Performance of zero-tillage furrow openers in different soil textures

Saad Gheni Yaqoob Alkhoury [1*], Ahmed Ibrahim Abed [2], Mahmood Awad Hussein[2], Adnan Abed Ahmed Luhaib[2] and Karam Ahmed Fathi[2]

[1]Department of Agricultural Extension and Rural Development, College of Agriculture Engineering .Sciences (CAES), University of Duhok, Duhok, Iraq

[2]Center for Arid Farming and Conservation Agriculture Research (C.AFCAR), University of Mosul, Mosul, Iraq

*Corresponding author's email: saad.alkhoury@uod.ac

Email addresses of coauthors: ahmedalshahin82@uomosul.edu.iq , mahmood.hussein@uomosul.edu.iq , adnan.luhaib@uomosul.edu.iq , karam.ahmed@uomosul.edu.iq

ABSTRACT

A field experiment was conducted in Al-Hamdaniya district, southeast of Mosul city, the center of Nineveh Governorate, during the agricultural season (2024-2025). The study aimed to investigate the effects of the furrow opener type of a no-till seeder on mechanized and agronomic performance indicators (draft force, vibration, and aboveground dry biomass) in two different soil textures for wheat crop under a no-till farming system (conservation agriculture). The results revealed significant differences for the studied factors and their interactions across all traits. The disc furrow opener significantly outperformed by recording the lowest draft force of 3.70 kN m^{-1}, compared to the tine opener, which recorded the highest draft force of 4.84 kN m^{-1}. The disc opener recorded the lowest values for clay loam and sandy loam soils at 3.90 kN m^{-1} and 3.49 kN m^{-1}, respectively. Regarding the vibration, the disc opener was significantly superior, recording the lowest value of 2.5 $m.s^{-2}$ compared to the tine furrow opener, which recorded 4.7 $m.s^{-2}$. The interaction between furrow opener type and soil type was also significant for vibration. The disc opener recorded the lowest vibration values for both soil types at 2.5 $m.s^{-2}$, compared to the tine opener. The clay loam soil recorded the highest biomass value of 4.8 ton ha^{-1}, compared to the sandy loam soil, which recorded 4.0 ton ha^{-1}. The disc opener achieved 5.0 ton ha^{-1} of biomass at clay loam soil, compared to the tine opener, which recorded 4.6 ton ha^{-1} on the same soil texture.

Keywords: Tractor; Seeders; Draft force; Disc and tin furrow opener.

INTRODUCTION

The type of furrow opener that choose for a seeder is a fundamental reason for increase or decrease crop productivity. It can really make or break how well planting operation goes. That choice affects how easily the opener penetrates the soil, how much force is needed to pull it, how much vibration it creates while running, and even the long-term health of the crops. Different seeders work in their own ways, with unique designs and effects on the soil **[1]**. Disc openers, for example, use rotating discs to slice through the surface and prep the seedbed. They're especially good at handling crop residue, which makes them a solid fit for conservation agriculture **[2]**. Research shows that the type of furrow opener also impacts seed placement, soil airflow, and how well the soil holds moisture things that are essential for good germination and growth **[3]**. Those factors, in turn, play a big role in how much biomass the plants produce. On the other hand, another study found that tine-type openers tend to disturb the soil more, which can increase vibrations when they move through the ground **[4]**. Whatever opener you go with, it needs to support not

ISSN 2072-3857

mess up how the rest of the seeding system works, like keeping seed spacing even and distribution consistent. Mechanical properties play a crucial role in evaluating the performance of different furrow openers. Vibration has been found to significantly affect seeder performance, especially for small seeds, as mechanical frequencies and vibrations are highly important in determining seeding accuracy and seeder performance **[5].** Furthermore, the interaction between seeder type and soil type affect practical outcomes. In clay loam soils, cutting and penetration require higher draft forces; a disc may increase draft resistance but cuts through crop residues efficiently while planting. In sandy loam soils, draft resistance is lower **[6]**. Uneven terrain causes complex vibrations, affecting seed distribution stability and potentially leading to seeding inaccuracy, which consequently impacts crop growth performance and final yield. Additionally, light sandy soils generate greater vertical vibration compared to clayey soils, leading to tangible effects on seeder performance **[7]**. Among the important traits used to assess the efficiency of any agricultural system are plant biomass, soil characteristics and quality, and their impact on machinery-related mechanical properties such as draft force and vibrations during planting. Therefore, biomass is a fundamental evaluation indicator that reflects the extent to which plants utilize resources (water, light, nutrients) by employing appropriate planting methods that reduce energy consumption and improve seed-soil contact **[8, 9]**.Using simulation to design a tine-type seeder, it was found that seeder type, planting depth, seeding rate, and row spacing significantly affect crop yield and biomass, demonstrating that the seeder's mechanical performance in terms of draft force and vibration is closely linked to biological outputs **[10, 11]** .The highest germination rate was found in fields planted using disc-furrow opener seeders. Regarding biomass, seeds planted in a manner that achieves good soil penetration and uniform distribution lead to better germination, stronger root growth, and stimulation of soil microbial activity, thereby increasing crop biomass and biomass **[12]**. Clay loam soils are characterized by their ability to retain moisture and provide nutritional support to plants compared to sandy soils, giving them an advantage in promoting early growth and reducing water stress, which is reflected in increased production and biomass **[13]** .In contrast, sandy soils are less stable and offer lower resistance, affecting furrow opener behavior and vibration levels during operation. Conservation agriculture is based on several key factors, including retention of plant residues, crop rotation, and the type of seeder used. It is defined as a tillage planting system that keeps at least 30% of the previous crop's residues covering the soil surface **[14]**. A study by **[15]** found that using disc planters improves seeding indices in conservation agriculture systems. Additionally, disc seeders are the most suitable for conservation agriculture in maize and wheat cropping systems **[16]**. To achieve the expected impact from no-till seeding machinery, important structural characteristics such as the type of furrow openers and covering components must be compatible with the climate, soil type, field conditions, and crop types **[17].** The importance of these systems emerged after it became evident that conventional moldboard plowing leads, over time, to a decline in organic matter and increased soil erosion, prompting the adoption of modern systems like zero tillage, which relies on opening narrow furrows to place and cover seeds without any prior tillage. Multiple studies have confirmed that selecting the appropriate furrow opener type contributes to proper seed placement and enhances subsequent growth stages, which in turn affects the final harvest outcome **[18]**. Thus conservation agriculture is an

ISSN 2072-3857

innovative approach that promotes sustainable agriculture while improving soil health.

The objective of this study is to investigate the effect of conservation agriculture seeder furrow opener type on some mechanical properties and the aboveground biomass of wheat crop by testing it under different soil textures.

MATERIAL AND METHODS

A field experiment was conducted in Al-Hamdaniya district, affiliated with Mosul city, across two fields during the agricultural season (2024-2025). The field topography was characterized by flatness. The actual experimental area used from each field was (10) dunums. Regarding soil properties as shown in Table (1).

Table 1. Soil texture.

Soil textures					
The First field (clay loam soil)			The Second field (sandy loam soil)		
clay	sand	silt	clay	sand	silt
28%	27 %	45 %	6%	87%	7%

Both fields were planted with the wheat crop (*Triticum aestivum* L.). Table (2) shows the average temperature and rainfall amounts during the experimental period. This study investigated two factors: furrow opener type and soil type. Two seeder types were used. The first was a disc seeder and the second was a tine-type with the two agricultural tractors of the type Massey Ferguson 285s were used to implement the experiment. The first tractor served as the primary source of draft power, while the use of the second tractor was limited to raising and lowering the seeder, and specifications as shown in the table (3, 4). The effect of these factors on the studied indicators was measured: (Draft force, Vibration and Biomass).

Experiment Design

Factorial Experiments conducted within a Complete Randomized Block Design (RCBD). Each factor was tested at two levels: furrow opener (disc, tine) and soil type (clay loam, sandy loam), with three replications. Each experimental unit had a length of 30 meters. Statistical Package for the Social Sciences (SPSS-version 23) software was used to analyses the data derived from the field study **[19]**. Analysis of variance was performed on the collected results according to Duncan's test. Significant differences between treatment means were tested at a (5%) probability level.

1- Draft Force.

The draft force was measured directly using a draft force measuring device (dynamometer) as shown in the Figure (1) and calculated according to the following equation. **[20].**

$$Fpu = Ft + Frm \dots\dots\dots (1)$$

$$Ft = Fpu - Frm \dots\dots\dots (2)$$

When Fpu was total pulling force process (kN), Ft was traction force (kN), and Frm was rolling strength resistance and without tillage (kN).

2- Vibration ($m.s^{-2}$).

Vibration was measured by mounting a vibration sensor on the seeder body. The sensor converts mechanical motion into measurable and analyzable digital signals. Measurements were repeated three times to ensure the highest levels of accuracy and reliability. This allowed for the evaluation of the interactive effect of both furrow

ISSN 2072-3857

opener type and soil properties on the vibration levels, as shown in Figure (2).

3- Aboveground biomass (ton ha^{-1}).

The crop was harvested manually by cutting a 2-meter section from each of the two central rows in every experimental plot. The cutting height was approximately 20 mm above the soil surface, carried out during May 2025. The samples were then oven-dried at 60°C for 72 hours. This dried material was used to estimate the aboveground biomass, expressed in Ton ha^{-1} at a 14% moisture content (weight/weight basis) according to the method described by **[21]**

Table 2. Temperature and Rainfall during the winter season of 2024–2025 in Al-Hamdaniya District (data sourced from Directorate of Agriculture in Ninawa).

Month	Max. Temperature (°C)	Min. Temperature (°C)	Rainfall (mm)
November 2024	21	12	45
December 2024	15	8	58
January 2025	13	5	62
February 2025	15	6	63
March 2025	20	9	63
April 2025	26	14	44
May 2025	33	20	15
Total Rainfall during the season			350

Table 3. Specifications types of seeders used

seeder types	
tine seeder	disc seeder
grain hopper capacity (250 kg)	grain hopper capacity (500 kg)
fertilizer hopper capacity (250 kg)	fertilizer hopper capacity (500 kg)
working width (2 m)	working width (3 m)
number of furrow openers (10)	number of discs (20)
Row spacing (20 cm)	Row spacing (15 cm)

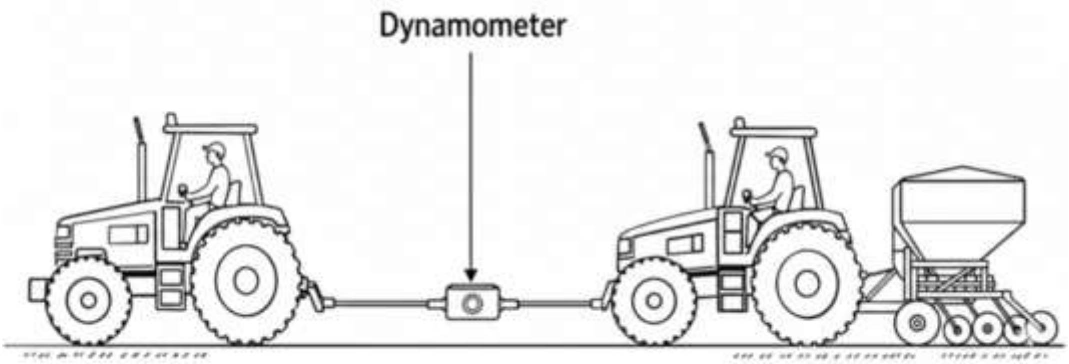

Figure 1. How the draft force was measured using dynamometer

ISSN 2072-3857

Table 4. Specifications of the agricultural tractor

Specifications of the agricultural tractor	
Massey Ferguson 285s	**Tractor type**
Two-wheel drive (2WD)	**Model**
31KN	Total tractor weight
Four-stroke diesel engine with direct fuel injection (2WD)	**Engine type**
4	**Number of cylinders**
17.5:1	**Compression ratio**
56.6	**Rated engine power (kW)**
2200 ± 25 rpm	**Maximum crankshaft speed under load (rpm)**
2310 ± 25 rpm	**Maximum crankshaft speed at no-load (rpm)**
(4 standard and 4 low-range)	**Number of forward gears: Eight**
(1 standard and 1 low-range)	**Number of reverse gears: Two**
30-18.4 **inch**	**Rear tire size**
16-17.5 **inch**	**Front tire size**

Figure 2. Accelerometer UNI-T UT315A

ISSN 2072-3857

RESULTS AND DISCUSSION

Table (5) reveal significant differences in the effect of furrow opener type on draft force (p-value < 0.05). The disc furrow opener recorded the lowest draft force of (3.70 kN m^{-1}), compared to the tine furrow opener which recorded the highest draft force of (4.84 kN m^{-1}). This is attributed to the smooth sliding action of the disc opener on the soil surface. In contrast, the tine opener has a larger contact area and a wider penetration angle which increases soil resistance and leads to higher draft force, as indicated by **[22]**. Additionally, disc openers reduce the direct contact area with the soil and decrease friction, as the disc cuts the soil in a rolling manner. This reduces draft force due to the slipping action of the disc during penetration and the consequent decrease in soil resistance. Regarding the factor of soil type, no significant differences were observed. The recorded values were (4.48 kN m^{-1} and 4.06 kN m^{-1}) for the clay loam and sandy loam soils respectively. Furthermore, the table shows significant differences for the effect of the two-factor interaction (furrow opener type × soil type) on draft force. The highest draft force was recorded with the tine opener in clay loam soil at (5.05 kN m^{-1}) which differed significantly from the disc opener on the same soil, which recorded the lowest value of (3.90 kN m^{-1}). This is because clay loam soil tends to be sticky and relatively moist at the working depth, increasing adhesion between the sticky soil and the opener, which in turn raises resistance during pulling compared to the disc opener **[23]**. Conversely, the lowest draft force was recorded with the disc opener in sandy loam soil at (3.49 KN m^{-1}), compared to the tine opener which recorded the highest value of (4.63 KN m^{-1}) on the same soil. The reason is that disc openers create a narrower furrow than tine openers, meaning a smaller volume of soil must be displaced sideways, leading to reduced resistance **[4]**. Additionally, disc openers distribute pressure over a relatively smaller area and reduce forward soil deformation, thereby decreasing overall draft resistance.

Table 5. Effect of the studied factors on the draft force (kN.m^{-1}).

Furrow Opener Type	Soil Type		Furrow Opener Type Mean
	Clay Loam	Sandy Loam	
Disc	3.90 b	3.49 b	3.70 b
Tine	5.05 a	4.63 a	4.84 a
Soil Type	4.48 a	4.06 a	

Table (6) showed significant differences in the effect of opener type on the vibration (m.s^{-2}). The tine-type opener recorded the highest vibration value compared to the disc-type opener, with the highest mean vibration for the tine opener reaching (4.7 m.s^{-2}), while the vibration value for the disc opener did not exceed (2.5 m.s^{-2}). This indicates that tine openers generate greater vibration during operation. This is attributed to the direct friction and deeper penetration of tine openers into the soil, which increases resistance and mechanical disturbance. In contrast, disc openers operate with smoother sliding over the soil surface and during soil entry, resulting in lower vibrations. This aligns with the findings of **[22],** who explained that tine openers, due to their geometry and blade design, directly influence vibration amplitude and the intensity of machine-soil interaction more than disc

ISSN 2072-3857

openers. Regarding the effect of soil type on vibration, no significant differences were observed. However, it is noteworthy that the clay-loam soil recorded a higher mean vibration of (3.8 $m.s^{-2}$) compared to the sandy-loam soil, which recorded (3.3 $m.s^{-2}$). This is due to the increased resistance of clay soil to the machine during operation, leading to higher mechanical vibrations of the planter **[23]**. As for the two-factor interaction between opener type and soil type, it had a significant effect on the vibration. The tine opener recorded the highest vibration values, reaching (5.2 $m.s^{-2}$) in clay-loam soil, which differed significantly from the disc opener in the same soil, recording (2.5 $m.s^{-2}$). This was followed by sandy-loam soil with the same opener type, also recording (2.5 $m.s^{-2}$), while the tine opener showed a significant difference from the disc opener in the same soil, recording (4.1 $m.s^{-2}$). This is attributed to the difference in opener design between the two types. Tine openers have a larger soil contact area and a wider penetration angle, leading to increased soil resistance and higher vibration intensity during operation. In contrast, disc openers penetrate the soil more smoothly with less friction, reducing tool oscillation during work. This was corroborated by **[24]**, who confirmed that the type and structure of the furrow-opening unit in planting machinery directly affect the operational vibration characteristics of the machine. The higher vibration in clay-loam soil compared to sandy-loam soil can be explained by its greater cohesion and higher density, which limit the absorption of vibrational waves and increase their transmission to the machine body. This is consistent with the results of **[25]**, who highlighted that soil density and internal cohesion are fundamental factors in determining soil response to vibrations.

Table 6. Effect of the studied factors on the vibrations ($m\ s^{-2}$)

Furrow Opener Type	Soil Type		Furrow Opener Type Mean
	Clay Loam	Sandy Loam	
Disc	2.5 b	2.5 b	2.5 b
Tine	5.2 a	4.1 a	4.7 a
Soil Type	3.8 a	3.3 a	

Table (7) showed no significant effect of opener type on the biomass trait (P>0.05). However, numerically, the disc opener recorded a higher biomass of (4.4 ton ha^{-1}), while the tine opener recorded a lower yield of (4.3 ton ha^{-1}). In contrast, the results revealed a significant effect of soil type on biomass. Clay-loam soil achieved the highest value of (4.8 ton ha^{-1}) compared to sandy-loam soil, which achieved (4.0 ton ha^{-1}). This is attributed to the superior water and nutrient retention capacity of clay-loam soil over sandy-loam soil, providing plants with an opportunity for higher dry matter accumulation when seed placement is adequate. Additionally, the texture of clay-loam soil features a greater ability to retain moisture and nutrients due to its physical and chemical properties, supplying water and nutrients to plants for a longer period compared to sandy-loam soil. This positively influences photosynthesis, leading to stronger vegetative growth and consequently increased biomass **[26, 27]**. The table also shows significant differences in biomass due to the interaction between opener type and soil type. Disc openers excelled in recording the highest biomass of (5.0 ton ha^{-1}) when planting in clay-loam soil, which differed significantly from sandy-loam soil with the same opener type, recording (3.9 ton ha^{-1}). Meanwhile, no significant difference was observed between

ISSN 2072-3857

clay-loam and sandy-loam soils when using tine openers, with yields of (4.6 ton ha^{-1}) and (4.0 ton ha^{-1}), respectively. The reason is that suitable soil physical conditions, combined with precise seed placement and good seed-soil contact, achieved the highest efficiency in resource utilization and improved plant biomass, as well as the best production performance in modern farming systems supported by soil properties that enhance moisture retention. The high efficiency of disc openers in ensuring consistent planting depth and uniform seed distribution promotes germination and growth uniformity **[28]**. Furthermore, disc openers tend to provide more consistent seed placement on surfaces with residues or heterogeneous topography, reducing depth variations and localized leveling, improving germination uniformity, and increasing biomass **[29, 17]**. This indicates that disc openers excel in placing seeds uniformly and effectively closing the seed furrow, leading to balanced vegetative growth, which in turn contributes to higher biomass. As for tine openers, they showed acceptable performance with an overall mean of (4.397 ton ha^{-1}). Their slight decline compared to disc openers results from their operating mechanism, which relies on direct soil penetration, increasing the likelihood of planting depth variability in cohesive or heterogeneous-textured soils **[23]**.

Table 7. Effect of the studied factors on the Biomass (ton ha^{-1})

Furrow Opener Type	Soil Type		Furrow Opener Type Mean
	Clay Loam	Sandy Loam	
Disc	5.0 a	3.9 b	4.4 a
Tine	4.6 ab	4.1 ab	4.3 a
Soil Type	4.8 a	4.0 b	

CONCLUSIONS

The results of this study demonstrated that opener type and soil type were significantly effect on the mechanical and agronomic performance indicators under no-till conservation agriculture conditions. The disc opener exhibited superior performance by recording the lowest draft force of (3.70 kN m^{-1}) compared to the tine opener, indicating its greater suitability for reducing draft requirements in no-till systems. This superiority was confirmed by the significant interaction between opener type and soil type, where the disc opener achieved the lowest draft force values in both clay-loam and sandy-loam soils, recording (3.49 kN m^{-1}) and (3.90 kN m^{-1}), respectively. Regarding generated vibrations, the disc opener achieved the lowest values at (2.5 $m.s^{-2}$). The interaction between opener type and soil type further showed that the disc opener consistently recorded the lowest vibration values in both soil types. In contrast, the tine opener recorded the highest values, particularly in clay-loam soil at (5.2 m s^{-2}). Concerning biomass, soil type played an important role with clay-loam soil recording a higher biomass than sandy-loam soil at (4.8 ton ha^{-1}). The interaction between opener type and soil type was also statistically significant. The disc opener combined with clay-loam soil achieved the highest biomass of (5.0 ton ha^{-1}), indicating a positive synergistic effect between this opener type and suitable soil conditions. Conversely, the tine opener showed no notable differences in biomass across the different soil types. Therefore, the disc opener is more efficient in no-till conservation agriculture systems

ISSN 2072-3857

particularly in clay-loam soil, due to its lower draft force, reduced vibration, and increased biomass. Consequently, the use of disc openers is recommended to enhance mechanical performance and crop productivity in no-till wheat cultivation.

ACKNOWLEDGMENTS

The authors sincerely appreciate the technical and the financial supports provided by the Center for Arid Farming and Conservation Agriculture Research (C.AFCAR) at the University of Mosul, and UN Word Food Programme (WFP) organization.

REFERENCES

[1] Parihar, D. S., Dogra, B., & Narang, M. K. (2023). Performance evaluation of different furrow openers for sustainable tillage: A review. *Indian Journal of Ecology*, *50*(4), 1133-1142. DOI: https://doi.org/10.55362/IJE/2023/4025

[2] Parihar, D. S., Dogra, B., Narang, M. K., Singh, S. K., & Khurana, R. (2022). Development and evaluation of notched concave disc seed drill for direct seeding of wheat in paddy stubble field. *Journal of Agriculture and Food Research*, *10*, 100421.https://doi.org/10.1016/j.jafr.2022.100421

[3] Swanepoel, P. A., Agenbag, G. A., & Strauss, J. A. (2018). Considering soil quality when comparing disc and tine seed-drill openers for establishing wheat. *South African Journal of Plant and Soil*, *35*(4),317-320.https://urlshortener.me/ 21CH

[4] Aikins, K. A., Barr, J. B., Ucgul, M., Jensen, T. A., Antille, D. L., & Desbiolles, J. M. (2020). No-tillage furrow opener performance: A review of tool geometry, settings and interactions with soil and crop residue. *Soil Research*, *58*(7), 603-621. https://doi.org/10.1071/SR19153

[5] Wang, Y., Zhang, W., Luo, X., Zang, Y., Ma, L., Zhang, W., & Zeng, S. (2024). Effect of Vibration Conditions on the Seed Suction Performance of an Air-Suction Precision Seeder for Small Seeds. *Agriculture*,*14*(4),559.https://2u.pw/vYr8AT

[6] Alsharifi, S., Shtewy, N., & Al-Janabi, T. (2020). The effect of sowing methods on the growth characteristics of wheat in Alhashemia, Iraq. *Asia Life Sciences*, *10*(4), 675-685. https://2u.pw/k42dRY

[7] Yu, D., Peng, F., Zeng, Z., Zhang, M., Yang, W., Zang, Y., & Wang, Z. (2024). Vibrational Dynamics of Rice Precision Hole Seeders and Their Impact on Seed Dispensation Efficacy. *Agriculture*, *14*(2), 324.https://doi.org/10.3390/agriculture14020324

[8] Dass, A., Kushwaha, H. L., Sahoo, P. K., Dhar, S., Choudhary, A. K., Khura, T. K., & Yadav, D. (2023). Comparative analysis of machine-planted and manual-planted wheat on crop and water productivity, and profitability under system of wheat intensification management. *Frontiers in Sustainable Food Systems*, *7*, 1187647. https://doi.org/10.3389/fsufs.2023.1187647

[9] Mahapatra, J., Tiwari, P. S., Singh, K. P., Nandede, B. M., Sahni, R. K., Pagare, V., ... & Mandal, S. (2024). An adjustable pneumatic planter with reduced source vibration for better precision in field seeding. *Sensors*, *24*(11), 3399. https://doi.org/10.3390/s24113399

[10] Wang, Z., Kang, R., Adilet, S., Hu, G., Yang, H., Liu, G., & Chen, J. (2024). Optimal Design and Discrete Element Method Model Development of the Acute Angle Hoe Opener for No-Till System.

Processes,*12*(4),711.https://doi.org/10.3390/pr12040711

[11] Aula, L., Easterly, A. C., & Creech, C. F. (2022). Winter wheat seeding decisions for improved grain yield and yield components. Agronomy, 12(12), 3061.https://doi.org/10.3390/agronomy12123061

[12] Çelik, A., & Altıkat, S. (2012). Seeding performances of no-till seeders equipped with different furrow openers, covering components and forward speeds for winter wheat. Journal of agricultural sciences, 18(3),226-238.https://doi.org/10.1501/Tarimbil_0000001210

[13] Hasimu, A., & Chen, Y. (2014). Soil disturbance and draft force of selected seed openers. *Soil and Tillage Research*, *140*,48-54. https://doi.org/10.1016/j.still.2014.02.011

[14] McCarthy, J. R., Pfost, D. L., & Wollenhaupt, N. C. (1988). Conservation tillage and residue management to reduce soil erosion. https://2u.pw/kyX1kw

[15] Raoufat, M. H., & Mahmoodieh, R. A. (2005). Stand establishment responses of maize to seedbed residue, seed drill coulters and primary tillage systems. *Biosystems Engineering*, *90*(3), 261-269. https://doi.org/10.1016/j.biosystemseng.2004.11.012

[16] Sawant, C., Kumar, A., Mani, I., & Singh, J. K. (2016). Soil bin studies on the selection of furrow opener for conservation agriculture. *Journal of Soil and Water Conservation*, *15*(2), 107-112. https://2u.pw/eHvP41

[17] Karayel, D., Jotautienė, E., & Šarauskis, E. (2024). The effect of furrow opener and disc coulter configurations on seeding performance under different residue cover densities. *AgriEngineering*, *6*(2),1277-1288 https://doi.org/10.3390/agriengineering6020073

[18] Bhatti, S. A., Kandhro, M. N., Chang, M. S., Sootaher, J. K., Buriro, K. A., Mongrio, N., ... & Wadho, M. (2022). Effect of Different Sowing Methods on The Growth and Yield of Wheat (Triticum aestivum L.). *RADS Journal of Biological Research & Applied Sciences*, *13*(1), 33-42. https://doi.org/10.37962/jbas.v13i1.412

[19] Swan, A. R., & Sandilands, M. 1995, Introduction to geological data analysis, Blackwell Science, Cambridge Mass, USA, p. 446. https://2u.pw/Nnd5M

[20] Hamid, A. A. A. (2023, December). Calculating some powers and traction force for two plows in primary tillage. In IOP Conference Series: Earth and Environmental Science (Vol. 1262, No. 9, p. 092007). IOP Publishing. doi:10.1088/1755-1315/1262/9/092007

[21] Hussein, M. A., Antille, D. L., Chen, G., Luhaib, A. A. A., Kodur, S., & Tullberg, J. N. (2017). Agronomic performance of wheat (Triticum aestivum L.) and fertiliser use efficiency as affected by controlled and non-controlled traffic of farm machinery. ASABE Paper No.: 1700586. In *2017 ASABE Annual International Meeting, American Society of Agricultural and Biological Engineers, St. Joseph, MI*. https://2u.pw/6mIoh5

[22] Bakhtiari, M. R., & Loghavi, M. (2009). Development and evaluation of an innovative garlic clove precision planter. *Journal of Agricultural Science and Technology*, *11*(2), 125–136. https://2u.pw/1rYTo2

[23] Ahmad, F., Weimin, D., Qishou, D., Rehim, A., & Jabran, K. (2017). Comparative performance of various disc-type furrow openers in no-till paddy field conditions.

ISSN 2072-3857

Sustainability, 9(7), 1143. https://doi.org/10.3390/su9071143

[24] Gao, Y., Zhang, X., Li, H., Zhao, W., & Liu, C. (2024). Study on operating vibration characteristics of different no-till planters. *Agriculture*, 14(11), 1878. https://doi.org/10.3390/agriculture14111878

[25] Wan, L., Li, Y., Song, J., Ma, X., Dong, X., Zhang, C., & Song, J. (2023). Vibration Response of Soil under Low-Frequency Vibration Using the Discrete Element Method. *Agriculture*, *13*(10), 1958.https://doi.org/10.3390/agriculture13101958

[26] Wang, L., He, Z., Zhao, W., Wang, C., & Ma, D. (2022). Fine soil texture is conducive to crop productivity and nitrogen retention in irrigated cropland in a desert-oasis ecotone, Northwest China. *Agronomy*,*12*(7),1509. https://doi.org/10.3390/agronomy12071509

[27] Meng, F., Hu, K., Feng, P., Feng, G., & Gao, Q. (2022). Simulating the Effects of Different Textural Soils and N Management on Maize Yield, N Fates, and Water and N Use Efficiencies in Northeast China. *Plants*, *11*(23), 3338. https://doi.org/10.3390/plants11233338

[28] Ferreira, C. J. B., Tormena, C. A., da Costa Severiano, E., Nunes, M. R., de Menezes, C. C. E., Antille, D. L., & de Oliveira Preto, V. R. (2023). Effectiveness of narrow tyne and double-discs openers to overcome shallow compaction and improve soybean yield in long-term no-tillage soil. *Soil and Tillage Research*, *227*,105622.https://doi.org/10.1016/j.still.2022.105622

[29] Swanepoel, P. A., Le Roux, P. J. G., Agenbag, G. A., Strauss, J. A., & MacLaren, C. (2019). Seed- drill opener type and crop residue load affect canola establishment, but only residue load affects yield. *Agronomy Journal*, *111*(4), 1658-1665. https://doi.org/10.2134/ agro nj 2018.10.0695

ISSN 2072-3857