Plant Archives Vol. 19, Supplement 1, 2019 pp. 1241-1248 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

EVALUATION OF THE SUBSOILER TINE DESIGNED AND MANUFACTURED LOCALLY AND ITS EFFECT ON SOME POWER INDICATORS AND CORN YIELD

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Abstract

This research study was conducted at Gerdarasha field, College of Agriculture, University of Salahaddin in Erbil during summer, 2018 on a silty clay loam soil texture. The experiment used completely randomized block design with split plot and three replications. Tillage depth was the first factor that three deepness of (20 – 25), (30 – 35) and (40 – 45) cm were studied. The second factor included type of tine (conventional which was manufactured in Massey Ferguson Corporation and modified one with wings and angels). Since the corn is very sensitive to soil compaction, it was selected to be grown. For comparing, the machinery indicators and crop yield were measured and evaluated. The summarized considerable points were:

Tillage depth was more influence on corn yield indicator which totally showed their highest values at the deepest tillage depth (40-45) cm and the lowest values at the shallowest depth (20 – 25) cm. The greater results were observed for this indicator and disturbed area by applying modified tine rather than conventional one (22.40% and 26.13% respectively),and, it increased by increasing the depth. Drawbar power was considerably affected when subsoiler increasing values were recorded by depth increasing. The highest value of that was recorded at the deepest depth when plow equipped with modified tine. Besides that, subsoiler showed better vertical stability at the shallower depths.

***Key words*:** Subsoiler tine design, Drawbar power, disturbed area.

Introduction

Soil compaction is a serious form of soil degradation that may be genetic or human induced. Several types of hard pans have been classified that cause many adverse effects on plant growth. One technique to reduce negative results of soil compaction is utilizing. Subsoiler as an implement to break the hard layers. Subsoiler is a primary tillage implements that works in deep depths (FAO, 1977).

Trukmann *et al*. (2008) clarified that soil compaction of agricultural soils is a global concern, due to adverse effects on the environment. The summarized adverse effects of soil compaction are reduction in crop yield especially in dry period as heat stress (Raza *et al*., 2007).

Kasisira (2005) clarified that for improving the efficiency of subsoilrs, wings or blades are often added to the foot to help working at the critical depth. Moreover, Raper and Sharma (2004) clarified that because of the significant draft forces required to break the subsoil compacted profiles, many different types of subsoilers have been designed and tested.

Zhang *et al*. (2006) designed a new subsoiler point (splitter point) and compared it to standard one. Results showed that the splitter point did reduce the above-ground soil disruption by more than 10%. Meanwhile, Hamel (2012) indicated that the incorporation of the winged tine on the combined subsoiler increases the disturbed area and the work efficiency. Moreover, Alimardani *et al*. (2009) noted that soil moisture content, bulk density, cone index and soil structure have effect on draft force and energy required for implements. Geometric shape of implement affects the soil failure too.

Raufat *et al*. (2007) found that the restricting factors for subsoiler using are the high energy consumption per unit of area and increasing operation costs. Also, Raper (2005) and Croitoru *et al*. (2016) noted that the shape of a subsoiler has an effect on draft requirement. Belowground soil disruption should be maximized while aboveground disruption should be minimized. Besides that Al–Tahan and Al-Irhayim (2010) studied three shapes of subsoiler tine (tapered-top with constant width and tapered-top with gradual width tine and conventional tine). Results showed that the second one has achieved the highest values for disruption area.

McKyes (1985) reported that the shape, width and rake angle of an individual soil cutting tool strongly influences the transport and mixing of soil particles. Moreover, Cholaky *et al*. (2010) noted that there is a relationship between the tillage tool geometry and the soil behavior during tillage. Askari *et al*. (2017) attached the wings to the sides of the subsoiler with a view to improve their performance in increment of soil loosened area and decrement of specific resistance (Spoor, Godwin 1978; Ramadhan 2011, 2014). Researches Ramadhan (2011, 2014); Askari *et al*. (2017). They conducted about the effect of depth and forward speed on force requirements of subsoil implements.

Numerous investigators are in agreement that an increase in plowing depth has a direct effect on increasing the drawbar power requirement (Al–Jarrah, 2011). Besides that, Jasim and Mankhi (2012) showed that increasing in subsoil tillage depth led to rise in the draft power loss due to slippage. Aday (2001), Al–Tahan and Al-Irhayim (2010), Abdullah and Dham (2012) showed that increasing the tillage depth leaded to raising disturbed area values in all tine types and cultivated or uncultivated soil conditions. Kasisira (2005) and Hilal (2007) reported a high significant increase in this parameter with an increase in plowing depth. Also Kees (2008) noted that shanks with winged tips may be more efficient than conventional tines.

The relevant investigation was conducted to highlight the following objectives:

The main objectives of this study were choosing the best shape of tine between conventional and winged tine, improving the physical condition of subsoil, and showing the contribution of modified sub-soil plow tine on increasing corn production compared with conventional one. To achieve these objectives.

Material and Methods

Experimental Design

Randomized Complete Block Design (RCBD) with split plot design was used for this experiment (Dawod and Ilyas, 1990). Main plot of depth of tillage was used and divided to three sub plots, Each subplot of plots was under the type of tine. The experiment was factorial and three factors were: firstly tillage depth with three levels (25, 35, and 45) cm, while the second one was type of tine of subsoiler plow with two levels (conventional and modified). There were three replications; therefore, the experiment had 3*2*3 (18) treatments. The length of refined treatments was 30 m. In order to avoid animal and human disturbance a fence with 1.5 meter height was constructed in all around the under study experimental field. The distance between fence and blocks was 10 meters. Also the spacing among blocks was 10 meters and distance between two plots was 5 meters to allow tractor with implement maneuver freely.

During this experiment underneath tractors, equipment, devices, and materials were used tractor type of Case with 120 HP and tractor type of New Holland double axle with 110 HP.

Soil and Field conditions;

Soil moisture content:

Soil moisture content from 0 to 50 cm with 5 cm increment and illustrated in Fig.1.

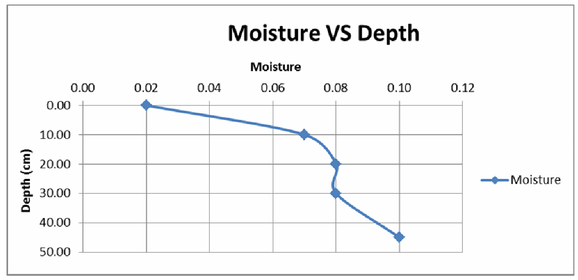

Fig. 1 : Soil moisture content

Bulk Density:

Fig.2. shows the soil balk density distribution changes under effect of subsoiling using both conventional and modified tines to a depth of 45 cm.

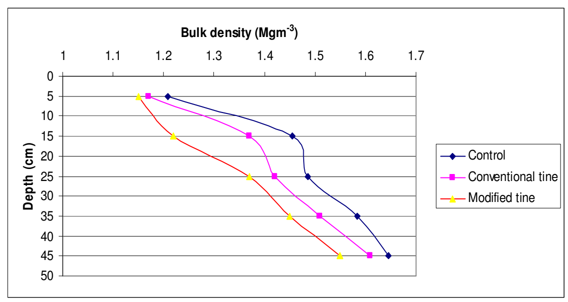

Fig. 2 : Distribution of soil bulk density with depth under some selected treatments (control, subsoiled with conventional tine, and subsoiled with modified tine).

Soil cone index:

The plant unharvest from the field was barley. The conducting time of experiment was summer and fall of 2013 Silty clay loam soil texture.

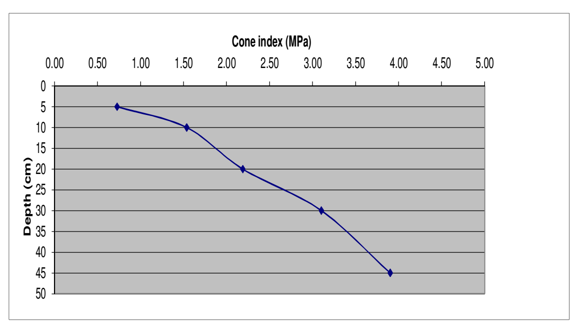

Fig. 3 : Soil cone index from 0 to 50 cm with 5 cm increment

Designing and manufacturing subsoil tine:

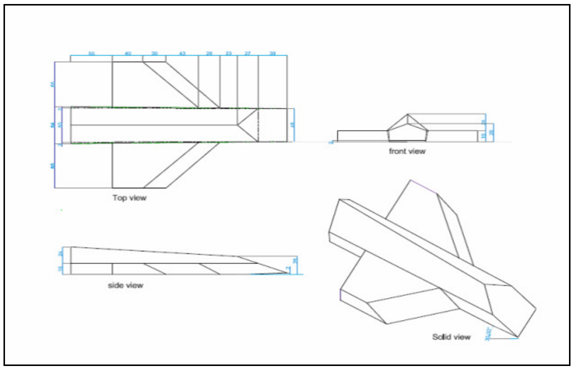

Fig. 4 : The scheme of Modified tine.

The modified tine is designed and manufactured to be elevated from the front for the horizontal line at an angle ʒ fig. 4 where, we observes from the force analysis as following:

Firstly, by assuming values of the shape of tine without the height of nose tine: Axial load N=50 kN, Penetration angle α=35o, Friction angle φ=20o, Reaction force N1=40 kN

$$Py = Ry = (N/\cos\varphi)\times\sin(\alpha+\varphi) + N_1\tan\varphi_1$$

$$Py = Ry = (N/\cos\varphi)\times\cos(\alpha+\varphi) - N_1$$

$$P = R = \sqrt{R^2x + R^2y}$$

$$Rx = (53.19\times0.819) + (40\times0.364) = 46.35 + 14.56 = 60.91$$

$$Ry = (53.191\times0.57) - 40 = 30.32 - 40 = -9.68$$

$$R = \sqrt{(60.91)^2 + (-968)^2}$$

$$R = \sqrt{3710.03 + 93.7}$$

$$R = \sqrt{4643.73} = 68.14\,\text{kN}$$

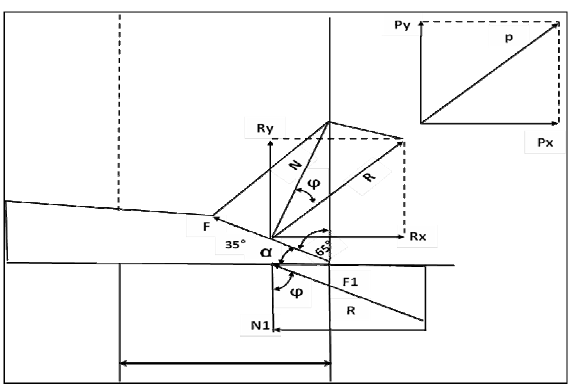

Fig. 5: Force analyses of Modified tine without height of nose tine.

Secondly, by assuming values of modified shape of tine as following: Axial load N=50 kN, Penetration angle α=35°, Friction angle φ=20°, Reaction force N_1=40 kN, Height of nose of tine angle ʒ=10°

$$Px = Rx = (N/\cos\varphi)\times\sin(\alpha+\varphi) + N_1\tan(\varphi_1 + z) - N_1$$

$$Py = Ry = (N/\cos\varphi)\times\cos(\alpha+\varphi) - N_1$$

$$P = R = \sqrt{R^2x + R^2y}$$

$$Rx = (53.19\times0.819) + (40\times0.58) = 46.35 + 23.1 = 69.44$$

$$Ry = 46.35 - 40 = 30.32 - 40 = -9.68$$

$$R = \sqrt{(69.44)^2 + (-968)^2}$$

$$R = \sqrt{4821.91 + 93.7}$$

$$R = \sqrt{4915.61} = 70.11\,\text{kN}$$

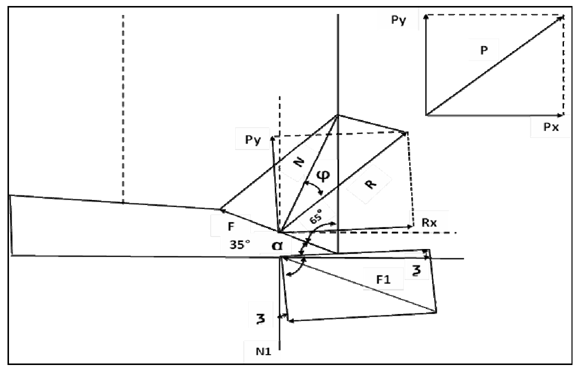

Fig. 6: Force analyses of Modified tine with height of nose tine.

In comparison with Figure 5 and Figure 6, the height of the nose of the tine at theangle ʒ of the horizontal line resulted in increasing the resultant in pushing the soil and thus increasing the sum of force P in lifting and pushing the soil, thus reducing the load on the part facing the soil from the tine to the leg along S as in Figure 4. The leg is stronger than the tine in front of a larger face of the soil, so we get two points first ease of penetration and the second momentum greater, in addition to the ease of movement of soil granules on the surface of the tine.

Stage of Cutting and Formation of the Metal

After suitable metal selecting, the cutting stage of metal was started by considering this point that three tines were required for the subsoiler. During this phase the actual wooden sample and dimensions of the design were used to gain an accurate device. Then grinding and polishing of them were done using special instruments that were explained by (Rahmet Allah, 1985). Now the points are ready but some characteristics of them should be improved. These operations were achieved in AL-Tesahul Laboratory of agricultural machinery industry in the Kirkuk city.

Table 1 : Mechanical and some of chemical properties of the metal before heat treatment

Mechanical properties	
*Hardness HB30 (kg mm-2)	142
*σy (Tensile strength, yield) (Mpa)	390
*σu (Tensile strength ultimate) (Mpa)	550
*El (Elongation at break) (%)	29
Chemical elements existence %	
Carbon (C)	0.106
Manganese (Mn)	0.488
AISI classification	ASAI 1010

Stage of Heat Treatment

In this step the prepared devices were heat treated to improve their mechanical properties. Table 2. Shows the mechanical properties of themetal that has been chosen for the manufacture of time after thermal treatments.

Table 2 : Mechanical properties after heat treatment

Hardness HB30 (kg/mm^2)	**Ultimate Tensile Strength (MPa)**
128	881.25

Hardness is an important property of materials to abrasion, cutting, or indentation. It also has relation with the ultimate and elastic strength of the material. The maximum force per unit of cross section area that a material can withstand is called the ultimate strength of the material (Culpin, 1981).

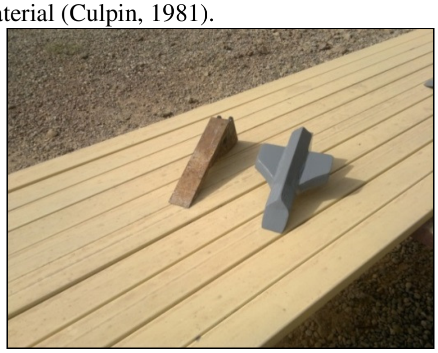

Fig. 7 : Modified tine at right and Conventional tine at left of the image

Study Indicators

In this experiment three types of indicators were studied.

Machinery (Mechanical) Parameters

For measuring some machinery indicators theoretical and practical speeds are necessary.

Drawbar Power

Below equation is used to calculate drawbar power as described by Veal *et al*. (2005)

$$Dp = (Ft \times Vp)/270(hp) \quad ....(2)$$

where:
Dp = Drawbar Power (hp)
Ft = Required pulling or draft force that is expressed by (kg)
Vp = practical speed (kmh^{-1})

Slippage Power Loss

For the purpose of estimating the power loss caused by slippage the following formula was used as described by Al – Tahan and Al-Irhayim (2010).

$$Sp = Ft \times (Vt - Vp)/270(hp) \quad ....(3)$$

S_p = Slippage Power Loss (hp)
Vt = Theoretical speed (kmh-1)

Disturbed Area

The disturbed area was obtained by measuring the cross section dimensions forming due to subsoiling and using the following formula which was described by Spoor and Godwin (1978). Cross section properties can be determined by hand excavation perpendicular to the plow line.

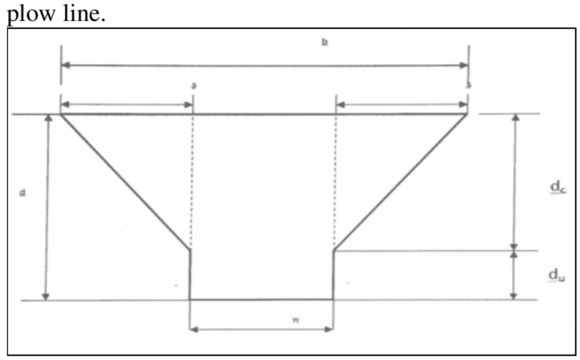

Fig. 9 : Cross section of subsoiler excavation

A = Disturbed soil area (cm^2) that can be calculated from below equation:

$$A = (s \times d_c) + (w \times d) cm^2 \quad ....(6)$$

where:
d = Subsoil plow depth. (cm)
d_c = critical depth from the surface. (cm)
d_u = distance between critical depth and furrow bottom. (cm)
w = Width of the tilled soil at the critical depth. (cm)
b = Disturbed soil width at the surface. (cm)
s = Disturbed distance on one side (cm)\

Results And Discussion

Effect of Subsoiling depth on Yield and Machinery Indicators

Corn Yield

From Table 3. We observed that yield indicator is considerably affected by changing in tillage depth. It increased by increasing the depth of subsoiling and totally gained to its highest values at the depth of (40 – 45) cm whereas the lowest rates were scored at the shallowest depth. Wayasa *et al*. (2012) confirmed that biomass yield of maize improved due to good soil conditions provided to crop for better growth and development by loosening the soil with deep tillage. Also Borghei *et al.* (2008) verified that yield per hectare and plant height were affected by tillage depth which attributed with improvement of soil physical circumstances such as bulk density and penetration resistance which ensure convenient root propagation as well as more root aeration.

Drawbar Power

Enhancing tillage depth resulted to significantly raising the drawbar power from 30.881 hp in first depth to 40.682 hp in second depth and 46.382 hp in third depth. Keskin *et al.* (2011), Raper (2007), Zhang *et al.* (2006) verified these results. This is due to increasing draft force requirement by increasing the tillage depth (as discussed here before) which consequently increases the drawbar power requirement. This is verified by Jasim and Mankhi (2012).

Slippage Power Loss

Table 3 reveals that tillage depth increment, resulted to significantly more slippage power loss, so that there was 4.507 hp power loss from (20 – 25) cm depth which rose to 7.128 hp for (30 - 35) cm and then 10.844 for (40 – 45) cm depth. Results confirmed by Jasim and Mankhi (2012), Al- Sharifi (2009) and Tahir (2004). This can be explained that by depth increment draft force increase due to more contacting area of plow and soil. Since the tractor is working with the highest power (that can be assumed as constant) more required draft force means that more time is needed to do the operation. While the distance is constant (in this study 30 m) the practical speed will reduce, resulting to greater slippage percentage value and finally higher slippage power loss. The result was confirmed by Jeejo (2013).

Disturbed Area

Disturbed area considerably increased from 2001.500 cm^2 to 3219.300 cm^2 then 4349.070 cm^2 respectively by increasing the subsoiling operation from first to second and then third depth. This was verified by Raper (2007). Increasing the tillage depth increases the critical depth from soil surface resulting more disturbed area. This is confirmed by Hilal (2007), Eshaghbeygi *et al*. (2005), and Mielke *et al*. (1994).

Table 3 : Effect of tillage depth on indicators

Indicator	Mean value		
	Tillage depth (cm)		
	20 – 25	30 – 35	40 – 45
Seed per hectare (ton/ha)	5.646	5.997 b	6.314 a
* Draw bar power (hp)	30.881 c	40.682 b	46.382 a
* Slippage power loss (hp)	4.507 c	7.128 b	10.844 a
Disturbed area (cm^2)	2001.500 c	3219.300 b	4349.070 a

Same letters mean there is no significant difference but different letters mean significant difference.
* Before indicators means the lower value is better. For remaining indices higher values are better.

Effect of Subsoiler Tine type on Indicators

Corn Yield

Table 4. revealed that subsoiler tine type significantly affected yield per hectare. This maybe related to more disturbed area of modified tine (here after is discussed) that means less soil bulk density. Ramazan *et al.* (2012) confirmed that the soil with low bulk density has more porosity, good hydraulic conductivity, thus has favorable condition for plant growth.

Slippage Power Loss

Modified tine showed 7.78% more power loss than conventional tine. This was due to considerably higher slippage% for modified tine than conventional one that reduces the practical speed, also, more draft force requirement that explained before. Al–Saadi (2011) and Al- Sharifi (2009) confirmed this reason.

Disturbed Area

Disturbed area of subsoiler equipped with modified tine is considerably 26.13% higher than that with conventional tine. Wings increase the width of tillage leading more disturbed area. Tine with wings increased attack surface, which would further soil rupture. The result was confirmed by Spoor and Foot (2000), and Ramadhan (2014).

Table 4 : Effect of subsoiler tine type on indicators

Indicator	Mean value	
	Type of tine	
	Conventional	Modified
Seed per hectare (ton/ha)	5.877 a	6.095 a
* Draw bar power (hp)	38.696 a	39.934 a
* Slippage power loss (hp)	7.213 b	7.774 a
Disturbed area (cm^2)	2821.350 b	3558.570 a

Same letters mean there is no significant difference but different letters mean significant difference.
*Before indicators means the lower value is better. For remaining indices higher values are better.

Effect of Interaction Between Tillage Depth and Type of Tine on Indicators

Corn Yield

Table 5. Illustrated the interaction between tillage depth and type of tine significantly affected on corm yield. They totally illustrated their highest values at the depth of (40 – 45) cm of subsoiling when utilizing the modified tine. The reason maybe was due to the highest disturbed area (as are showing thereafter) in this treatment which helped the plant to find nutrients and water easier due to better root proliferation. At the same

time entire indicators showed their lowest values when the plow worked at the depth of (20 – 25 cm) and was equipped with conventional tine. Solhjou and Mohammadi (2007) gave detail proving that subsoiling helps plant to persist against water crisis. This was maybe a reason to explain plant indicators demonstrations especially for this study that was performed in summer production.

Drawbar Power

Subsoil plow at the deepest depth when equipped with modified tine illustrated the greatest drawbar power of 47 hp; whereas when equipped with conventional tine showed the lowest value of 30.407 hp. Veal *et al*. (2005) verified that depth increment significantly raised the drawbar power requirement. Furthermore at each depth modified tine demonstrated higher values rather than conventional one. This was because of drawbar power dependency to draft force. The reasons were discussed before. The result was confirmed by Jeejo (2013).

Slippage Power Loss

Subsoiling with modified point at the depth of (40 – 45) cm showed the highest value of 11.228 hp of slippage power loss; in the other hand, the lowest value of that was 4.297 hp which was scored at the depth of (20 – 25) cm with conventional tine. The results were verified by Al-Irhayim (2009). This indicator significantly increased by increasing the subsoiling depth. For each depth it was higher for modified point comparing to conventional one. This was due to higher slippage percentage and draft force requirement for modified tine when working at the deepest depth that was

Disturbed Area

Disturbed area of modified tine at the depth of (40 – 45) cm illustrated the highest value of 4849.930 cm^2 in contrast to the lowest value of 1725.400 cm^2 for conventional tine at the depth of (20 – 25) cm. Results were confirmed by Al-Tahan and Al-Irhayim (2010) .Depth increment significantly increased this indicator which was higher at any depth for modified tine type comparing to conventional one. Under the effect of increasing the depth and working width, the critical depth is tried to drive down resulting more disturbed area as before explained. The result was confirmed by Jeejo (2013).

Table 5 : Effect of interaction between tillage depth and type of tine on indicators

Tillage depth (cm)	Type of tine	Seed per hectare (ton/ha)	* Draw bar power (hp)	* Slippage power loss (hp)	Disturbed area (cm^2)
20 - 25	Conventional	5.782 bc	30.407 c	4.297 c	1725.400 f
	Modified	5.980 ab	31.355 c	4.718 c	2277.600 e
30 - 35	Conventional	6.310 a	39.918 b	6.882 b	2890.440 d
	Modified	5.510 c	41.447 b	7.375 b	3548.170 c
40- 45	Conventional	6.015 ab	45.763 a	10.460 a	3848.220 b
	Modified	6.318 a	47.000 a	11.228 a	4849.930 a

Same letters mean there is no significant difference but different letters mean significant difference.
* Before indicators means the lower value is better. For remaining indices higher values are better

Conclusions

- The majority of the studied plant indicators exhibited their highest values at the depth of (40 – 45) cm of subsoiling done on using the modified tine type.
- Briefly, by comparison between two tine types, it was observed that all indicators showed greater values by equipping the subsoiler with modified tine. Although, this superiority was not significant in some indices Such as slippage power loss, and fuel consumption showed higher values by using modified tine; this was covered by positively greater values of ther indicators especially disturbed area, plow stability. Another significant machinery indicator was specific resistance that was considerably lower for modified tine.

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