 and 44 mm, respectively. Moreover, by adding conventional wings (backward and forward bent wings to the paraplough), the MWD decreased by 6, 34 and 41 mm, respectively.

Besides creating the appropriate structure of aggregates using the tillage implements, the conservation of water resources in agricultural lands, especially in semi-arid and arid regions, is of great importance (Barzegar et al., 2004). The lack of proper management in the use of tillage implements and the burning of crop residues have caused the soil of semi-arid and arid regions to be exposed to wind erosion (Helm, 2005). Conservation tillage is the proper management in the use of machinery by controlling the crop residues and creating a barrier to minimize the water evaporation loss. This would be especially useful for semi-arid and arid territories, however, in developing countries (including Iran), the tillage machines cannot implement and perform conservation tillage (Shahgholi and Moinfar, 2021). Compared to the conventional tillage method, in addition to reducing the number of agricultural operations, conservation tillage prevents the moisture loss, soil structure degradation, and oxidation of crop residues and this increases water efficiency (Bayhan et al., 2005). All researchers are unanimous in terms of the benefits of conservation tillage, but the effects of climate conditions are different, as the benefits of conservation tillage vary according to the conditions from a region to another (Stot et al., 2001). In a study on leaving crop residues to increase soil organic matter, Roozbeh and Rajaie (2021) found that, for a sustainable production, the crop residues should remain at least by 58% on the soil surface to increase soil organic matter and decrease soil erosion.

The main aim of research was to determine and compare the performance of mouldboard plough and paraplough equipped with three types of wings at different working depths and forward speeds in terms of the MWD of the soil aggregates. Moreover, the crop residues left on the soil surface after performing the tillage operations by these implements were investigated. By considering the soil aggregation and the crop residues remaining on the soil surface after the tillage operation, the suitability of employment of winged paraplough subsoiler instead of mouldboard plough in the arid and semi-arid areas for the conservation tillage was evaluated.

Material and methods

Experimental design and setup

The trials were conducted at the research farms of Mohaghegh Ardabili University (48° 17′ 35″ E longitude, 38° 12′ 40″ N latitude, and 1350 m altitude above sea level), where the residues of wheat from the previous cultivation remained on the ground. Trials were performed at three depths of 0–10; 0–20; 0–30 cm, and three forward speeds of 2, 5, and 7 km·h^{-1} using mouldboard plough and paraplough with three wing modes (Askari, et al., 2018) – without wings, with backward wings and with forward wings (Fig. 1) – in loamy-clay soil (Cambisols in World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB, 2015)).

The soil of the experimental site was clay loam (Cambisols in WRB – IUSS Working Group WRB, 2015). The soil moisture and other properties were measured at three ranges of

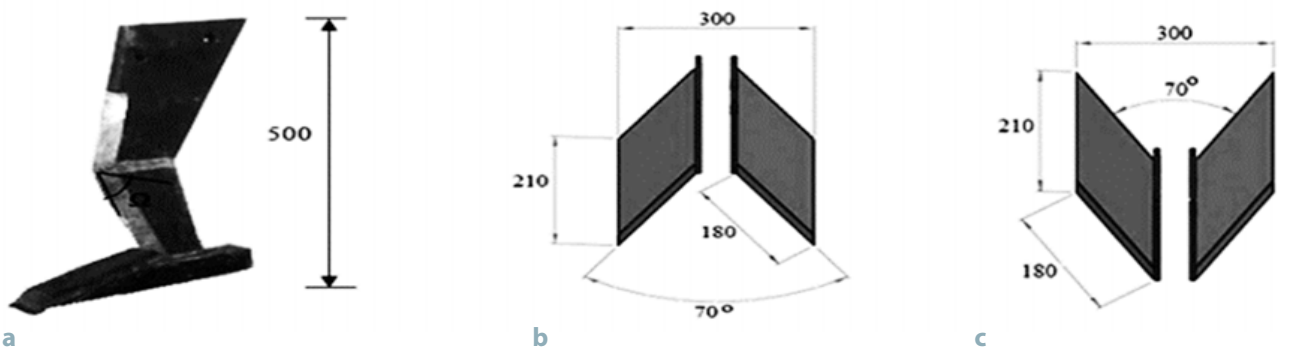


Fig. 1 a – paraplough without wing; b – top view of forward wings; c – top view of backward wings

Table 1 Analysis of soil at the experiment site

Property	Value
Sand (0.02–2 mm)	41 g 100 g^{-1}
Silt (0.002–0.02 mm)	28 g 100 g^{-1}
Clay (<0.002 mm)	31 g 100 g^{-1}
Organic carbon	0.29 g 100 g^{-1}
Dry bulk density (0–10 cm)	948 kg m^{-3}
Dry bulk density (0–20 cm)	1004 kg m^{-3}
Dry bulk density (0–30 cm)	1112 kg m^{-3}
Moisture content (ds) (0–10 cm)	7.76 g 100 g^{-1}
Moisture content (ds) (0–20 cm)	11.24 g 100 g^{-1}
Moisture content (ds) (0–30 cm)	18.46 g 100 g^{-1}

ds – dry soil

soil depth (0–10 cm, 10–20 cm, and 20–30 cm). Selected characteristics of Ardabil agricultural research centre are presented in Table 1.

A two-wheel drive tractor (Massey Ferguson, MF-285) with a 75-hp engine equipped with precision measuring instrument systems was utilized for the purposes of experiment. A total of 180 plots were performed in a RCBD and each plot was 2.5 m wide and 15 m long. The mouldboard plough was a mounted implement and included three bottoms, which is a standard plough produced in Iran. The plough bottoms were replaced by paraplough shanks in a manner that its working width was the same as the width of mouldboard plough (Fig. 2).

Soil mean weight diameter and crop residue measurements

To measure the degree of soil pulverization, the MWD as an index of aggregates was calculated as follows (Salar et al., 2013):

$$MWD = \sum (W_i \cdot D_i) / W_t \quad (1)$$

where: MWD – mean weight diameter of aggregates (mm); W_i – weight of soil remaining on sieve (g); W_t – total weight of pulverized soil in each test sample (g); D_i – diameter of aggregates (sieve size) (mm)

The standard sieves with different sizes were used to determine the diameter of aggregates. Loosened soil inside the profile was removed gently by hand and shovel. Subsequently, different soil samples were taken at three different depths (0–10 cm; 10–20 cm; 20–30 cm) from two sides of trench using a soil sampler with minimum soil structure change. For experiments at 0–10 cm depth, the average result was obtained based on three replications. Considering 0–20 cm depth range, the average results were based on 3 replications at each depth range of 0–10 cm and 10–20 cm and 6 replications in total were reported for this case. For 0–30 cm operating depth, the average results were based on 3 replications at each depth range (0–10 cm; 10–20 cm; 20–30 cm), therefore 9 replications in total were conducted and presented. Obtained samples of each plot were sieved by hand shaking for approx. 30 s to eliminate the crushing effect of shaker on soil particles. The sieves used in this study had the opening sizes of 19.05 mm, 11.125 mm, 4.75 mm, 4 mm, 2 mm, 1 mm, 0.5 mm, 0.125 mm, and 0.075 mm. Furthermore, a GP30K scale with the precision of 0.1 gr was used to weigh the remained soil samples on each sieve.

The percentage of crop residues remaining on the soil surface was measured using a 1 × 1 m interweaved frame consisting of 100 squares of 10 × 10 cm, each square representing one percent. Before the tillage, the frame was randomly placed in each plot. Subsequently, after the tillage, the frame was again placed in the same place of that plot. After placing the frame on the ground, the weeds were counted manually. This was conducted before and after tillage and the average of weeds was determined for each plot. By comparing the crop residue before and after tillage, the percentages of buried residue and remained residue were determined (Fig. 3) (Askari et al., 2018).

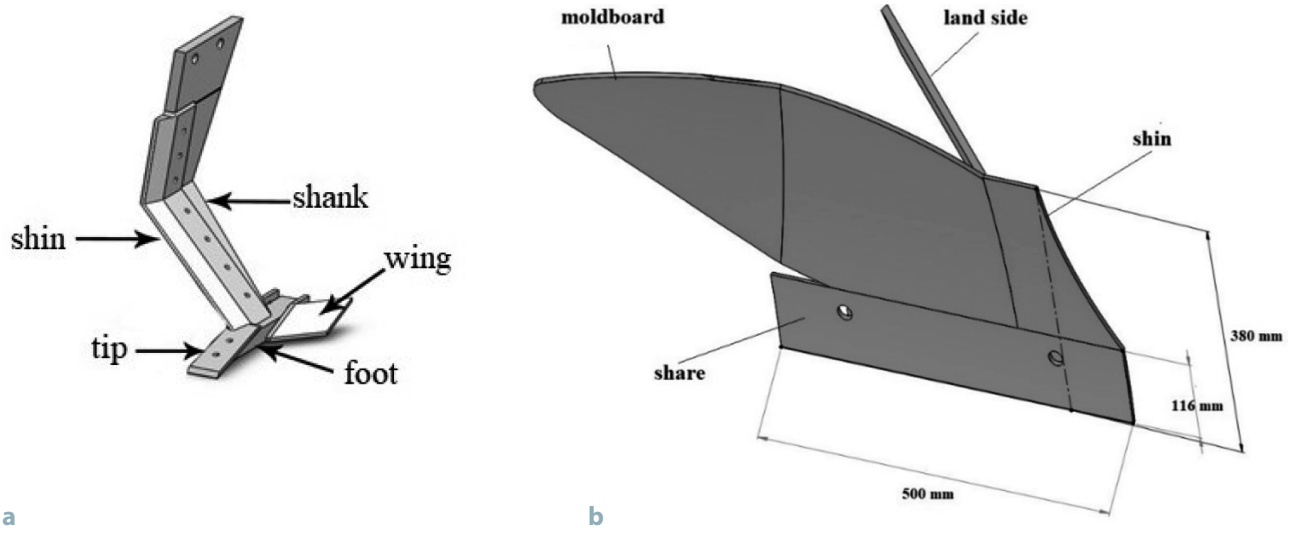


Fig. 2 a – paraplough tine and its components; b – mouldboard bottom and its components and dimensions



Fig. 3 Crop residue condition in the field before tillage (a) and after tillage (b)

The quality of tillage and ploughing operations is determined by examining the compaction of the soil under plough tine – for this, the soil cone index (CI) (as a measure of agricultural soil compaction) was measured using a manual cone penetrometer (CP20). It was equipped with cone diameter of 20.27 mm and tip angle of 60 degrees; its penetration speed was 30.5 mm·s^{-1} and sampling rate was 40 Hz. The CI was measured at three different points with three replications at each plot at depth of up to 48 cm before and after the tillage operations. Then, the average of 9 measurements was represented as CI of each plot.

Draft and travel speed measurement

In order to measure the tractor forward speed, the fifth wheel mechanism was utilized (Fig. 4). This wheel was equipped with an electronic odometer (pulse measurement) that senses the gear teeth installed on the centre of wheel and generates the pulse. To obtain the tractor forward speed, the encoder signal (HZ) was converted as follows:

$$S = \frac{1}{26.96}(HZ - 530.09) \quad (2)$$

where: S – tractor forward speed, m·s^{-1}



Fig. 4 a – mouldboard plough installed on dynamometer and connected to the tractor using three-point hitch; b – paraplough with backward wings; c – fifth wheel mechanism for measuring real forward speed

To measure the depth, a gauge wheel was used on the implement frame. The shank that provided the connection between the wheel and the frame had three positions to provide three desired depths, which allowed the implements to operate at the specified depth and prevent the implement from penetrating to lower depths. To ensure the accuracy of operating depth of the implements, the desired depths were manually measured, and the gauge wheel performance was assessed.

After the data collection, statistical analysis of data was performed using SAS software (version 9.1). The mean comparison of data was conducted using the Duncan's multiple range test (p <5%).

Results and discussion

The three-way interaction effect of parameters on MWD of soil aggregates

Table 2 shows the results of comparing the triple interaction of tillage implement type, forward speed and operating depth on the MWD of aggregates. The highest MWD of 13.66 mm occurred using paraplough without wings at 0–30 cm depth and 7 km·h^{-1} speed. The least MWD of aggregates – 1.92 mm – also occurred using paraplough with backward wings at 0–10 cm operating depth and 2 km·h^{-1} speed. The latter arrangement is suitable for planting the seed of plants such as wheat, barley, alfalfa, chickpea and lentil, which need to be planted at a depth of less than 10 cm. All tillage implements used at all levels of forward speed caused significant increases in the MWD of aggregates with increasing operating depth.

Figure 5 shows the triple interaction effect of implement type, forward speed and operation depth on the MWD of aggregates, indicating that the MWD of aggregates was affected significantly by the type of implement, which is consistent with the research results of Barzegar et al. (2004) and Nunes et al. (2020). The comparison of the effects of the paraplough without wings and the winged paraplough on the MWD of aggregates showed that addition of wings to both sides of paraplough reduced the aggregate size (Salar et al., 2013). Moreover, the performance comparison between winged paraplough and mouldboard plough suggests the proper performance of winged paraplough, allowing replacement of mouldboard plough with winged paraplough (especially paraplough with backward wings) to reduce energy consumption and create suitable pulverization for seedbed production. Furthermore, the MWD of paraplough with forward wings was lower than the MWD of mouldboard plough at all experimental conditions.

Figure 5 depicts the effect of forward speed and depth increments on the MWD of aggregates during the tillage operations. Although the minimum value of 1.92 mm was occurred at velocity of 5 km·h^{-1}, increment in operation speed from 2 to 5 km·h^{-1} was not significant on MWD change. Several investigations (Boydas and Turgut, 2007) conducted at a range with the maximum value of 5 km·h^{-1} showed that, with increasing forward speed, the MWD of aggregates reduced significantly. In the research presented, as the speed increased from 5 to 7 km·h^{-1}, the size of aggregates increased significantly, which is due to the formation of larger fragments when cutting soil at high speeds especially at the maximum operation depth of 0–30 cm. The increment in MWD of aggregates at the forward speed of above 5 km·h^{-1} is consistent with the results of studies of Abbaspour-Gilandeh and Sedghi (2015). Therefore, it can be concluded that, due to the low MWD at low speeds compared to the high speeds, it is better to perform the tillage operations at optimum speed range of 3–5 km·h^{-1} to achieve a suitable seedbed (Kabiri and Zareian, 2002).

Figure 5 also indicates the effect of furrow depth on the MWD of aggregates. The MWD increased with ploughing depth with maximum values 9.15 and 13.15 mm at 0–30 cm

Table 2 Comparison of triple interaction effect of tillage implement type, forward speed and operating depth on the MWD of aggregates

Tools	Speed (km·h^{-1})	Depth (cm)		
		0–10	0–20	0–30
Paraplough without wings	2	3.03**	3.45**	4.48**
	5	3.19**	3.76**	4.66**
	7	6.27**	7.23**	13.66**
Paraplough with backward wings	2	1.92**	2.6**	2.8**
	5	2.23**	2.81**	3.11**
	7	2.88**	3.1**	4.64**
Paraplough with forward wings	2	2.49**	3.12**	3.5**
	5	2.6**	3.23**	4.23**
	7	3.42**	3.8**	4.55**
Mouldboard plough	2	4.04**	4.22**	4.45**
	5	4.12**	4.25**	4.72**
	7	7.27**	8.12**	9.15**

** P <0.01; ns: not significant

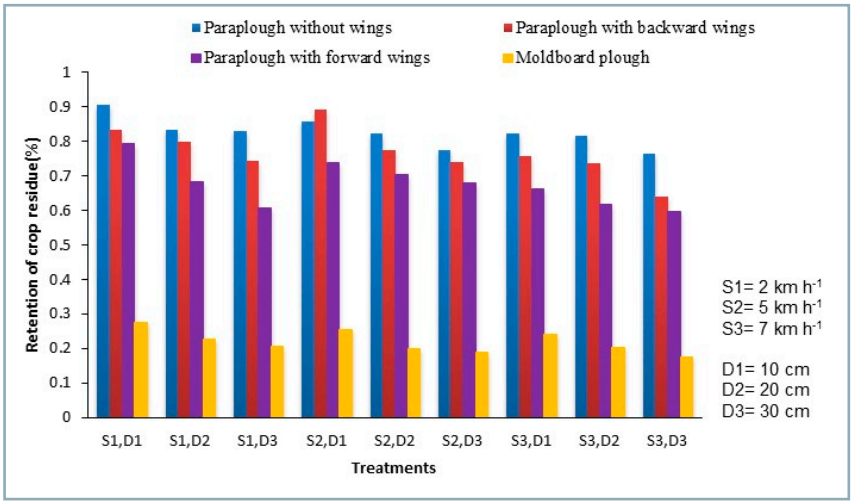


Fig. 5 Effects of tillage implement type, forward speed and operation depth on the MWD of aggregates

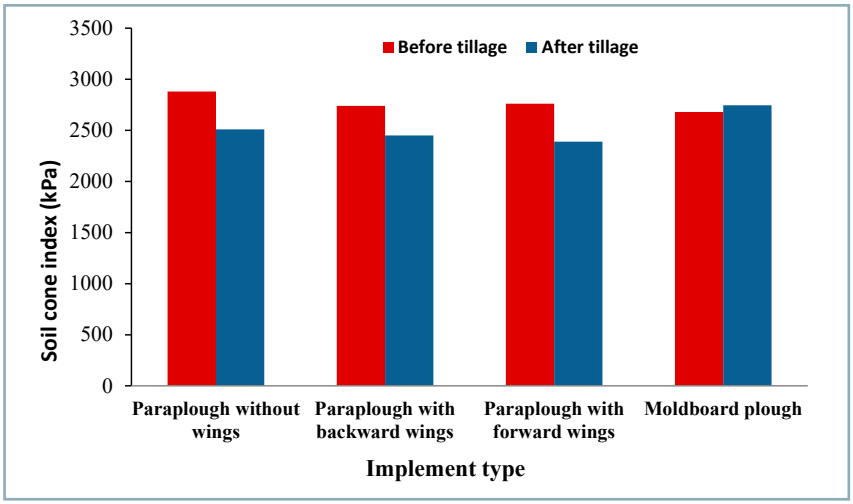


Fig. 6 Soil cone index in soil layer below plough bottom (at 30–50 cm depth range) created by different implements before and after tillage operations

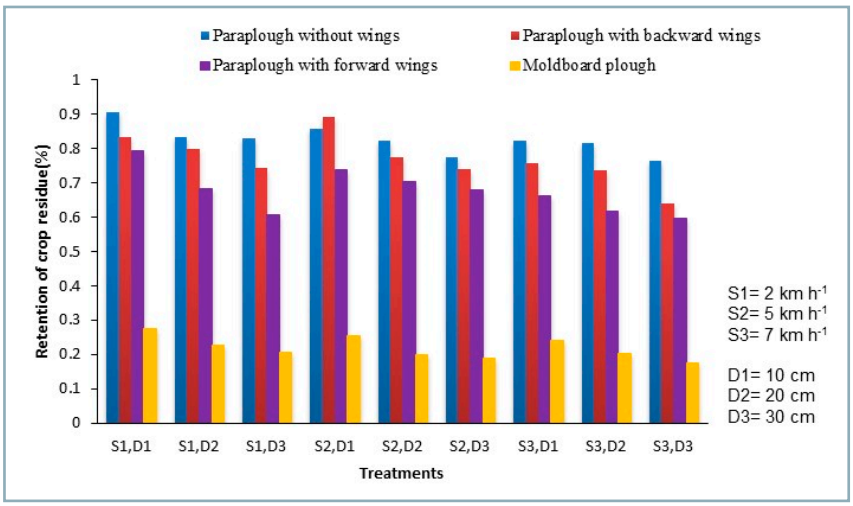


Fig. 7 Effect of tillage implement type, forward speed and operation depth on preservation of crop residues

operation depth using paraplough without wings and mouldboard plough. At 0–20 cm depth, there was no significant increase in the MWD of aggregates. The least MWD value of aggregates occurred at 0–20 cm depth range with an average of 3.58 mm, which shows that, in terms of soil pulverization, this range is suitable for the direct planting of crops. This is consistent with the study of Dal Ferro et al. (2014) who considered the most appropriate size of aggregates for favourable seedbed to be varying from 1 to 5 mm. The results showed that, with increasing the operating depth, the MWD of aggregates increased, which is consistent with the research results of Boydas and Turgut (2007) and Dal Ferro et al. (2014). In general, it can be stated that the most suitable range of operating depth for the implements utilized is up to 20 cm. However, with operating depth higher than 20 cm, the MWD of aggregates significantly increased.

Seedbed compaction after tillage

Figure 6 shows the CI values before and after the tillage operations using the mouldboard plough and the paraplough with three wing types. Considering the mouldboard plough, the CI increased at 30–50 cm depth range after the tillage (2745 kPa) in contrast to the CI at the same depth before the tillage (2680 kPa). Therefore, it can be stated that the mouldboard plough utilization caused the compaction in the plough bottom due to the pressure of the tilling tool exerted on the soil layer, which is consistent with the studies of Younesi Alamouti and Navabzadeh (2007). The use of paraplough with and without the wings did not induce any soil compaction under plough bottom; furthermore, the CI decreased by 13% on average in contrast to the values before tillage, which is consistent with the studies of Askari et al. (2018) and Salar et al. (2013). The lower CI values of paraplough represent a great advantage since the main purpose of this study was to investigate the possibility of replacing mouldboard plough with paraplough in order to create conservation tillage. It can be thus concluded that, in terms soil

compaction, the use of paraplough is more preferrable to mouldboard plough utilization.

Crop residues preservation

The effect of tillage implement type on the crop residue remaining is provided in Fig. 7. The highest percentage of preserved crop residues (90%) was obtained using paraplough without wings and the lowest percentage of crop residues (17.6%) was observed in operation employing mouldboard plough. The average percentage of remaining crop residues utilizing the paraplough with backward wings was 77%, which was higher than the crop residue percentage value observed for paraplough with forward wings (68%). Due to the shape and form of the wings, paraplough with the forward wings carried a certain amount of crop residues during the operation and transferred them out of the plot. It can be stated that a high percentage of crop residues remained on the farm surface while working with paraplough, which is suitable for preventing the evaporation, as well as soil erosion (Roozbeh and Rajaie, 2021).

Additionally, the impact of forward speed on the crop residues preservation is also suggested in Fig. 7 – the percentage of crop residues remaining on the soil surface decreased with increasing the forward speed, which is consistent with the research of Kabiri and Zareian (2002) who investigated the effect of ploughing depth and forward speed of tractor on the size of created clods and the burial rate of crop residues using the mouldboard plough and reported that, with increasing the speed, the burial of crop residues increased.

Figure 7 depicts the impacts of operating depth on the preserved percentage of crop residues. The high average percentage of preserved crop residues – 63% – occurred at 0–10 cm depth; the lowest average percentage of preserved crop residues (61%) occurred at 0–30 cm depth. As the operating depth increased, the amount of crop residues remaining on the soil surface decreased, which is consistent with the conducted studies by Hůla et al. (2005) and Kabiri and Zareian (2002) who found that the percentage of crop residues remaining on the soil decreases with increasing depth.

Conclusion

The design of experiment consisted of three forward speeds and three operating depths with four tillage tool modes (mouldboard plough, paraplough without wings, with backward wings, and with forward wings). The aggregates mean weight diameter (MWD), soil cone index, surface crop residues, and tillage tool draft were used to evaluate the performance of the tillage implements. The results indicate significant impacts of implements, operating depth and forward speed on the MWD of aggregates and percentage of crop residue remaining on the soil. Moreover, the triple interaction effects of tilling implement type, tractor forward speed and operating depth proved to be significant on the MWD and residue remaining on the soil at $P < 1\%$. Increasing the forward speed and operating depth resulted in an increase in the MWD of aggregates. The least MWD of 2.9 mm occurred using paraplough with backward wings and the highest MWD of 5.59 mm occurred using mouldboard plough. The percentage of residue remaining on the soil decreased with increase in the forward speed and operating depth. The highest percentage of preserved residues (82%) was obtained using paraplough without wings, and the least value (22%) was obtained by the mouldboard plough. Considering the MWD of aggregates, percentage of crop residue remaining on the soil surface and required draft, the results showed that paraplough with wings (especially the paraplough with backward wings) can be used as a suitable implement for the conservation tillage, especially in the semi-arid and arid areas in place of mouldboard plough.

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