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COMPARATIVE STUDY OF CHISEL PLOUGH TYPES AND THEIR EFFECT ON SOME PERFORMANCE CHARACTERISTICS

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This article aims to compare the performance of two types of chisel ploughs as well as study the influence of shank types on indicators, average fuel consumption, slip percentage, field efficiency, plough shank vibration, and noise in the tractor driver's environment. The experiment included three factors: the first one was plough shank type (rigid or flexible), and the second factor was two driving speeds (4.5 and 7.7 km·h^{-1}), while the third factor was two tillage depths (10 and 20 cm). The greatest effect of tractor driving speed was observed during acceleration, resulting in increased slippage by 26.39%, plough shank vibration by 17.42 m·s^{-2}, and noise around the driver by 94.61 dB, with a reduction of fuel consumption by 15.87 l·ha^{-1} and field efficiency by 61.94%. The results showed that the plough with the flexible shank outperformed compared to the rigid shank by having less fuel consumption 19.56 l·ha^{-1} and slip of 17.31%, as well as the best field efficiency of 70.06% with a unique shank vibration of 22.63 m·s^{-2} and the lowest noise emission around the driver 89.77 dB. The high speed of the flexible shank has a positive effect on fuel consumption 14.20 l·ha^{-1} and shank vibrations 27.81 m·s^{-2}.

Keywords: flexible shank plough; fuel consumption; field efficiency; plough shank vibrations; noise

The chisel plough is considered one of the most essential ploughs, widely used due to its characteristics of improving the physical properties of the soil, reducing the pressure on the soil, maintaining its fertility, and thus increasing agricultural production (Syromyatnikov et al., 2024). The variety of imported heavy agricultural implements in Iraq and the world and their use in different soil conditions has led to soil degradation due to soil pressure (Cherubin et al., 2016; Tahir et al., 2018). The deterioration of the soil's physical properties negatively affects root growth (de Souza et al., 2014). The chisel plough is the most suitable for use on Iraqi soils and land compared to other ploughs because it has the lowest fuel consumption and carbon monoxide emissions and has the highest crop productivity (Abdul-Munaim, 2013). The speed and depth of ploughing are among the most critical factors that significantly impact the quality of ploughing (Marey et al., 2020). Schlosser et al. (2019) pointed out that clay soils consume more fuel than sandy soils and attributed this to the increase in the draft force of 40.26 kN at a depth of 45 cm in clay soils, which led to the highest slippage value of 34.44%. The chisel plough saves about a half of fuel consumption compared to the mouldboard plough when the composition of the chisel plough shank is changed by increasing the manganese content by 52% and the carbon content by 24%, which increases the flexibility and hardness of the shank (Barut and Özdemir, 2024). Engine thermal efficiency and fuel consumption depend on engine operating conditions, soil type, and machine. When driving speed was increased from 3 to 5 km·h^{-1}, fuel consumption decreased from 28 to 18 l·ha^{-1} and productivity increased from 24 to 53% when a chisel plough was used to develop an equation for fuel consumption (Karparvarfard and Rahmanian-Koushkaki, 2015).

Also, increasing the tractor speed resulted in a decrease in the fuel consumption of the chisel plough and machines due to the speed factor and its importance in the characteristics as mentioned by Taha et al. (2016), Nassir et al. (2022), and Hamid (2024), in addition to the effects of increasing the direct ploughing depth on fuel consumption. Another study found that increasing the ploughing depth from 15 to 35 cm resulted in a 14.44% increase in fuel consumption (Singh et al., 2018). The best tractor performance was achieved with a low slip ratio (Abrahám et al., 2022). In a study conducted by Almaliki et al. (2021) to create a mathematical model to evaluate tractor slip, slip increased by 33% when speed was increased to 5.5 km·h^{-1} and depth was increased to 25 cm. Increasing ploughing depth and tractor speed increased slip, as shown by Mamkagh (2019) and Al-Aani (2024). In studies conducted to evaluate the tractor performance, field efficiency decreased with increasing depth from 50.09 to 42.82% (Amer et al., 2020).

The high vibration is an essential factor in improving the quality of tillage and reducing the tractive force of the chisel plough, and vibration speed increased by 57% with the increase in ploughing speed from 2.22 to 3.33 m·s^{-1} (Dzhabborov et al., 2021). The dynamic properties of the flexible shank, as a result of vibration acceleration, affect the destruction of soil formation and, thus, the reduction of energy costs (Rao and Chaudhary, 2018; Kosulnikov et al., 2020). Mahmood et al. (2011) found that there is a direct proportionality with the vibrations of ploughs when speed increases from 1.5 to 4 km·h^{-1} and that the difference in mechanical designs and materials plays a vital role in vibrations. The plough's vibration movement, with increasing speed, depth, and tillage angles, significantly reduces the tillage resistance force to 10–20% (Awad-Allah et al., 2009). Egela and Hamed (2017) pointed out that a noise exposure of more than 90 dB leads to an increase in systolic and diastolic blood pressure SBP and DBP, and this should be accompanied by a reduction in working hours for the tractor driver to less than 8 hours, according to the permissible working hours with a noise level of 85 dB. At this level, the Occupational Health and Safety Standards (OSHA, 1983) (Lalremruata et al., 2019) and the National Institute for Occupational Safety and Health (NIOSH, 1998) (Chan, 1998) advise to the wearing of hearing protection by the driver. The standard that determines the pressure in the engine cylinder when the fuel is burned, and thus the noise level, depends on the type of engine, the number of cycles, the cylinder diameter, and the type of fuel used, as well as other mechanical effects (Nair and Singh, 2021). The noise generation of agricultural tractors has the highest values with increasing engine speed, and the noise generation of agricultural tractors increases from 90.06 to 91.81 dB with increasing engine speed from 1000 to 1500 rpm (Awwad et al., 2023). The research aims to improve the work of the flexible shank plough by conducting a comparative study with the rigid shank plough for work in challenging soil conditions, through which the best speed and depth are found with the vibrations that the plough is exposed to in the soil with the best work performance.

Material and Methods

The study was conducted in one of the College of Agriculture and Forestry fields at the University of Mosul, Mosul City, Iraq. The experiment was performed on clay soil with flat topography. The field was uncultivated, and the soil moisture content was 14.5%. It was measured using an Extech MO750 device, based on the volume of water in the soil. A New Holland TD80 4WD tractor, manufactured in 2022 with an engine power of 58.8 kW (80 hp), was used in the experiment. Two types of chisel plough shank shapes (rigid type and flexible type) were used, manufactured locally by Mosul Mechanical Works Company Ltd. in Mosul City, Iraq (Fig. 1, Table 1). In the field at ploughing, bulk density was 1.23–1.7 g·cm^{-3} at a 5–25 cm depth. Soil texture was loamy clay (clay 48.45, silt 26, sand 25.55 g·kg^{-1}).

Fig. 1 Two types of chisel plough shank during ploughing
1 – flexible type; 2 – rigid type

Table 1 Characteristics and specification of chisel plough types

Characteristics	Rigid shank plough	Flexible shank plough
Model	157	154
Number of rows	3	2
Working width (cm)	190	190
Number of shares	9	9
Type of shares	reversible spikes	one-way spikes
Distance between shares (cm)	25	25
Frame height (cm)	46	46
Shank shapes	straight	curve
Hitching	three-point hitch	three-point hitch

Experiment design and statistical design

The experiment was conducted in the field according to a randomised complete block design (RCBD) with a split-split plot method. The experiment was factorial with three factors:

1. shank type at two levels (rigid type and flexible type);
2. tractor driving speed at two levels 4.5 and 7.7 km·h^{-1};
3. tillage depth at two levels 10 and 20 cm, with three replicates for each treatment and by length 30 m.

The software used was SAS. The analysis of variance (ANOVA) was conducted to show significant differences between group means and interactions. Duncan's multiple range test was used at the probability level (0.05) and (0.01) to compare the means of different treatments.

Indicators studied

1. Fuel consumption

Calculated by refilling the tractors fuel tank to the same level using a 1000 ml graduated cylinder after each ploughing treatment (Nassir et al., 2022).

$$Fc = \frac{(Fca \cdot 10)}{(Wp \cdot Lp)} \qquad (1)$$

where: Fc – total fuel consumption (l·ha^{-1}); Fca – amount of fuel consumed (ml); Wp – actual width (m); Lp – length of the transaction line (m)

2. Slippage percentage.

Calculated according to Ranjbarian et al. (2017).

$$S = \left(1 - \left(\frac{Vp}{Vt}\right)\right) 100 \qquad (2)$$

where: S – slippage percentage (%); Vt – theoretical speed (km·h^{-1}); Vp – practical speed (km·h^{-1}).

3. Field efficiency

Refers to the ratio of effective field capacity to theoretical field capacity as a percentage. It is calculated by the equation described by Amer et al. (2020).

$$FE = \left(\frac{Efc}{Tfc}\right) \cdot 100 \qquad (3)$$

where: FE – field efficiency (%); Efc – effective field capacity (ha·h^{-1}); Tfc – theoretical field capacity (ha·h^{-1})

3.1 Effective field capacity

The actual area covered. It is calculated according to Tahir et al. (2018).

$$Efc = 0.1 \cdot S \cdot W \cdot E \qquad (4)$$

where: Efc – effective field capacity (ha·h^{-1}); S – actual driving speed (km·h^{-1}); W – actual tillage width (m); E – efficiency (70–90)%, taken 85% (ASAE, 2006)

4. Vibration

Vibration was measured with an LCD Accelerometer UNI-T UT315A, as shown in Fig. 2. The device contains a contact point for a wire with a sensitive and magnetic metal tip for fixation and is connected to the contact point of the shank with the chisel plough body during ploughing for each treatment. Vibrations are read on the device's screen and recorded in three replications for all the experimental factors (Fig. 3).

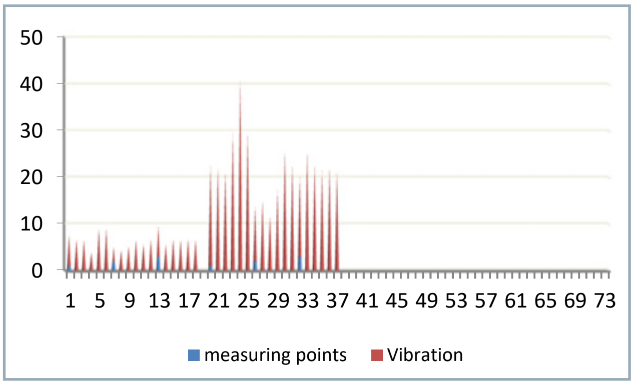

Fig. 3 Diagram showing the vibrations of ploughs at measurement points

5. Noise

Extech 407750 with a measuring range of 30–135 dB and a response time of 0.5 s was used to measure machine

Fig. 2 The device attached to the plough and reading the vibrations during ploughing

noise near the tractor driver (HRN ISO 5131, 2018). The measured values were recorded on the device's display for all parameters and three replications. The noise levels were measured while the tractor was moving, and the device's microphone was positioned at the level of the driver's ear according to the dimensions described by Taha et al., 2022).

Results and Discussion

The individual effect of plough shank type, tillage depth, and tractor driving speed on fuel consumption

Table 2 shows the effects of factors and their interactions on fuel consumption. The statistical analysis showed significant differences for shank type, tillage depth, and driving speed on fuel consumption (*P* <0.01), with the rigid type showing the highest value of 25.48 l·ha^{-1}, while the flexible type showed the lowest value of 19.56 l·ha^{-1}. The chisel plough with the flexible type has high flexibility to resist traction and showed the lowest fuel consumption, which could be due to the kind of metal the flexible type is made of and its role in reducing and absorbing shocks in heavy soils (Barut and Özdemir, 2024). The driving speed had a significant effect, and increasing it resulted in the lowest fuel consumption of 15.87 l·ha^{-1} at a speed of 7.7 km·h^{-1}. In comparison, the highest value reached 29.17 l·ha^{-1} at a driving speed of 4.5 km·h^{-1}, as increasing the engine speed resulted in better utilisation of the engine's thermal capacity and efficiency, which is consistent with Karparvarfard and Rahmanian-Koushkaki (2015) and Taha et al. (2016).

The depth of 10 cm gave the lowest fuel consumption of 19.80 l·ha^{-1} compared to a depth of 20 cm, which gave the highest value of 25.24 l·ha^{-1}. The reason for this is the long time required for the work, as the large soil masses resist the machine parts with increasing depth in the soil, as shown by Singh et al. (2018) and Chenarbon (2022).

The effect of plough shank type, tillage depth, tractor driving speed, and their interactions on fuel consumption

The interaction of the flexible type with the driving speed of 7.7 km·h^{-1} recorded the lowest fuel consumption of 14.20 l·ha^{-1} compared to the other treatments, while the interaction of the flexible type with the depth of 10 cm recorded the lowest value of 16.43 l·ha^{-1}. In addition, the lowest value of 13.20 l·ha^{-1} was recorded for the interaction at a speed of 7.7 km·h^{-1} with a depth of 10 cm. The three-way interaction of factors shows that the lowest fuel consumption value for the flexible type was 11.84 l·ha^{-1} at the lowest tillage depth and the highest driving speed. This could be because the flexible shank's dynamic properties influence the soil destruction process through acceleration vibrations when the tractor speed increases. This is in line with the results of Kosulnikov et al. (2020) on the causation of forced vibrations on the plough shank.

Duncan's multiple range test was used at the probability level (0.05) and (0.01) to compare the means of the different treatments and interactions.

The individual effect of plough shank type, tillage depth, and tractor driving speed on slip percentage

Table 3 shows that tractor driving speed had the most significant effect on the slip percentage, with significant differences (*P* <0.01) between treatments. Slip increased directly with increasing speed from 4.5 km·h^{-1} to 7.7 km·h^{-1}, resulting in a slip percentage increase from 15.49% to 26.39%.

The load on the tractor and plough increases with increasing tractor driving speed and traction, which reduces the tractor's tires contact with the ground and increases slippage, which is consistent with the results of Ranjbarian et al. (2017) and Mamkagh (2019). There was a significant effect when the ploughing depth was increased from 10 cm to 20 cm, as the slip percentage increased from 17.47% to 24.40%. The relationship between them was linear, as the slip increased due to the high resistance to the movement of soil forces and insufficient energy requirements due to high traction force, as indicated and confirmed by Schlosser et al. (2019), Almaliki et al. (2021), and Saleh et al. (2023).

As the speed and depth increased, the pressure and load on the plough shank increased as the contact area of the soil layers increased, causing high friction due to the interactions, resulting in an increase in traction and slippage, as noted by El-Sheikha et al. (2021) and Al-Aani (2024). The flexible shank

Table 2 Effect of factors and triple interactions on fuel consumption (l·ha^{-1})

Shank type (*St*)	Driving speed (*Ds*)	Ploughing depth (*Pd*)		Interactive *St · Ds*	Effect *St*	Effect *Ds*
		10	20			
Rigid	4.5	31.78	35.08	33.43	–	–
	7.7	14.56	20.51	17.53	–	–
Flexible	4.5	21.03	28.82	24.92	–	–
	7.7	11.84	16.57	14.20	–	–
Interactive *St · Pd*	rigid	23.17	27.79	–	25.48 a	–
	flexible	16.43	22.69	–	19.56 b	–
Interactive *Ds · Pd*	4.5	26.40	31.95	–	–	29.17 a
	7.7	13.20	18.54	–	–	15.87 b
Effect *Pd*		19.80 b	25.24 a	–	–	–

* lower value is better, and the letters indicate a significant difference

Table 3 Effect of factors and triple interactions on slippage percentage (%)

Shank type (*St*)	Driving speed (*Ds*)	Ploughing depth (*Pd*)		Interactive *St · Ds*	Effect *St*	Effect *Ds*
		10	20			
Rigid	4.5	13.59	23.99	18.79	–	–
	7.7	27.78	32.89	30.34	–	–
Flexible	4.5	8.04	16.32	12.18	–	–
	7.7	20.49	24.40	22.44	–	–
Interactive *St · Pd*	rigid	20.69	28.44	–	24.56 a	–
	flexible	14.26	20.36		17.31 b	–
Interactive *Ds · Pd*	4.5	10.82	20.16	–		–
	7.7	24.13	28.65	–	–	15.49b
Effect *Pd*		17.47 b	24.40 a			26.39 a

* lower value is better, and the letters indicate a significant difference

plough had the lowest slip at 17.31%, while the rigid type had the highest at 24.56%. According to field observations, the flexibility and curvature of the flexible type led to more excellent vibrations and less slippage, especially at higher speeds (Goudarzi et al., 2015).

The effect of plough shank type, tillage depth, tractor driving speed, and their interactions on slip percentage

The interaction between the flexible type and a driving speed of 4.5 km·h^{-1} had the lowest slip percentage of 12.18% compared to the other treatments, while the interaction between the flexible type and the depth of 10 cm gave the lowest value of 14.26%. Furthermore, the lowest slip value of 10.82% was found for the interaction at the first speed and depth. It is noted from the triple interaction that the lowest value recorded for the slip percentage was between the flexible type and ploughing depth of 10 cm and speed of 4.5 km·h^{-1}, reaching 8.04% compared to the other treatments.

The individual effect of plough shank type, tillage depth, and tractor driving speed on field efficiency

Table 4 shows the significant effect of three factors and their interactions on field efficiency, where the highest field efficiency reached 70.06% for the flexible shank plough. At the same time, it was 63.02% for the rigid type, which is due to the high flexibility of the shank caused by rebound and vibration that reduces the time required for the implement to cope with soil fragmentation (Goudarzi et al., 2015; Barut and Özdemir, 2024). The high slip significantly affected the decrease in field efficiency with increasing tractor speed, with the slow speed achieving the highest significant field efficiency of 71.13%. In comparison, the high speed achieved the lowest efficiency of 61.94%. However, the high speed was superior to the slow speed in practical productivity due to the differences between the speeds and their effects on theoretical and practical productivity. The highest field efficiency was 69.22% at shallow depth. The efficiency decreased to 63.86% with increasing ploughing depth, which is due to the density of soil masses facing the plough with increasing depth in the soil layers, resulting in a decrease in practical speed and time utilisation coefficient (Amer et al., 2020).

The effect of plough shank type, tillage depth, tractor driving speed, and their interactions on field efficiency

The data also showed that the interaction between the speed of 4.5 km·h^{-1} and the flexible type gave the highest field efficiency of 74.59%, and the speed factor

Table 4 Effect of factors and triple interactions on field efficiency (%)

Shank type (*St*)	Driving speed (*Ds*)	Ploughing depth (*Pd*)		Interactive *St · Ds*	Effect *St*	Effect *Ds*
		10	20			
Rigid	4.5	71.80	63.57	67.68	–	–
	7.7	59.93	56.78	58.36	–	–
Flexible	4.5	77.88	71.30	74.59	–	–
	7.7	67.26	63.81	65.53	–	–
Interactive *St · Pd*	rigid	65.87	60.17	–	63.02 b	–
	flexible	72.57	67.55	–	70.06 a	–
Interactive *Ds · Pd*	4.5	74.84	67.43	–	–	71.13 a
	7.7	63.59	60.30	–	–	61.94 b
Effect *Pd*		69.22 a	63.86 b	–	–	–

* Higher value is better, and the letters indicate a significant difference

generally had the most significant effect on the characteristics of ploughing depths, as shown by the interactions. This is consistent with the findings of Okoko and Akpankpuk (2023). As for the interaction between the type of plough shank and depth, the flexible type at the depth of 10 cm gave the highest field efficiency of 72.57% compared to the other treatments. As for the interaction between speed and depth, slow speed at shallow depth gave the highest field efficiency of 74.84%, and the triple interaction between flexible type, slow speed, and 10 cm depth gave the highest field efficiency of 77.88% compared to the other treatments for the reasons mentioned above.

The effect of plough shank type, tillage depth, tractor driving speed, and their interactions on vibration

Table 5 shows that the change in driving speed, ploughing depth, plough shank type, and their interaction affect the vibrations. Table 5 shows that the higher driving speed led to stronger vibrations of the flexible type, which had the highest machine vibrations of 27.81 $m \cdot s^{-2}$ at high speed, while the rigid type had the lowest value of 5.33 $m \cdot s^{-2}$ at slow speed. This effect becomes more pronounced as driving speed increases from 4.5 to 7.7 $km \cdot h^{-1}$. This is due to the direct relationship between speed and vibration, which is an essential factor in loosening soil particles and reducing traction, thereby increasing speed (Rao and Chaudhary, 2018; Kosulnikov et al., 2020; Dzhabborov et al., 2021). In addition, the increase in speed had a slight effect on the vibrations of the rigid type.

It is essential to point out that the changes in vibration values are also caused by increasing ploughing depth, as shown in Table 5. The vibration value of the flexible type increased from 17.36 to 27.9 $m \cdot s^{-2}$ when the depth was raised from 10 to 20 cm. In comparison, the vibration value of the rigid type ranged from 5.5 to 6.86 $m \cdot s^{-2}$ for depths of 10 and 20 cm, respectively. As the depth increased, the vibration value of the flexible type doubled to some extent compared to the rigid type, indicating the interaction of the dynamic force of the machine with the soil. This is due to the relationship that vibration overcomes soil resistance and facilitates ploughing depth, which was confirmed by Awad-Allah et al. (2009). Vibration increases with depth and speed. The highest value was 20.56 $m \cdot s^{-2}$ for the high speed of 7.7 $km \cdot h^{-1}$ at the depth of 20 cm, and the lowest value of vibration was 8.58 $m \cdot s^{-2}$ for the low speed of 4.5 $km \cdot h^{-1}$ at the depth of 10 cm. This is due to the reasons mentioned above. The relationship among the flexible type, high speed, and 20 cm ploughing depth gave the highest vibration of 33.80 $m \cdot s^{-2}$ compared to the other treatments for the reasons mentioned above.

The effect of plough shank type, tillage depth, tractor driving speed, and their interactions on noise

Table 6 shows the relationship among plough shank type, tractor driving speed, ploughing depth, noise level, and the interaction effect between them. The noise level increased with increasing machine driving speed for both rigid and flexible types. The flexible type had the lowest noise level at a speed of 4.5 $km \cdot h^{-1}$, at 86.21 dB. In comparison, the rigid type had the highest noise level at a 7.7 $km \cdot h^{-1}$ speed, at 95.90 dB. This is due to the increase in the tractor driving speed. It leads to an acceleration in the engine speed and thus an increase in the pressure in the engine cylinder as a result of fuel combustion, which led to an increase in noise in addition to the effects of other mechanical noises caused by the exhaust, intake fan, pumps, transmission, etc. (Nair and Singh, 2021; Taha et al., 2022; Awwad et al., 2023).

Table 6 shows the interaction effect of ploughing depths and shank type on the tractor noise level. The average noise level increased with increasing ploughing depth for both flexible and rigid types. The lowest noise level was 88.03 dB at the 10 cm depth for the flexible type, and the highest noise level reached 94.46 dB at the 20 cm depth for the rigid type. This is due to the increased load on the engine, which requires more power, resulting in higher noise levels (Abood et al., 2015).

Table 6 shows the interference effect between the average noise level generated by the tractor at different ploughing depths and driving speeds of the tractor. It can be seen that the average noise level increases with increasing ploughing depth at both tractor driving speeds. When the driving speed is constant, the noise increases with increasing depth, and when the ploughing depth is constant, the noise increases with increasing speed. The lowest value of the noise level was measured at 86.10 dB at a depth of 10 cm and a driving speed of 4.5 $km \cdot h^{-1}$, the highest value at

Table 5 Effect of factors and triple interactions on vibrations ($m \cdot s^{-2}$)

Shank type (*St*)	Driving speed (*Ds*)	Ploughing depth (*Pd*)		Interactive *St · Ds*	Effect *St*	Effect *Ds*
		10	20			
Rigid	4.5	4.26	6.40	5.33 c	–	–
	7.7	6.73	7.33	7.03 c	–	–
Flexible	4.5	12.90	22.0	17.45 b	–	–
	7.7	21.83	33.80	27.81 a	–	–
Interactive *St · Pd*	rigid	5.50 c	6.86 c	–	6.18 b	6.18 b
	flexible	17.36 b	27.90 a	–	22.63 a	22.63 a
Interactive *Ds · Pd*	4.5	8.58	14.20	–	–	–
	7.7	14.28	20.56	–	–	–
Effect *Pd*	Effect Pd	11.43 b	17.38 a	–	–	–

*Higher value is better, and the letters indicate a significant difference

Table 6 Effect of factors and triple interactions on noise (dB)

Shank type (*St*)	Driving speed (*Ds*)	Ploughing depth (*Pd*)		Interactive *St* · *Ds*	Effect *St*	Effect *Ds*
		10	20			
Rigid	4.5	87.80	91.63	89.71	–	–
	7.7	94.50	97.30	95.90	–	–
Flexible	4.5	84.40	88.03	86.21	–	–
	7.7	91.66	95.00	93.33	–	–
Interactive *St* · *Pd*	Rigid	91.15	94.46	–	92.80 a	–
	Flexible	88.03	91.51	–	89.77 b	–
Interactive *Ds* · *Pd*	4.5	86.10	89.83	–	–	87.96 b
	7.7	93.08	96.15	–	–	94.61 a
Effect *Pd*		89.59 b	92.99 a	–	–	–

* Lower value is better, and the letters indicate a significant difference

96.15 dB at a depth of 20 cm and a speed of 7.7 km·h^{-1}, for the reasons mentioned above.

It is noted from the relationship between the factors that the lowest noise value recorded between the flexible type, 10 cm depth, and slow speed is 84.40 dB compared to the other treatments. It turns out that the noise level is higher than the 85 dB level set by OSHA (Occupational Safety and Health Administration), which means that the operator should take preventive and safety measures by wearing hearing protectors and reducing working hours or setting up an enclosed cab due to exposure to noise pollution.

Conclusion

The flexible type performed best compared to the rigid type, as it had the lowest fuel consumption of 11.84 l·ha^{-1} and the highest field efficiency of 77.88% at a forward speed of 4.5 km·h^{-1} and a ploughing depth of 10 cm, while the rigid type had the highest fuel consumption of 35.08 l·ha^{-1} at a speed of 4.5 km·h^{-1} and depth of 20 cm. The highest slip rate of 32.89% and the lowest efficiency of 56.78% were determined with the rigid type at a speed of 7.7 km·h^{-1} and a depth of 20 cm. The highest vibrations were recorded for the flexible type and increased with increasing speed and depth until they reached 33.80 m·s^{-2}, which helped to loosen soil particles, reduce slip rate, and facilitate ploughing. In comparison, the lowest vibrations of 4.26 m·s^{-2} were recorded with the rigid type at a speed of 4.5 km·h^{-1} and a depth of 10 cm. The noise level at the driver's ear decreased with the flexible type at a tractor speed of 4.5 km·h^{-1} and a ploughing depth of 10 cm, reaching the minimum value of 84.40 dB. The noise level increased with increasing speed and ploughing depth, especially with the rigid type, reaching the maximum value of 97.30 dB, higher than 85 dB specified by OSHA and NIOSH. In this case, the operator must take preventive measures to protect himself from the effects of noise like wearing earmuffs for operator, the regular maintenance of the tractor, using noise absorbing materials in the cabin, or sound proofing and vibration damping to reduce noise, etc.

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