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Development and evaluation of a combined two-level subsoiler for strip-tilling sugarcane fields

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ABSTRACT

In Khuzestan province of Iran, the number of traffic passes made by heavy farm machinery in sugarcane land preparation varies depending upon field conditions, ranging from a minimum of 10 to a maximum of 16 passes annually. To reduce energy, time and cost, it is imperative to use conservation tillage as well as controlled traffic systems. The objectives of this research were to develop, and evaluate a combined strip deep tillage machine equipped with a two-level deep tillage implement including a dual sideway-share and a winged subsoiler, cum with a set of discs. For optimizing the dual-sideway-share subsoiler, the effects of share rake angle (7.5 and 15°) and length (150 and 200 mm) on the implement field performance were examined. Also, to optimize the winged subsoiler, it was tested with its wing having different lengths (0, 200, 250, and 300 mm). Finally, the performance of the developed combined strip deep tillage machine was compared with a conventional subsoiler used for deep tillage in the fields. The results showed that the optimized combined strip deep tillage machine should be equipped with the dual sideway-share subsoiler having a share with a 7.5° rake angle and 150 mm length, and the winged subsoiler with 250 mm length for its wing. The results showed that the specific resistance of the developed machine as compared to the conventional subsoiler decreased by 34%. Therefore, the machine has higher efficiency and is an environmentally friendly implement for sustainable sugarcane production in southwest Iran.

Keywords: Conservation tillage; Controlled-traffic; Draft; Ripper; Specific resistance; Subsoiler.

1. Introduction

Sugarcane (*Saccharum officinarum*) is a giant tropical grass, whose stalk has the particular capacity to store a crystallizable sugar, sucrose. **Sugarcane cultivation in the irrigated fields of agricultural and industrial companies in Khuzestan, a province in the southwest of Iran, is fully mechanized. In general,** the mechanized operations in sugarcane production can be

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categorized into four primary stages, **which included** (1) soil preparation, (2) planting, (3) **growing** (comprising irrigation, fertilization, pesticide application, and ratooning), and (4) harvesting (involving cutting, loading, transportation to the factory, and unloading) (Monjazi et al., 2017). These operations are characterized by substantial traffic of heavy machinery across various production operations, particularly during cultivation and harvesting, and often practiced under unfavorable moisture conditions. This could result in soil compaction. However, it is well known that, soil compaction **can reduce** crop yields (Shaheb et al., 2021). Therefore, it is necessary **to develop** an effective **cultivation** system with minimum soil compaction.

The nature of soil tillage operations for sugarcane land preparation is energy-intensive, time-consuming and expensive. To reduce energy and time it is **necessary** to use conservation tillage as well as controlled-traffic systems. In conservation sugarcane farming system, zonal or strip tillage is when only the row area is cultivated in preparation for planting the sugarcane sett and the inter-row area remains undisturbed and used as traffic zone. Therefore, strip tillage represents a farming method that combines the advantages of reduced tillage for crop rows, with the benefits of no-till in the inter-row spaces (Voorhees, 1991; Licht and Al-Kaisi, 2005; Laufer and Koch, 2017). Sugarcane harvesting involves the use of sugarcane harvesters and transport baskets and the machinery traffic affects approximately 50% of the total field area. Consequently, the implementation of traffic control principles becomes crucial. This approach entails segregating the area required for crop growth from the region impacted by machinery traffic (Mouazen and Palmqvist, 2015; McHugh et al., 2009 and 2020).

The adoption of traffic control methods can result in a remarkable reduction in energy consumption, up to 23%, during crop production stages when compared to conventional random-traffic farming (RTF) (Chen et al., 2008 and 2010).

In today's agricultural practices, there is growing interest in integrated tillage methods. Integrated tillage approaches have gained prominence due to their ability to reduce operating time, fuel consumption, and energy requirements (Prem et al., 2016). Essentially, integrated tillage combines various operations to prepare the soil with desirable characteristics, intending to reduce costs and operating times (Manian and Kathirvel, 2001). Integrated machinery tends to be more complex compared to single-purpose machines but offers numerous advantages and greater efficiency within a similar timeframe (Sahu and Raheman, 2006).

Considering the heavy texture of the soils of North Khuzestan due to their high clay content and the traffic of heavy machinery in unfavorable soil moisture conditions at the time of harvesting, conventional sub-breakers is used to reduce dense layers of soil.

Generally, four common types of subsoilers are used for deep tillage: the bulldozer ripper, the conventional/winged subsoiler, the Para plow, and the bent leg subsoiler (Harrison and Licsko, 1989b; Harrison, 1990; Raper, 2005). In addition to the quantity and quality of the disturbed soil volume; the choice of subsoiler for deep tillage depends on its critical depth, and the required draft force; therefore, an ideal subsoiler has a greater critical depth and requires less draft force **(Godwin and Spoor, 1977).**

The critical depth is the depth below which soil loosening does not occur and only soil smearing and compaction is observed. In other words, the critical depth is the depth at which the soil no longer creates a crescent failure radiating from just above the tine point but whose failure zone has its base part way up the tine shank and the soil at the tine base starts to flow forward and sideways rather than lifting upwards (Godwin and Spoor, 1977; Godwin and O'Dogherty, 2007).

The tine implements such as chisel or subsoiler, which are used for shallow and deep soil tillage, are equipped with forward-sloping shares **(Hoseinian et al, 2022).** Recently, a new tine implement with sideway shares has been introduced for shallow subsurface tillage. It was field-tested by Salar et al. (2013) and the effect of geometrical variables such as rake angle, tilt angle and share size on tool resistance forces and the soil disturbance areas were analyzed using discrete element method (DEM) by Hoseinian et al. (2022).

In this research, the concept of the "sideway shares" was used for developing a new deep tine implement (subsoiler) as part of a combined strip deep tillage machine for sugarcane fields. Thus, the primary objective of the current study is to develop, and evaluate a combined tillage machine equipped with a two-level deep tillage implements comprising the dual sideway-share subsoiler and the winged subsoiler, cum with a set of discs for strip deep tillage in sugarcane fields. The research aims to compare the performance of this machine with that of a conventional subsoiler in sugarcane land preparation operation, considering performance factors such as draft force, area of the disturbed soil, and specific resistance.

2. Materials and methods

2.1. Farm characteristics

The experimental tests were conducted in the fields of Imam Khomeini Sugarcane Agro-industry (31°39´- 31°55´N and 48°39´- 48°48´E). The agro-industry Co. is situated in the Shoaibiye region, located approximately 30 km south of Shushtar city in Khuzestan province, Iran. For having soils with different physical and mechanical characteristics, two fields, namely SC13-32 and B1-131, were selected.

2.2. Selected soil physical properties

The physical properties of the soil, including soil texture and bulk density, were measured at three layers: 0-200, 200-450, and 450-700 mm. To account for the influence of soil texture on bulk density, relative bulk density (RBD) was employed (Eq. 1).

$$RBD = \frac{BD}{BD_{REF}} \quad (1)$$

Where, BD represents the bulk density of the soil, while BD_{REF} signifies the reference bulk density. Given the substantial clay content in the study fields, the Jones equation (Eq. 2) was utilized to determine the reference bulk density.

$$BD_{REF} = 1.985 - 0.00857 clay\% \quad (2)$$

2.3. Specifications of the subsoiler used in conventional deep tillage in the sugarcane fields

In the sugarcane agro-industry Co. of Khuzestan, a conventional subsoiler with a curved (C shaped) shank having a rectangular share with a rake angle of 18 degrees and without any wing is used for deep tillage.

2.4. Specifications of combined two-level tilling machine for strip deep tillage of sugarcane fields

The combined two-level tillage machine for strip deep tilling for the sugarcane fields, as depicted in Fig. 1; includes two implements: 1) **the two** dual sideway share subsoiler in front and 2) the winged subsoiler at a distance at the back on the machine frame. Additionally, a gang of discs is mounted at the end of the frame to crush sugarcane residues.

Fig. 1. Combined two-level deep tillage machine cum with a conical-type disc gang.

For developing the dual sideway-share and winged subsoilers, several parameters were taken into consideration. These parameters account for the physical and mechanical properties of the soil, dimensions, rake angle, and the tilt angle of the shares and wings. Moreover, since the intended tractor is a track-type bulldozer with an output power of 280 hp, it is crucial for the subsoilers not only withstand compressive and tensile stresses but also be resistant to bending forces (resulting from sudden twists of the bulldozer). To meet these requirements, ST52 alloy steel was used to make the shares and wings.

2.4.1. Specifications of dual sideway-share subsoiler

To determine the suitable geometry of the dual sideway-share subsoiler for achieving adequate penetration into soil and having low specific resistance, the results of the discrete element method (DEM) simulations of Hosienian et al. (2022) were considered. Their results stated that the draft force increases with the increase of the rake angle and they considered the rake angle less than 15 degrees to be appropriate. Also, their results stated that different tilt angle do not have much effect on draft force, but in the range of 20 to 30 degrees, it will bring minimum specific resistance. Two rake angles, 7.5 and 15 degrees, were selected. In addition, considering the required tilled width of the soil bed (800 mm) for planting two rows of plants on each bed, the shares with widths of 150 and 200 mm were tested. The angle of attachment of the shares to the shank (tilt angle) was set at 30°.

2.4.2. Specifications of winged subsoiler

To achieve subsoiling to a depth of 700 mm, a winged subsoiler having a share with an 18° rake angle was employed (Fig. 2). To provide the necessary disturbed soil volume in depth of root growth, three different wings with the lengths of 200, 250, and 300 mm were evaluated. The rake angle of the wings matched the subsoiler's share rake angle, which was 18°, and their tilt angle was set at 30°.

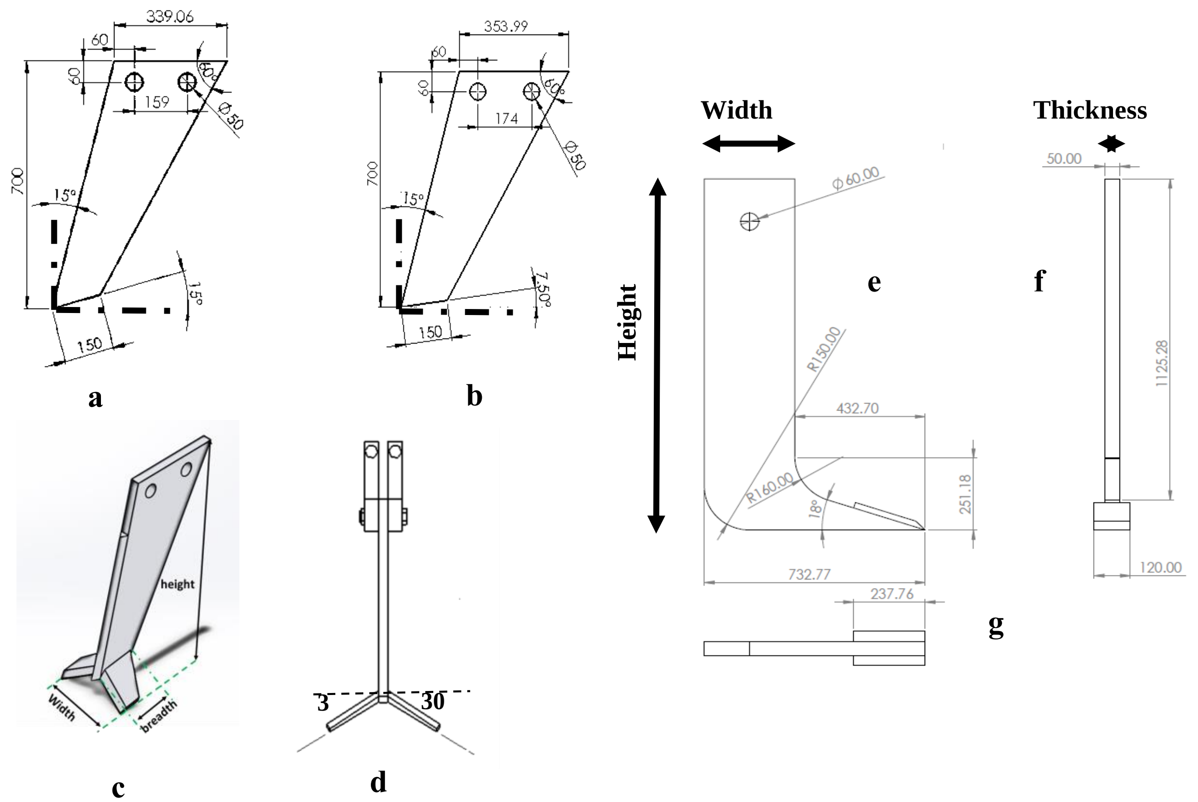

Fig. 2. Dimensional characteristics of the dual sideway-share subsoiler: a) 7.5° rake angle, b) 15°rake angle, c) direction of subsoiler movement (dimensions in mm) and d) 30° tilt angle, and the views of the winged subsoiler having a share with an 18° rake angle from: e) front, f) right, and g) top.

2.4.3. Specification of disc gang

To break down the remaining clods and plant residues after subsoiling, four 710-mm (28-in) conical discs, manufactured from boron steel by O.F.A.S Italy, equipped with 230-mm spools, were used. The shaft of the disc gang was positioned at distances of 800 and 450 mm from the ground surface and the winged subsoiler, respectively (Fig. 1). Disks gang angle?

2.4.4. Field evaluation of the combined deep tillage machine

The field evaluation of different parts of the combined two-level deep tillage machine was based on specific resistance, which is obtained from the ratio of the draft force to the cross-sectional area of the disturbed soil. To measure the draft, two-tractor test (RNAM method) was employed. For this purpose, a load cell (S-shaped; H3-C3-20t-6B-D55 model) manufactured by Zemic Co, Germany was utilized. Data from the load cell were recorded using a data logger with a sampling rate of 1.0 s. The recorded data were stored on a 2-gigabyte memory card.

To measure the cross-sectional area of the disturbed soil, a profile meter with a width of 1000 mm and a height of 800 mm was used. The calculation of the cross-sectional area of the disturbed soil was based on Equation (3).

$$\mathbf{A} = \left(\left(\sum_{\mathbf{i=1}}^{\mathbf{n}} \mathbf{d_i}\right) - (\mathbf{d_1} - \mathbf{d_n})\right) \times \mathbf{L} \qquad (3)$$

Where: A is the area of disturbed soil in mm^2, di **is readings** taken from the profile meter rods **in** mm, d_1 & d_n **are readings** obtained from the first and last profile meter rods **in** mm and L **is the** longitudinal distance between the first and last profile meter rods, mm.

2.5. Statistical analysis

Bulk density and relative bulk density at three layers of 0 to 200, 200 to 450, and 450 to 700 mm of soil, as well as draft force, area of disturbed soil, and specific resistance of the subsoilers, were assessed. This assessment was performed for the dual sideway-share subsoiler working to a depth of 450 mm, whereas for the winged subsoiler tilling to a depth of 700 mm. **the rake angle and lengths of the shares were consider for dual sideway-share subsoiler. Also, the length of the wings were considered for winged subsoiler. In each experiment a randomized completely block design** with three replications was used for field experiments. After checking the **normality of the data by Kolmogorov-Smirnov methods** and the uniformity of variances, an analysis of variance was conducted, and the means of the data were compared using the Duncan statistic in SAS software (Version 9.4) at 5 percent probability level.

3. Results and discussion

3.1. Soil texture and bulk density

The texture, bulk density, and relative bulk density values at three soil layers in both fields are presented in Table 1. Both fields have the same soil texture, namely, silty clay. The results indicate that despite having similar soil texture, the two fields exhibit different bulk densities. Soil structure and texture largely determine bulk density. Therefore, the two fields differ and they do not have similar soil structures. Relative bulk density shows the compactness of the soil. The 0-450 mm and 450-700 mm layers of the soil have different relative bulk densities. The average bulk density and relative bulk density across the 0-700 mm soil depth were 1.67 g cm^{-3} and 1.05 in the SC13-32 field, while in the B1-131 field, they were 1.55 g cm^{-3} and 0.97, respectively. It is reported that the ideal soil bulk density for silt loams and silty clay loams should be less than 1.40 g cm^{-3}, whereas the value of bulk density more than 1.65 g cm^{-3} restricts root growth (Anonymous, 2023). Therefore, bulk density values in all soil layers for both fields indicate that the soils are over-compacted. However, the SC13-32 field is more compacted than the B1-131 field.

Table 1. Soil texture, bulk density and relative bulk density in different soil layers in SC13-32 and B1-131 fields.

Field	Depth	Soil particle percentage			Texture	Bulk density	Relative bulk
	(mm)	Clay	Silt	Sand		(g cm^{-3})	density
SC13-32	0-200	47	43	10	Silty clay	1.63b*	1.03b*
	200-450	47	43	10		1.62b	1.04bc
	450-700	49	43	8		167b	1.07c
B1-131	0-200	41	41	18		1.52a	0.93a
	200-450	47	45	8		1.53a	0.97a
	450-700	47	45	8		1.61b	1.02b

*Mean values followed by the same letter in each column are not significantly different according to Duncan's new multiple range test at the 5% level of probability.

3.2. Field performance of dual sideway-share subsoiler

The cross-sectional areas of the disturbed soil for the subsoiler having two different share rake angles and lengths tilling 450 mm deep in both fields show that the implement was working above its critical depth (Fig. 3 and Table 2). This is due to the large width of the shares (with an aspect ratio greater than one and less than six, Godwin and Spoor, 1977), and therefore, the dual sideway-share subsoiler functioning as a narrow tillage tool and operating above its critical depth.

To determine the efficiency of soil loosening, the data of the measured draft force (Table 2) and the area of disturbed soil were analyzed and used to calculate specific resistance.

Table 2. Draft force (KN) and specific resistance (KN m^{-2}) of the dual-sideway-share subsoiler in different soil.

SL (mm)	α (deg.)	Draft force (KN)		Specific resistance (KN m^{-2})	
		SC13-32	B1-131	SC13-32	B1-131
150	7.5	19.51a	16.56a	96.70a	64.60a
200	7.5	22.34b	20.83b	101.30a	76.20b
150	15	30.90c	22.80b	138.50b	86.40b
200	15	37.57d	25.99c	149.40b	82.0b

Mean values followed by the same letter in each column are not significantly different according to Duncan's new multiple range test at the 5% level of probability. Explain the SL, α, SC13-32 and B1-131 here. The reader should not refer to the text to understand the table

The field experiments indicated that an increase in the angle or length of the share resulted in a higher draft force requirement. The DEM simulation results given by Hosienian et al. (2022) also showed that the increase of the share rake angle or its cutting width linearly increased the draft force of a single sideway share subsurface tillage implement. Notably, the force value in the B1-131 field was significantly lower than in the SC13-32 field. Therefore, the SC13-32 field is more compacted than the B1-131 field as shown by measuring the soil bulk density (Table 1).

In the B1-131 field, which had lower soil bulk density compared to the SC13-32 field, there was a greater amount of disturbed soil and soil upheaval (height of accumulated soil on the surface). The smallest disturbed soil area was associated with the subsoiler having a share with a 7.5° rake angle and 150-mm length, while the largest disturbed soil area was related to the subsoiler featuring a share with a 15° rake angle and 200-mm length (refer to Figs. 3). Increasing the rake angle from 7.5 to 15° did not significantly increase the width of the disturbed soil.

The lowest specific resistance was achieved with the dual sideway-share subsoiler equipped with a 7.5° rake angle and a 150-mm share length. Additionally, its value in the B1-131 field was significantly lower than in the SC13-32 field. Conversely, the highest specific resistance was observed in the soil of the SC13-32 field when using a 15° rake angle and a shared length of 200 mm (Fig. 3). These results agree with the findings of Salar et al. (2013).

The selection of the optimal share dimensions was determined by comparing the specific draft (resistance) of the subsoiler equipped with different share sizes. The minimum specific draft was associated with the subsoiler having a share with a 7.5° rake angle and 150-mm length tilling soil in the B1-131 field. On the other hand, the maximum specific force was related to soil tillage using the subsoiler equipped with a share having 15° rake angle and 200-mm length in the SC13-32 field (Table 2). In growing two rows of sugarcane plants on a bed, for growth and development of the plant roots, a disturbed soil volume with a width of 110-cm and 45-cm depth is required (Sugarcane & by products development company, 2012). Therefore, to determine the optimal distance between the two units (shanks) of the dual sideway-share subsoiler, the disturbed surface of the soil in depth and the possibility of passing sugarcane clods and stumps with a diameter between 30 and 40 cm were also taken into consideration. Therefore, the center-to-center distance of 50 cm was considered between the two shanks of the subsoiler (Figure 4); the winged subsoiler with a vertical shank, with working depth of 700 mm is mounted in the middle of the two shanks at the back of the machine frame.

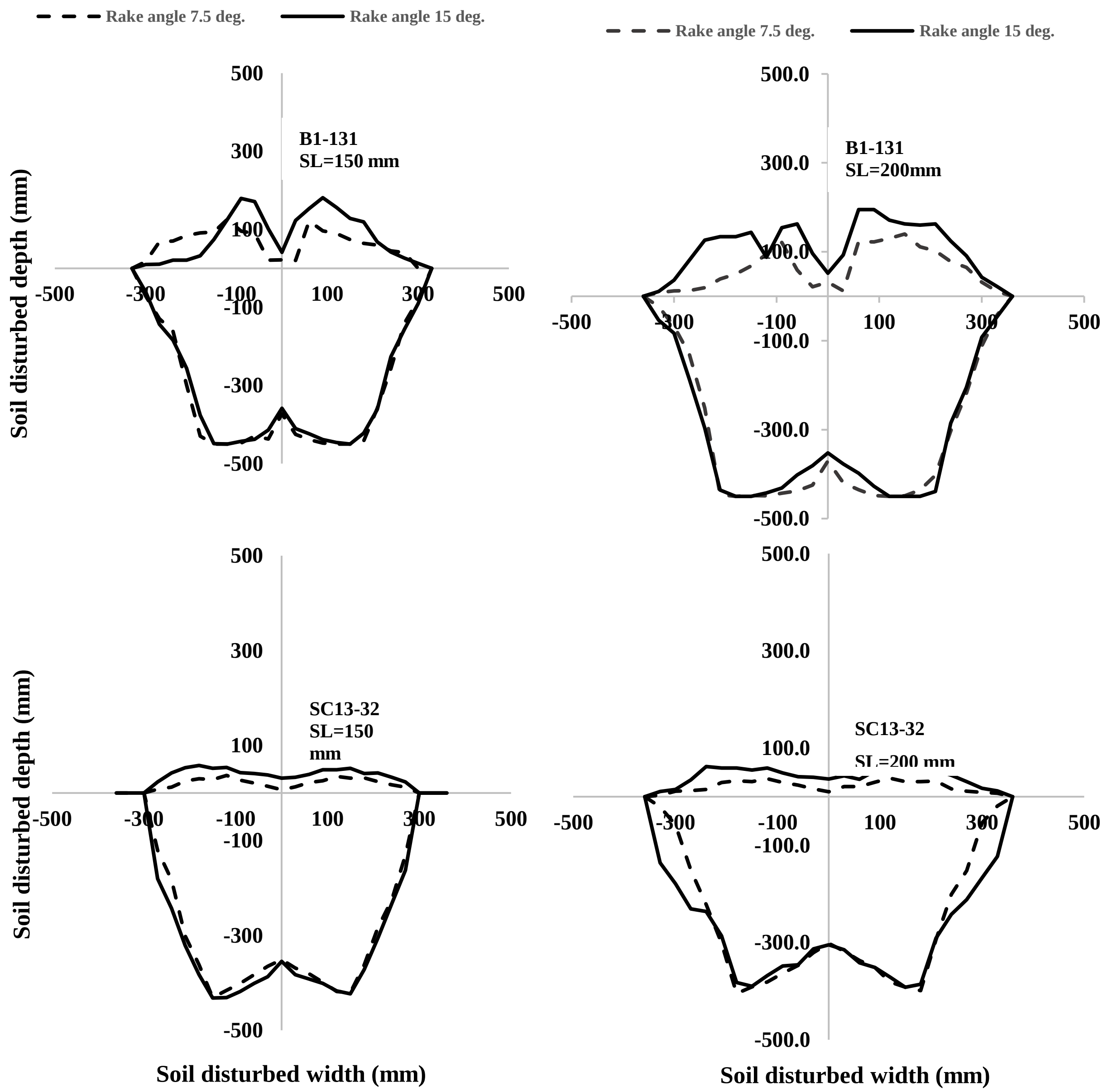

Fig. 3. The soil disturbed area (mm^2) using the dual sideway-share subsoiler with different rake angles (α) and share lengths (SL) in both fields.

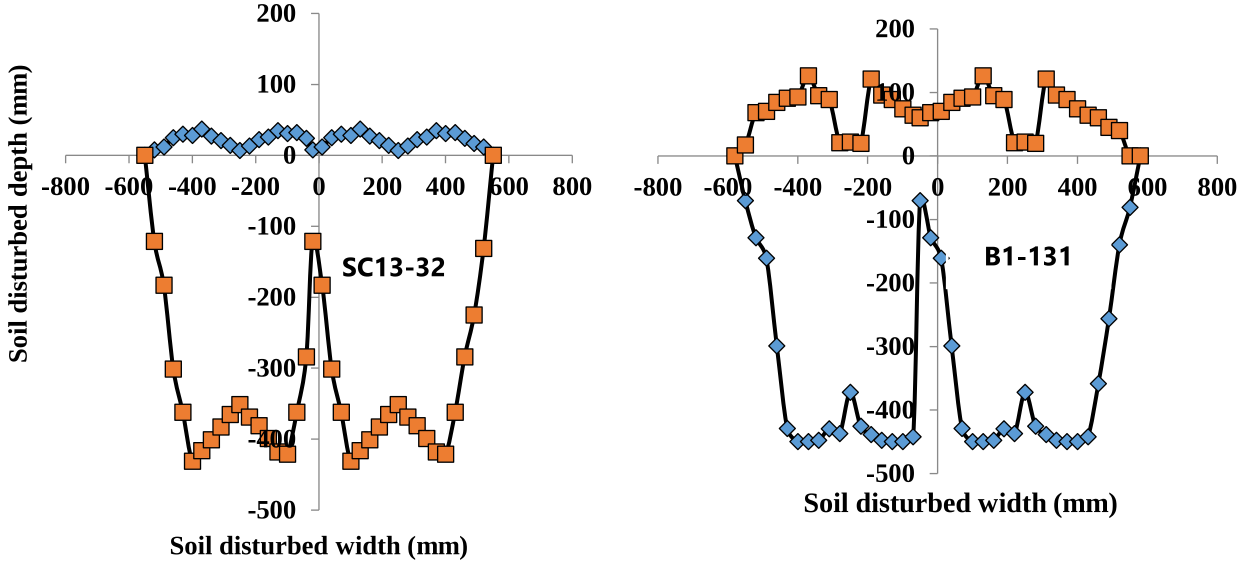

Fig. 4. The cross-sectional area of the disturbed soil and soil upheaval during deep tillage with two shanks of the dual sideway-share subsoiler. (Use same color to show soil upheaved and disturbed area. For example, use yellow dots for upheaved area at both diagrams and blue dots for disturbed area)

The specific resistance values for conventional and the dual sideway-share subsoiling at the depth of 450 mm are presented in Table 3. The results indicate that in the sugarcane fields of Khuzestan, the specific resistance of the dual sideway-share subsoiler is at least 20% and, in some cases, up to 30% lower than the conventional subsoiler working at 450-mm depth. Because using the dual sideway-share, the increase in soil rupture has exceeded the increase in tensile force.

Table 3. Specific resistance (kN m^{-2}) of the dual-sideway-share subsoiler as compared to the conventional subsoiler.

Fields	Dual-sided bent share	Conventional	Percentage of reduction
SC13-32	96.7	123.1	21.1
B1-131	66.7	96.1	30.20

3.3. Field performance of winged subsoiler and its optimum wing size

To evaluate the performance of the winged subsoiler, measurements were taken for the draft force, area of disturbed soil, and subsequently, computing its specific resistance. This assessment involved wings with lengths of 0, 200, 250, and 300 mm. To create similar soil conditions as those achieved by the combined two-level deep machine, first, the two units of the dual-sided bent share subsoiler were used to till the soil to a depth of 450 mm.

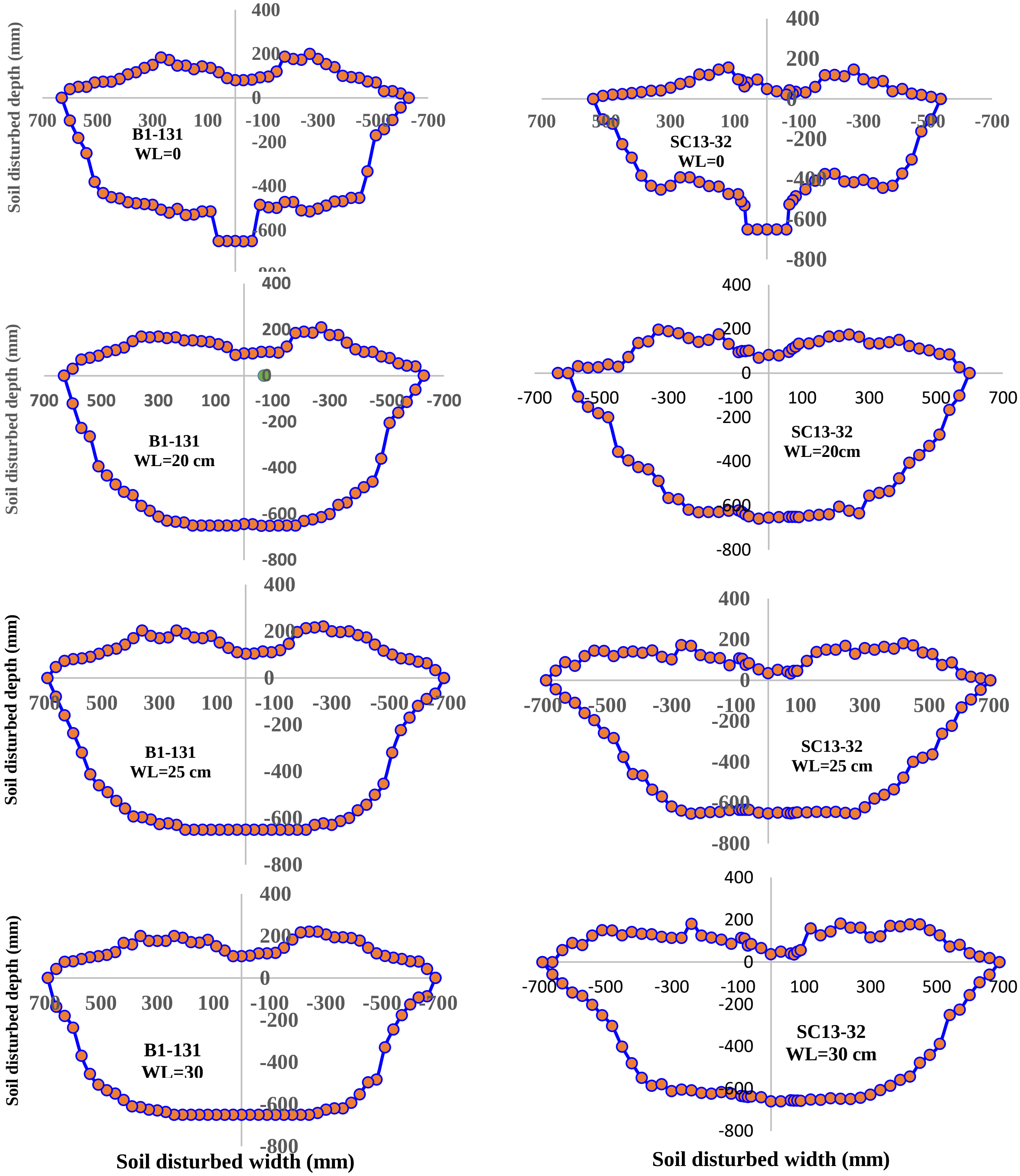

Fig. 5. Soil disturbance and upheaving in deep tillage using winged subsoil with different wing lengths.

The results of the disturbed soil area measurements using the winged subsoiler are presented in Fig. 5. These results reveal that the critical depth for the wingless subsoiler is about 500 mm.

Below this depth, soil loosening (upheaving) does not occur, however, a channel with smeared walls of the same width as the shank in the soil is created. Moreover, increasing the length of the wing leads to increased soil disturbance volume. The area of soil disturbance and soil upheaval due to varying wing length are summarized in Figure 5. The data shows that as the wing length increases, both soil upheaval and the area of soil disturbance increase.

The results of the draft force and specific resistance for the winged subsoiler are presented in Table 4. According to these findings, there is an upward trend in draft force as the length of the wing increases. However, there were no significant differences in specific resistance between the wingless and winged subsoilers. In other words, while increasing the wing length led proportionately to a larger area of soil disturbance; it did not significantly affect the specific resistance. Field observations revealed that in these clay-rich and compacted soils, no horizontal cracks in the direction of the share (point) tip, as reported in other studies (Godwin and O'Dogherty, 2007), were observed. Therefore, each wing probably mimicked the behavior of the share (point) in undisturbed soil, and the draft force as well as the volume of the disturbed soil increased proportional to wing length. Consequently, adding wings did not reduce the subsoiler-specific resistance.

Table 4. Draft force (KN) and specific resistance (kN m^{-2}) of winged subsoiler in different soil.

WL (mm)	Rake angle (deg.)	Draft force (KN)		Specific resistance (KN m^{-2})	
		SC13-32	B1-131	SC13-32	B1-131
0	20	18.93a	17.49a	32.27a	25.72a
200		22.23b	20.16b	30.83a	25.81a
250		26.65c	22.38c	33.73a	25.64a
300		28.41d	24.37d	35.51a	27.32a

Mean values followed by the same letter in each column are not significantly different according to Duncan's new multiple range test at the 5% level of probability. All parameters must be defined here.

In the sugarcane agro-industry Co. of Khuzestan province, two rows of sugarcane billets are planted on each ridge (bed) with a horizontal spacing of 450 mm. additionally, each sugarcane shoot requires a growing space with a radius of 250 mm to develop without competition. Since 70% of the sugarcane billet roots grow within the range of 0 to 450 mm deep in soil (Blackburn, 1984), it is recommended that strip tillage machine provides a bed with a width of 500 mm and a depth of at least 450 mm for each sugarcane shoot. Therefore, based on the findings presented in Table 4, it is advisable to use wings with a length of 250 mm. Furthermore, for both fields with different bulk densities, using wingless subsoilers for strip tillage in sugarcane cultivation is not recommended.

3.4. Optimum positioning of the winged subsoiler on the combined machine frame

The efficiency of the subsoilers can be maximized while the longitudinal distance between the two is such that it allows the soil failure by the front subsoiler to stabilize before the rear subsoiler reaches it. Therefore, in determining the longitudinal spacing between the winged and the dual sideway-share subsoilers for developing a combined two-level deep tillage machine it was necessary to find out the forward “rupture distance” of the winged subsoiler. This ensures that the longitudinal rupture generated by the winged subsoiler intersects under the soil disturbance caused by the front subsoiler while avoiding interactions between the soil disturbances of both subsoilers (Fig.6). The findings indicate that the deep-working winged subsoiler disrupts the soil in front of itself, covering a distance of up to 740 mm (referred to as the rupture distance) from its share tip. Consequently, to enable independent soil tillage by both implements, there should be a minimum spacing of 740 mm between the shanks of the dual sideway-share subsoiler and the share tip of the winged subsoiler. This ensures that each tool can effectively perform its soil disturbance functions without interfering with the other.

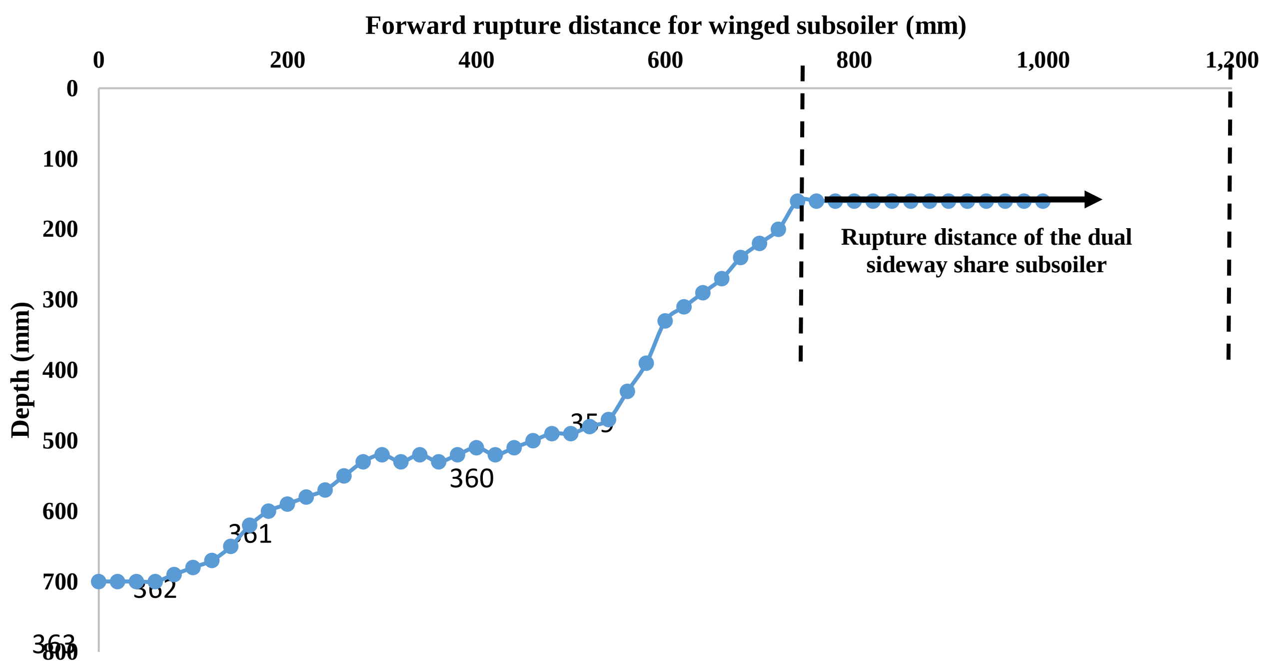

Fig. 6. Forward soil disturbed by the winged subsoiler with a 250-mm wing.

3.4. Conventional subsoiling versus strip subsoiling using the combined machine for sugarcane deep tillage

The results of comparing the performance parameters of conventional subsoiling with the combined machine are presented in Table 5. The findings indicated that while the draft force required for the combined strip tillage tool in sugarcane cultivation is 29% higher than that of the conventional subsoiler, the amount of soil loosened in the strip tillage method is 90.54% higher compared to the conventional method. Therefore, the specific resistance of the combined deep strip tillage machine is 33.7% lower than that of the conventional deep tillage. Consequently, it is recommended to use the combined two-level strip deep tillage machine in sugarcane cultivation.

Table 5. Comparison of performance parameters of conventional subsoiler versus the combined two-level strip deep subsoiler.

Tillage method / Parameter	Conventional	Strip deep*	Percentage increase or decrease
Draft force (kN)	42.1	54.3	+29
Area of disturbed soil (m^2)	0.32	0.63	+90.54
Specific resistance ($kN\ m^{-2}$)	132	86.3	-33.7

*Includes two dual-bent share subsoiler shanks + a winged subsoiler + a four-disc gang.

The obtained results are in line with the findings reported by Godwin and Spoor (1977). They observed that the addition of wings and surface-working tools in front of deep-working tools led to an increasing trend in draft force and the disturbed soil area. However, the specific resistance decreased compared to using a single deep-working tool. Moreover, the results obtained from this study are consistent with the findings reported by Gazor and Laghavi (2006). Therefore, strip tillage, which can create an optimal environment for sugarcane plant growth without transferring the compaction effect zone to the crop area, holds significant importance (Mcphee et al., 2020).

The results obtained from the effect of the rake angle on the draft force in deep tillage as compared to the results obtained in shallow tillage Hoseinian et al. (2022) showed that the minimum draft force was obtained at the same rake angle (7.5 degrees) for both shallow and deep dual sideway-share implements. **Askari et al. (2019) studied a new tiller, the bent-winged tines, and they found a 10-degree inclination angle to be appropriate compared to a 20-degree angle at 400 mm depth.**

4. Conclusions

The combined strip tillage machine equipped with two-level deep tillage implements comprising a dual sideway-share subsoiler and a winged subsoiler, cum with a set of discs is a novel and effective approach to deep tillage in sugarcane fields. Using this new tillage machine, in addition to decreasing the production costs, the soil structural damages could be reduced. Based on the results from the field experiments, the following conclusions were drawn:

1- The dual sideway-share subsoiler, with a 7.5° rake angle and 150-mm share length can reduce specific resistance by more than 20% compared to conventional sugarcane deep tillage. For strip tillage in sugarcane, the minimum distance between the two adjacent dual sideway-share subsoiler's shanks should be 550 mm.

2- Deep tillage with a wingless subsoiler beyond its critical depth can promote soil compactness, rather than removing compaction due to plastic failure of the soil around the share and lower shank. Winged subsoilers can provide high levels of tillage efficiency and eliminate critical depth issues, providing the wingspan is sufficient. The best wing for deep subsoiling in fields with a high clay content is 250 mm in length.

3- To use two-level subsoiler for deep strip tillage, the first-level subsoiler should operate at a depth of 450 mm, and the second-level deep subsoiler can operate at as depth as 700 mm.

4- Using the developed combined strip deep tillage machine compared to conventional subsoilers demands more draft force but significantly increases soil disturbance, resulting in a reduction of at least 33% in specific resistance.

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ساخت و ارزیابی زیرشکن دوسطح کار نواری در مزارع نیشکر

سینا لطیف التجار، و عباس همت

چکیده

در استان خوزستان تعداد تردد ماشین‌آلات سنگین کشاورزی برای آماده‌سازی زمین نیشکر بسته به شرایط مزرعه متفاوت و از حداقل 10 تا حداکثر 16 تردد در سال متغیر است . برای کاهش انرژی، زمان و هزینه‌ها، استفاده از خاکـورزی حفاظتی و همچنین سامانه‌های ترافیکی کنترل شده ضروری است. اهداف این تحقیق توسعه، و ارزیابی یک ماشین خاکـورزی عمیق نواری ترکیبی مجهز به یک ابزار خاکـورز عمیق دو سطح‌کار، شامل یک زیرشکن کج تیغه دوطرفه، یک زیرشکن بالـه‌دار به همراه مجموعه‌ای از دیسک‌ها بود. برای بهینه سازی زیرشکن کج تیغه دوطرفه ، تاثیر زاویه حمله (7.5 و 15 درجه) و طول تیغه (150 و 200 میلی متر) بر عملکرد ابزار مورد بررسی قرار گرفت. همچنین برای بهینه سازی زیرشکن باله‌دار، بال آن با طول های مختلف (0، 200، 250 و 300 میلی متر) مورد آزمایش قرار گرفت . در نهایت، عملکرد دستگاه خاکـورز عمیق نواری توسعه‌یافته با یک زیرشکن معمولی مورد استفاده برای خاکـورزی عمیق در مزارع نیشکر مقایسه شد. نتایج نشان داد که ماشین خاکـورز عمیق نواری ترکیبی بهینه‌شده باید به زیرشکن کج تیغه دوطرفه با زاویه حمله 7.5 درجه و طول 150 میلی‌متر و زیرشکن باله‌دار به طول 250 میلی‌متر مجهز شود. نتایج نشان داد که مقاومت ویژه ماشین توسعه یافته نسبت به زیرشکن معمولی 34 درصد کاهش یافت. بنابراین، این دستگاه دارای راندمان بالاتری است و ابزاری سازگار با محیط زیست برای تولید پایدار نیشکر در جنوب غربی ایران می‌باشد.