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Research Article/Araştırma Makalesi

Comparison of various single-disc type furrow openers used in no-till seeders in terms of furrow properties and acting forces

Doğrudan ekim makinalarında farklı tek diskli tip gömücü ayakların çizi profili ve etki eden kuvvetler yönünden karşılaştırılması

Yusuf AYDIN[1], Ahmet ÇELİK[2], Mehmet Zahid MALASLI[3*]

[1]Ministry of Agriculture and Forestry, Sivas Provincial Directorate, Divriği District Directorate, 58300 Divriği, Sivas, Turkey
[2]Department of Agricultural Machinery and Technologies Engineering, Faculty of Agriculture, Atatürk University, 25240 Erzurum, Turkey
[3]Department of Biosystems Engineering, Ereğli Faculty of Agriculture, Necmettin Erbakan University, 42310 Ereğli, Konya, Turkey

[1]https://orcid.org/0000-0003-3952-9932; [2]https://orcid.org/0000-0001-6225-3220; [3]https://orcid.org/0000-0002-5845-1272

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***Address for Correspondence:**
Mehmet Zahid Malaslı
e-mail:
mzmalasli@erbakan.edu.tr

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ABSTRACT

The purpose of this study was to examine the impact of various single-disc type furrow openers used in no-till seeders on furrow aspects and forces acting on the discs at various soil moisture contents, soil compaction levels, and seeding depths in soil bin. Factors included plain, notched, wavy, concave, and fluted types of disc coulters, two soil moisture levels (12-18%), two soil compaction levels (2-3 MPa), and two seeding depths (50-75 mm). According to the results, the plain, notched, and fluted type discs had the lowest vertical, draft, and side force, while the wavy type disc had the maximum vertical force, draft force, and side force and the concave type disc had the highest side force. The vertical, draft, and side force requirements of all furrow openers were found to be lower in loose soils with low moisture content and greater in compacted soils with high moisture content. Fluted, concave, and wavy-type discs produced the best results in terms of the specific vertical, specific draft, and specific side forces, respectively. While the highest furrow cross-sectional area was obtained in the wavy disc, this furrow opener was followed by concave, notched, fluted, and plain-type furrow openers, respectively.

Key Words: No-till, disc type furrow opener, furrow profile, soil compaction, soil bin

ÖZ

Bu çalışmanın amacı, doğrudan ekim makinalarında kullanılan farklı tek diskli tip gömücü ayakların, farklı toprak nem içeriklerinde, toprak sıkışma seviyelerinde ve ekim derinliklerinde, çizi profiline ve disklere etki eden kuvvetler üzerindeki etkisini toprak kanalında incelemektir. Faktörler arasında düz, kertikli, dalgalı, konkav, yivli tip disk açıcılar, iki toprak nem seviyesi (%12-18), iki toprak sıkıştırma seviyesi (2-3 MPa) ve iki ekim derinliği (50-75 mm) yer almaktadır. Sonuçlara göre, düz, kertikli ve yivli disklerin minimum düşey, yan ve çeki kuvvetlerine sahip olduğu, dalgalı tip diskin ise maksimum düşey kuvvet, çekme kuvveti ve yan kuvvete sahip olduğu ve konkav tip disklerin ise en yüksek yan kuvvete sahip olduğu gözlemlenmiştir. Tüm gömücü ayakların düşey, çekme ve yan kuvvet gereksinimlerinin gevşek, az nem içeriğine sahip topraklarda daha düşük, buna karşılık; sıkıştırılmış, yüksek nem içeriğine sahip topraklarda daha yüksek olduğu bulunmuştur. Yivli, konkav ve dalgalı tip disklerin sırasıyla özgül düşey, özgül çekme ve özgül yan kuvvetler açısından en iyi sonuçları verdiği tespit edilmiştir. En yüksek çizi kesit alanı dalgalı diskte elde edilmiş olup, bu gömücü ayağı konkav, kertikli, yivli ve düz tip çizi açıcılar izlemiştir.

Anahtar Kelimeler: Doğrudan ekim, diskli tip gömücü ayak, çizi profili, toprak sıkışıklığı, toprak kanalı

Introduction

A furrow opener is the most important unit of no-till seeders (Seidi et al., 2010; Troger et al., 2012). Furrow openers open a furrow with sufficient depth and width in residue field conditions and place the seeds into the furrow. Depending on the soil type and working conditions, many types of furrow openers are available (Karayel and Özmerzi, 2007; Altikat et al., 2013).

Furrow openers comprised of hoes, chisels, winged chisels, reverse T's, discs types (single disc, double disc, and three disc rotating discs driven by tractor pto) are used in reduced tillage and direct seeding methods (ASABE, 2013). Single and double disc type furrow openers are used more widely (Tajuddin and Balasubramanian, 1995) to expose the soil to less impact and compaction (Karayel and Šarauskis, 2011). The furrow opener used in no-till seeders firstly cuts the soil and residue well and leaves the existing residue on the surface without burying it in the furrow (Doan et al., 2005).

Single disc type furrow openers which are commonly used in no-till seeders, can be large-diameter, flat, wavy or notched type. The reason why very different types of single disc type furrow openers are available is because they penetrate well into soil in residue field conditions and have a high residue cutting success (Murray et al., 2006). Plain discs that can cut the soil better are also easy to self-sharpen. Since the wavy type discs are self-sharpening, the risk of soil adhesion is low. Although narrow fluted type and fluffy hole type discs loosed soil sufficiently, they have limited use in high clay content and sticky soil conditions. Although wide fluted discs have the ability of opening the desired furrows in easily dispersible soils, in some soil conditions, they can form large clods that cannot cover the seeds in the furrow as expected (Çelik, 2009).

Soil-tool interactions are explained in terms of draft and vertical forces, as well as soil particle displacement (Conte et al., 2009; Lisowski et al., 2016). Force requirement of the disc-type furrow opener is influenced by soil moisture content, soil texture class, penetration resistance, residue level, furrow opener geometry, and rotational speed of the opener (Kushwaha et al., 1986). There are various studies on the performance of different disc-type furrow openers. In terms of sugarcane residue-cutting capabilities and vertical force requirements, tooth-type disc openers outperformed smooth-type single-disc furrow openers (Magalhaes et al., 2007; Bianchini and Magalhaes, 2008). Ahmad et al. (2015) stated that the diameter, seeding depth, and forward speed had significant effects on the draft and vertical forces acting on the double disc opener having various diameters. The mean draft values were 648.9, 737.2, and 784.6 N, while the vertical forces were 904.7, 1553.9, and 1620.4 N for the openers with diameters of 330, 450, and 600 mm, respectively. Ahmad et al. (2017) studied the draft and vertical force requirements, as well as straw-cutting ability of double disc with smooth-edge, notched, and toothed single-disc furrow openers in no-till paddy fields. According to the findings of this study, furrow opener type, operating depth, and speed, all had a substantial influence on draft and vertical forces, with double disc-type furrow openers having the maximum draft and vertical force. Ov et al. (2008) investigated the force needs of plain and several types of wavy disc furrow openers used in no-till planting in soil bin conditions at varied forward speeds. They stated that while maximum draft force is obtained in plain disc, maximum vertical force occurs in 26 wavy discs. Magana et al. (1994) evaluated the residue cutting performance of notched and smooth type coulters with 425 mm diameter and determined that the smooth coulter had a poorer sugarcane cutting capacity than the notched type coulter. Zeng et al. (2021) three vertical tillage discs with different shapes, namely notched, plain, and rippled, were tested in a soil bin at two different working depths, shallow (63.5 mm) and deep (127 mm). The study was conducted using corn residue. Deep working depth was found to result in 5.1% higher residue mixing, 53.4% greater soil cutting forces, and 34.9% larger soil displacements as compared to the shallow depth.

In the no-till seeding technology, the furrow

profile is an important soil disturbance component. The cross-sectional area is the distance between the furrow profile and the furrow bottom, whereas the spoiled soil area is the distance between the original profile and the soil surface after it has been disturbed. These parameters can be determined by means of graphical representations and different representations of their areas can be surveyed by means of planimetric techniques and/or computer software programs, as recommended by various researchers (Conte et al., 2009; Santos et al., 2010; Hasimu and Chen, 2014; Francetto et al., 2016).

This study was carried out to test the single disc type furrow opener with different properties, which are widely used in no-till seeders, at different soil moisture content and soil compaction levels. The aim of the experiments carried out under controlled soil bin conditions was to determine the most suitable furrow opener in terms of some important soil physical properties as well as the furrow profile properties and the forces acting on the discs from different directions.

Material and Methods

Soil bin

This research was carried out in the soil bin conditions located at Atatürk University, Agricultural Machinery and Technologies Engineering Laboratory. The soil bin is 16 m long, 2.5 m wide and 0.8 m deep. The soil bin carriage has a slide that can be moved manually in both directions on the X-axis and a shaft that can be moved in both directions with the help of an electric motor along the Y-axis (Fig. 1).

The soil preparation stages before the experiment consisted of cultivating with a rotary hoe, gaining the appropriate moisture level with a pulverization, periodically applying the soil to the desired compaction level with the wavy and flat type rollers used by mounting on the soil bin carriage, and leveling it with a scraper blade. Soil samples taken from the plots determined to represent the soil bin were weighed with a precision scale with a sensitivity of 0.01 g.

An electric motor with a power of 15 kW was used as the power unit of the soil bin carriage. The speed of the carriage which was adjusted by the speed control unit, was kept under control during the trials with a speed radar mounted on it. In the study, 6 load cells with a capacity of 2 tons were used to reveal the draft, vertical, and lateral forces in different disc-type furrow openers. The values taken from the load cells and speed radar were stored by the data logger and sent to the computer.

Figure 1. Soil bin carriage

This research was carried out to compare the performance of five various single disc coulters which are commonly used in no till seeders in different soil conditions. For this purpose, the discs on the furrow opener unit were designed and manufactured for easy change and use. The furrow openers were made of steel with a diameter of 460 mm and a thickness of 4 mm (Fig. 2). The furrow

openers were connected to the soil bin carriage by means of a specially designed disc connection unit.

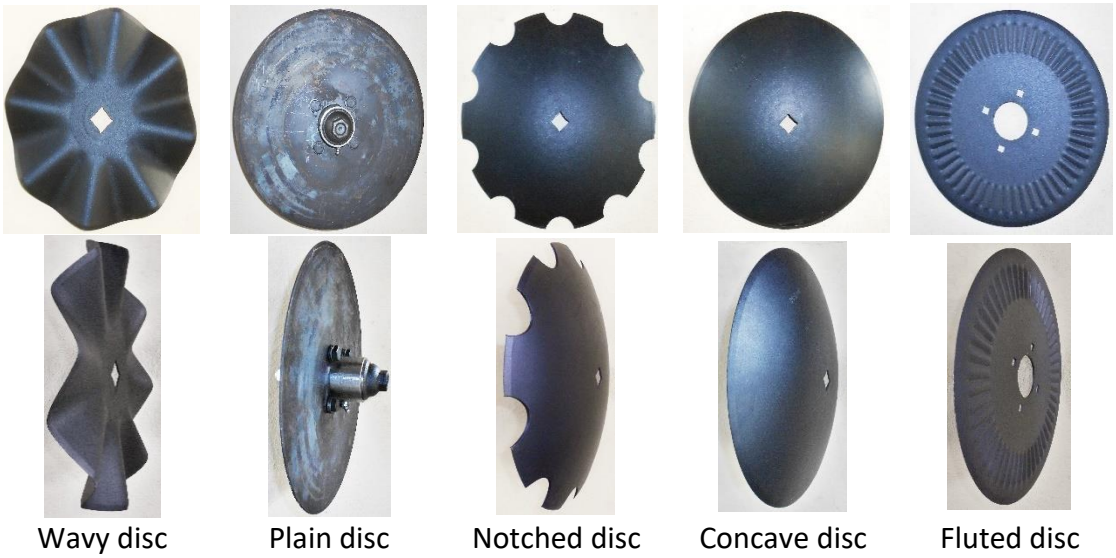

Figure 2. The disc type furrow openers used in the study

Experimental design

In this study, which was carried out under controlled soil bin, five different disc type furrow openers, two different soil compaction levels, two different soil moisture levels and two different planting depths were considered as factors. The research was carried out in three replications according to the divided plots design. The diameter value of 460 mm, which is widely used in no-till seeders, was taken into account for the diameter of the disc type furrow opener with zero tilt and disc angle. Some important parameters considered in the experiment such as working depth, forward speed, soil moisture content and soil compaction level are given in Table 1.

Table 1. Factors and factor levels

Factors	**Level of factors**
Disc types	Wavy, plain, notched, concave and fluted disc
Disc diameters (mm)	460
Forward speed (km/h)	3.6
Seeding depth (mm)	50 - 75
Soil moisture content (% d.b.)	12 - 18
Soil penetration resistance (MPa)	2 - 3

Determination of soil moisture content and penetration resistance

Undisturbed soil samples were taken from 0-5 and 5-10 cm soil depths in four replications, taking into account the working depth before starting the experiments in the soil bin to determine the soil moisture content. After the samples were weighed on a precision scale, they were left to dry in an oven at 105 °C for 24 hours. The soil samples taken from the oven were weighed and their dry weights were obtained and moisture content values were calculated (ASABE, 2015).

The soil compaction level was determined with measurements made with five replications from each plot before the disc opener passed, and the compression effects of the furrow opener in the furrow region were determined with measurements made after the furrow opener passed. The impact was determined with two replication measurements made along the furrow line at 5 cm intervals and a depth of 10 cm from the center of the furrow line and 20 cm towards the edges of the furrows (Malasli and Celik, 2019).

Determination of furrow depth and furrow profile

In the experiments, the furrows were cleaned after the passage of the disc opener and the depths of the furrows were measured using a caliper depth measuring apparatus with two repetitions from each plot. The obtained values

were compared with the measurements made with a profilograph and an evaluation was made.

A rod-type profilograph consisting of 36 aluminum rods spaced at 1 cm intervals placed perpendicular to the direction of advance was used to determine the profiles of the furrows immediately after the passage of the furrow opener (Fig. 3). The values obtained from the measurements made in duplicate from each plot were transferred to graphs and plot profiles were obtained (Jester and Klik, 2005; Karayel and Özmerzi, 2006; Troger et al., 2012).

Figure 3. Rod type profilograph

Determination of vertical, draft, and side forces

The disc-type furrow opener operates under the influence of three important forces: vertical (shear), horizontal (drawn), and side (Abu-Hamdeh and Reeder, 2003; Armin et al., 2017). 6 S-type load cells with a composite error rate of 0.02-0.03%, placed with special connections to the buttress to which the furrow opener is attached, were used to determine these forces (Afify et al., 1998; Aminzadeh, 2014; Zhang, 2016). The signals obtained from the load cells were stored in a data logger (Campbell CR1000 type) and transferred to the computer (Malasli and Celik, 2019).

Statistical analysis

All results from the experiments were subjected to analysis of variance. As a result of the analysis, the averages of the factor levels were subjected to the DUNCAN multiple comparison test. Graphs of the analysis of variance results and graphs of the important interactions were prepared in Excel. SPSS package program was used to analyze the variance of the data obtained from the experiment and compare the means.

Results and Discussion

Results on soil moisture content penetration resistance

The soil moisture content and penetration resistance results after the soil bin preparation and just before starting the experiments are given in Fig. 4. The average soil moisture content and compaction level values during the winter and summer wheat planting periods in Erzurum conditions were taken into consideration in the experiments. Accordingly, the soil moisture content for soil depths of 0-5 and 5-10 cm was 12% and 18%, and the penetration resistance was found to be very close to the target values chosen as 1.7 MPa and 2.6 MPa, respectively (Fig. 4).

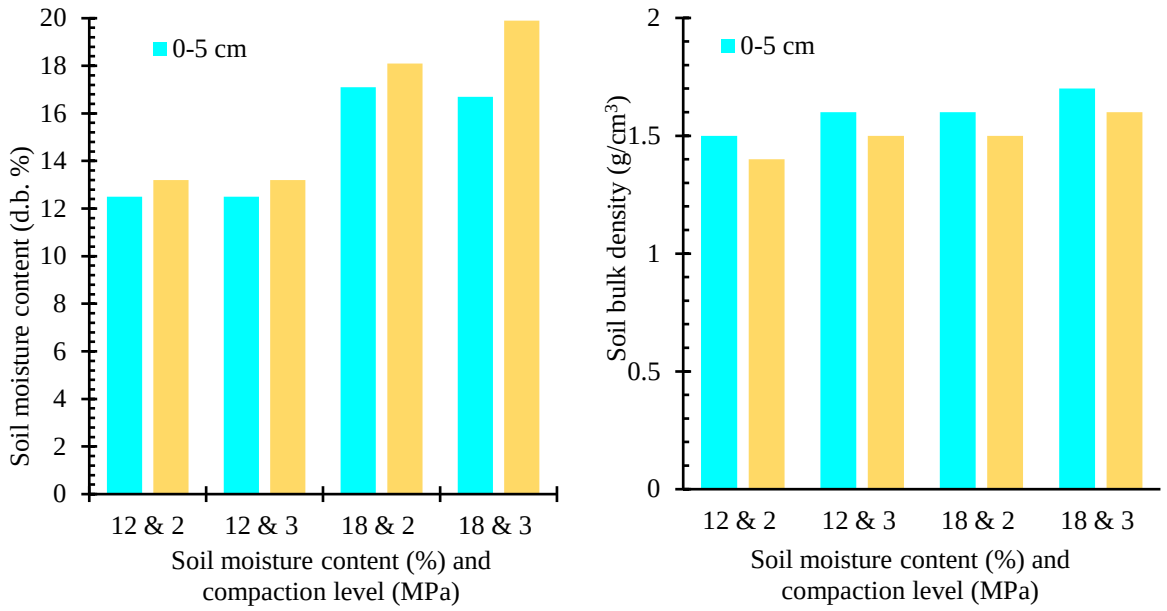

Figure 4. Soil moisture content and penetration resistance values

Results on draft, vertical, and side forces

Instantaneous measurements were made in the study from the load cells to determine the effects of different soil moisture contents, compaction levels, and working depths on the forces acting on the single disc-type furrow openers. The obtained data were recorded by the data logger and transferred to the computer and evaluated. The results of the analysis of variance applied to the draft, vertical and side forces are given in Fig. 5. According to the obtained results, the lowest vertical force was determined in the flat type disc and the lowest side force and draft force were determined in the notched type disc furrow opener. Ahmad et al. (2017) stated that the highest vertical and draft forces occur in double disc, notched disc, toothed disc and flat type single disc furrow openers, respectively. On the other hand, the highest draft force and vertical force were found in the wavy type, and the maximum side force was in the concave type disc opener. McKyes (1985), stated that tillage equipment with a wider cutting width demand more draft force. Similarly, Darmora and Pandey (1995) stated that seven furrow openers with different widths create different draft forces. Hasimu and Chen (2014) stated that winged hoe type openers have higher draft force and specific draft requirements than other hoe type openers because they open a wider furrow.

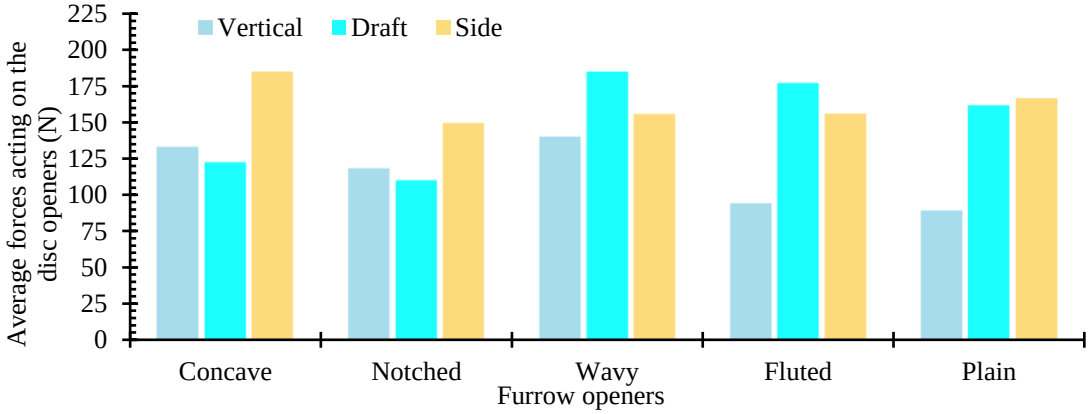

Figure 5. Average vertical, draft, and lateral force values acting on the furrow openers

The results related to the effects of different soil compaction, moisture content and working depth levels on the forces acting on different types of discs in the study are given in Fig. 6. Accordingly, the effect of different soil compaction levels on the forces acting on the furrow openers was found to be statistically insignificant. The side force values for both compaction levels were found to be

higher than those for the draft force and vertical force. The forces on the discs were found to be statistically significant according to the change in soil moisture content. The vertical, draft, and side force requirements of all furrow opener types have been determined to be lower in low soil moisture content and compaction level, and greater in high soil moisture content and compaction level. It was determined that the amount of soil cut by the furrow openers increased with the target furrow depth increasing the force acting on the discs. As with soil compaction and moisture content levels, side force was found to be higher than draft force and vertical force at different furrow depths.

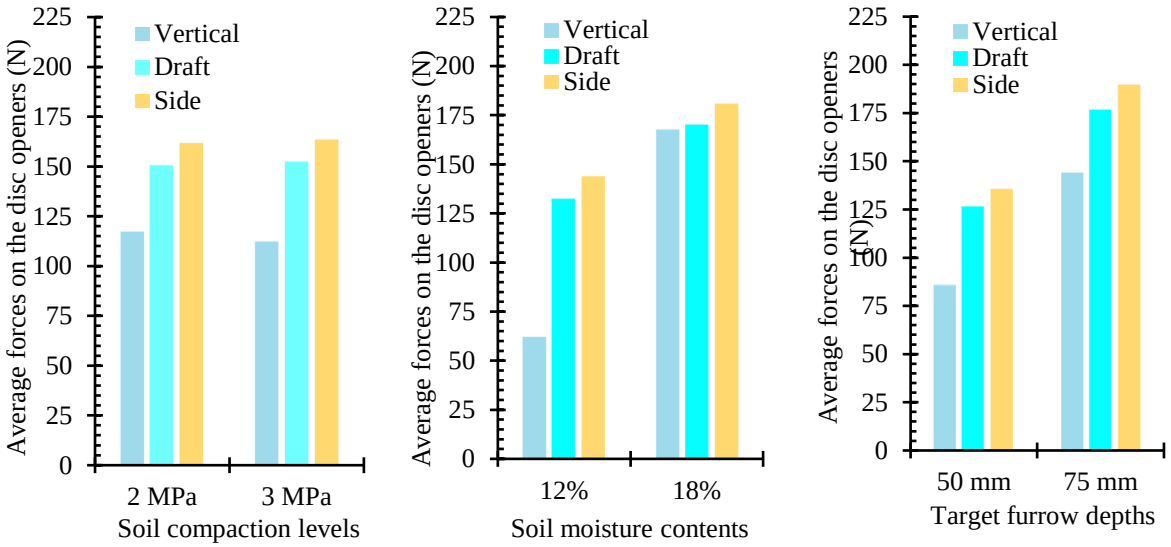

Figure 6. The effects of different soil compaction, moisture content and furrow depth levels on the forces on different disc type furrow openers

Results on specific draft, vertical and side forces

The specific draft force was obtained by dividing the obtained draft averages by the cross-sectional area of furrows. Specific draft force, which is defined as the force per unit soil area in no-till seeders, is considered a good performance indicator. In practice, it is preferred that the specific draft force values are small. Two factors are taken into account for the specific draft force: the draft force requirement and the furrow dimension formed by the furrow opener. The results obtained from the experiments revealed that the smallest specific vertical, side and draft force values were obtained in the fluted, concave and wavy type discs, respectively. While the highest specific vertical force was obtained in the notched type disc, the highest specific draft force and side force were obtained in the plain type disc (Table 2).

Table 2. Specific force values in different disc type furrow openers

Furrow opener type	Specific vertical force kPa	Specific draft force kPa	Specific side force kPa
Concave	53.2 a	54.3 c	78.1 b
Notched	64.3 a	56.4 c	77.4 b
Wavy	57.3 a	76.6 b	65.9 b
Fluted	46.9 a	94.0 a	85.1 ab
Plain	50.5 a	98.3 a	99.9 a
P	0.004	0.000	0.270

The effect of soil compaction levels on specific forces was found to be insignificant. While the specific forces were almost the same in both soil compaction levels, the specific side force was found to be higher than the specific vertical and specific draft force. The specific forces of the furrow openers were statistically significant at 12% and 18% soil moisture levels. The specific forces

increased as the soil moisture content increased (Fig. 7).

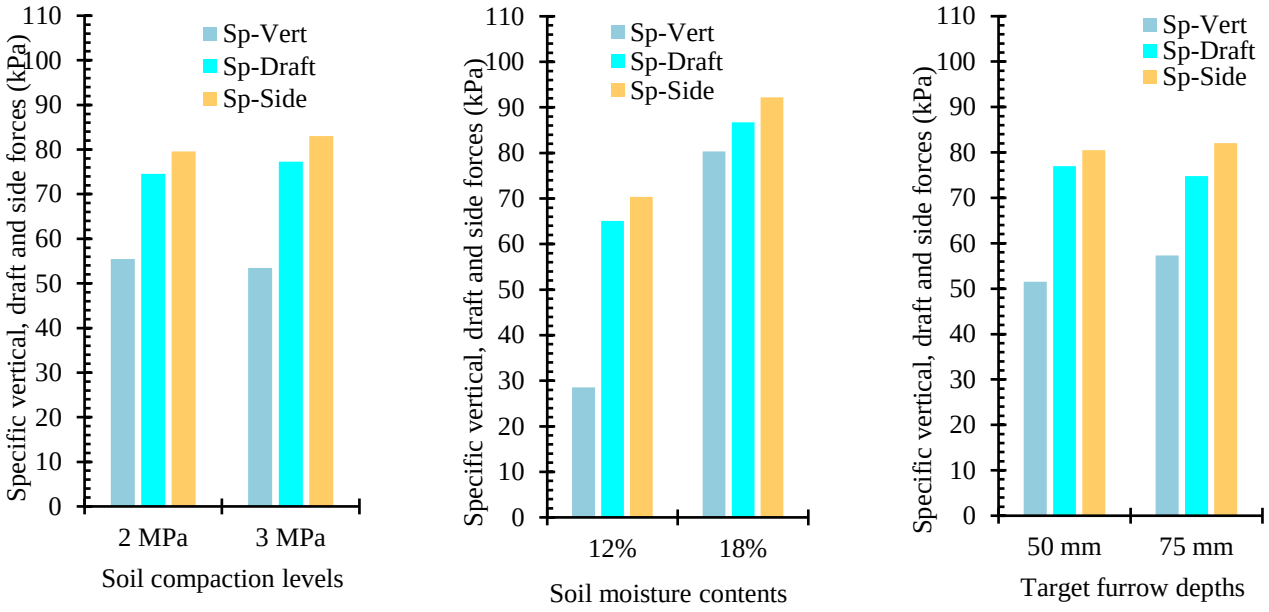

Figure 7. The effects of different soil compaction, moisture content and furrow depth levels on the specific forces acting on different disc type furrow openers

Results on furrow profile

In the study, the furrow depth and furrow width data, which were measured immediately after the furrow opener passed, were transferred to the MATLAB program and the furrow cross-sectional area was calculated. According to the obtained results, the effect of different disc type furrow openers on the furrow width and furrow cross-sectional area was found to be statistically significant. While the highest furrow cross-sectional area was obtained in the wavy disc, this furrow opener was followed by concave, notched, fluted and plain type furrow openers, respectively (Fig. 8). Considering the characteristics of the furrow openers in terms of shape, the highest furrow cross-sectional area was obtained with the wavy disc, as expected, and the lowest furrow cross-sectional area was obtained with the plain type disc. The change in soil compaction level and moisture content did not have a significant effect on the cross-sectional area. The values obtained on the target furrow depth created a larger cross-sectional area in furrow as expected.

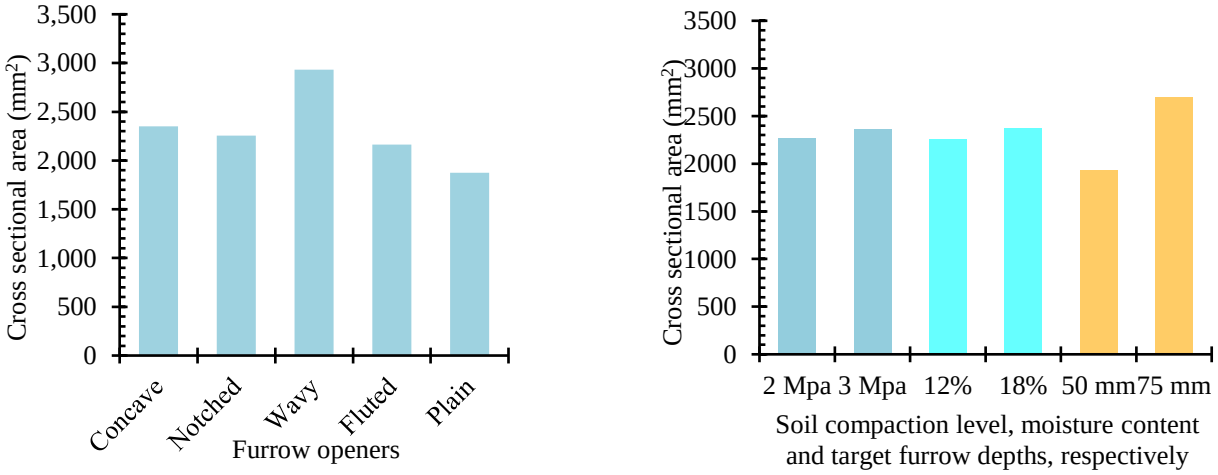

Figure 8. Results on the furrow cross-sectional area

As in the furrow cross-sectional area, the highest furrow width occurred after the passage of the wavy type disc type furrow opener, followed by concave, notched, fluted and plain type discs, respectively. A furrow width of 2/3 of the wavy disc was obtained with the plain disc type furrow opener. For this reason, it is more preferred in no-till since narrow furrows do not cause much soil

deformation. The effect of the soil compaction level and soil moisture level on the width of the furrow was not found to be statistically significant. The variation of the furrow depth according to the target depth significantly affected the width of the furrow. When the depth of the furrow increased from 50 mm to 75 mm, there was an increase in the width of the furrow due to the increased soil deformation, as the furrow opener sank deeper into the soil.

As in the results obtained regarding the furrow width, the changes in soil compaction and moisture content did not create a significant difference in the furrow depth, while the targeted planting depth was found to be statistically significant.

The furrow profiles formed by the different disc-type furrow openers vary depending on the soil moisture content, soil compaction level and the targeted furrow depth (Fig. 9 and Fig. 10). Although the obtained furrow profiles looked similar to each other, more distinctive profiles emerged at a target furrow depth of 75 mm. The furrow profile of each furrow opener at 18% soil moisture content and 3 MPa compaction level was found to be more pronounced and closer to the desired target than 12% soil moisture and a 2 MPa soil compaction level. In addition, values close to the targeted furrow depth were obtained for all furrow opener types at 18% soil moisture and 2 MPa compaction levels.

Considering the profiles formed by the furrow openers, the concave, notched and wavy type furrow openers have formed a wider line than the plain and the fluted type disc. Again, while values close to the targeted furrow depth were obtained in all discs, the amount of degraded soil, which is considered as loosened soil accumulated at the edge of the cut, was higher in concave, notched and wavy type discs.

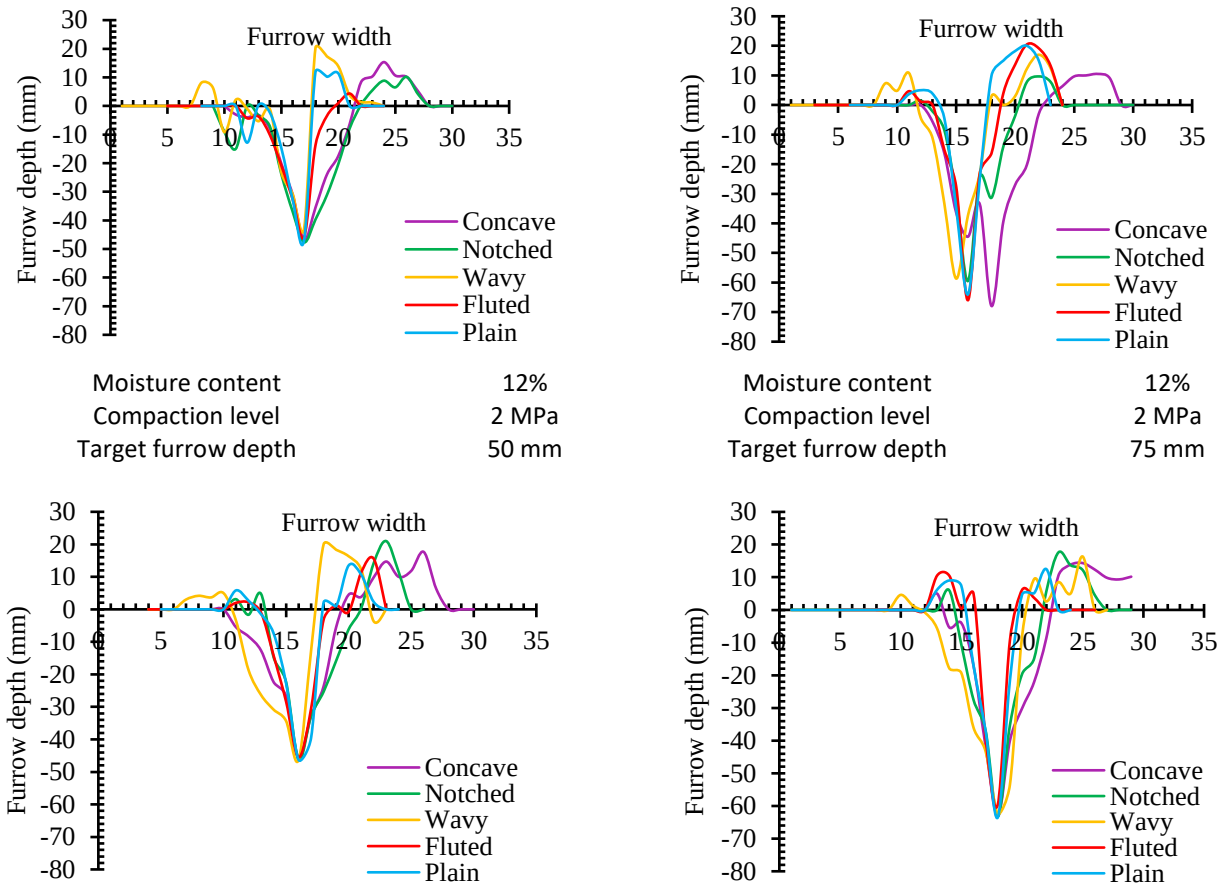

Figure 9. Furrow profiles formed at different compaction levels and furrow depths with 12% soil moisture content

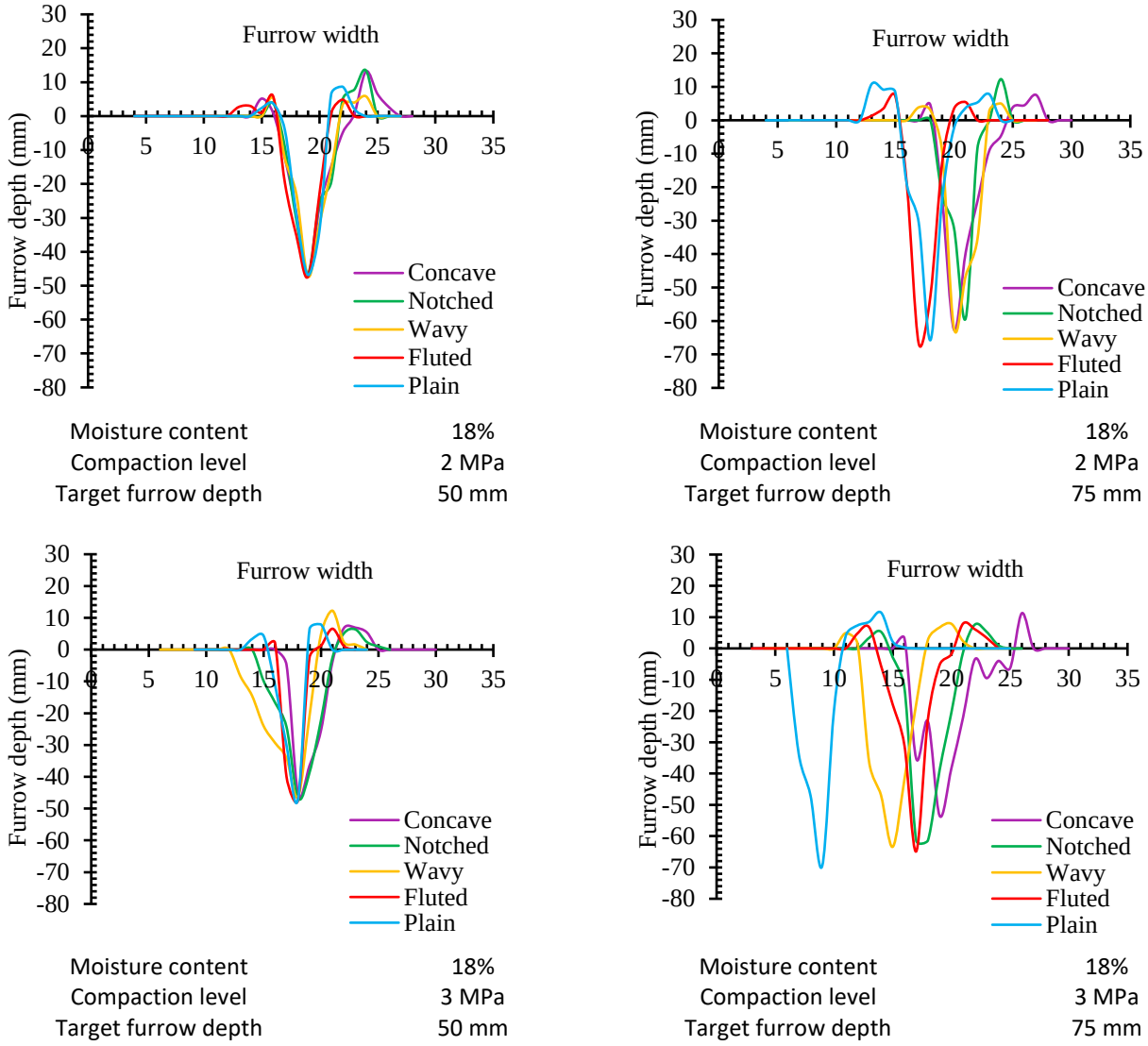

Figure 10. Furrow profiles formed at different compaction levels and furrow depths with 18% soil moisture content

Conclusion

According to the results obtained from the research, no furrow opener gave the best results on the basis of all parameters. The best results were obtained with plain type discs in terms of furrow width, furrow cross-sectional area and vertical force while notched type discs delivered the best results in terms of draft force and side force and fluted, concave and wavy type discs produced the best results in terms of specific vertical force, specific draft force and specific side force, respectively.

The results revealed that soil conditions are a very important factor in the selection of the disc type furrow opener to be used in no-till seeders. According to these results obtained, using a plain disc type furrow opener in wet and hard soils, and a concave type disc furrow opener in low moisture level and soft soils can be recommended in terms of the furrow profile and the acting forces. In addition, it is important for companies that manufacture no-till seeders with a single disc type furrow opener not to ignore important working parameters such as soil moisture content and compaction level and working depth, and to design and manufacture by taking into account different field conditions.

It is of great importance that the analysis and evaluation of the results obtained by testing different disc type furrow openers at zero-degree tilt and disc angles are taken into account in future researches that will be planned by taking tilt and disc angles into account different. Investigating different residue conditions together with these features, which could not be taken into account due to the scope of the study, but are planned for future research, will contribute significantly to the more effective use of disc type furrow openers.

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Conflict of interest: The authors declare that there is no conflict of interest.

Author contributions*:* Ahmet Çelik conceived the idea and supervised the study, whereas Yusuf Aydın and Mehmet Zahid Malaslı designed and manufactured the furrow openers and conducted the tests in the soil bin and wrote the manuscript.

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