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Comparison of Fiber Reinforced Polymer (FRP) Composite Blade with Steel Blade Performance Used in Chisel Plow

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Abstract

All over the world, farmers choose different implements for tillage, which depend on crop type, soil type, the amount of plant residue from the previous crop, etc. Tillage implement selection is also affected by the availability of implements, power consumption, labor costs, and fund. In this research, the draft force, soil disturbance area, soil cone index, and fuel consumption were considered. The effects of rake angle, forward speed, and soil moisture content on the above-mentioned parameters were investigated. In this research, a comparison between the performance of a Fiber Reinforced Polymer (FRP) composite blade and a conventional steel blade was carried out. Tests were based on the split-split plot in a completely randomized design. The factors of soil moisture content, rake angle, and forward speed were included in three levels. Three levels for the soil moisture content (9.3, 13, 16.7 %), rake angle (20°, 30°, 40°), and forward speed (3, 5, 7 km.h^{-1}), were considered. The FRP composite blade (on average in the desired range for variables) has reduced the draft force, fuel consumption, and soil cone index, 14.97%, 16.63%, and 35.08%, respectively, than the steel blade. Also, the soil disturbance area created by the FRP composite blade was 4.93% higher than the steel blade. Based on the results of this study, it is clear that the FRP composite blade has better performance rather than the conventional steel blade for the aforementioned test variables. The FRP composite is inexpensive than the steel, this leads to remarkable save money in the production of the FRP composite blade used in the chisel and combined tillage tools that is economical for the farmer and manufacturer.

Keywords: Forward speed, FRP composite blade, Rake angle, Soil moisture content, Steel blade

Introduction

Tillage operation is the most important step in the production of crops and provision of agricultural land that consumes a great amount of power and energy. In the past decades, several tillage tools have been designed to achieve the main purpose of the tillage operation. Although a farmer is free to choose any of the tools, he always attempts to recognize their consumption energy and choose them according to the cultivation conditions (Godwin, 2007). The amount of energy used in tillage is very high compared to the other agricultural operations. Therefore, saving a small portion of consumption energy in agricultural operations will reduce the costs (Sanchez-Giron *et al.*, 2005). Due to the problems of conventional tillage, the conservation tillage in the form of minimum and no-tillage was introduced gradually. For this purpose, implements such as chisel and combined tillage tools were developed. The most important part of these tillage tools is their blade, which is typically made from steel. Adjustment of the blade is effective on draft, fuel consumption, and plowing quality. However other factors such as soil moisture content, forward speed, depth of tillage, and blade angles also have significant effects on

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the plowing quality (Liu and Kushwaha, 2006).

Some researchers investigated the effects of forward speed, rake angle, and soil moisture content on several factors such as draft force (Akbarnia *et al*., 2014; Ibrahmi *et al*., 2015), soil disturbance area (Manuwa, 2009; Jafari *et al*., 2011), fuel consumption (Ranjbarian *et al*., 2017), and cone index (Kumar *et al*., 2012). Khalilian *et al*. (1998) compared the required draft force of the tillage tools including subsoiler, the Para plow, and chisel plow at different tillage depths. They estimated the amount of draft force for the chisel, subsoiler, and Para plows as 2.88, 4.45, and 5 kN, respectively. Rahman and Chen (2001) compared two types of disk tillage tools and sweep plows in terms of soil disturbance area. They considered the applied treatments as the depth of tillage and forward speed and reported that with increasing the tillage depth and forward speed, the amount of soil disturbance area increased in both tillage tools, and the sweep blades showed better performance rather than the disk in soil disturbance. Chaplain *et al*. (2011) showed that the continuity in the no-tillage causes to increase in the bulk density, mechanical strength of the soil, and the soil cone index, which results in reducing water infiltrations and also root reduction in the soil, and increasing soil erosion. The results of some researches on the fuel consumption of the tractor showed that increasing the forward speed and depth of tillage increased the fuel consumption (Al-Jasim, 1993; Ranjbarian *et al*., 2017).

Some other researchers, using other materials in the form of the cover or employing the main materials for making the blade, tried to improve draft force, fuel consumption, etc. (Soni *et al*., 2007; Barzegar-Tabrizi *et al*., 2017). Chen *et al*. (1990) compared the draft force resulting from a plate of moldboard plow made from Teflon material with steel Ck45. The results showed that the draft force decreased by 25%, due to the reduction in friction between Teflon and soil, and stated that friction between Teflon and soil (apparent friction of soil) was 50% less than friction between steel Ck45 and soil. Ren *et al.* (1990) used Teflon as a coating on the surface of a moldboard plow to reduce soil-tool friction and they reported that Teflon coating causes draft force decreases. Salokhe *et al*. (1990) reported that the enamel-coated plows reduced draft force by up to 14% and 16% at 3.6 and 4 km.h^{-1}, respectively. Soni *et al*. (2007) constructed the moldboard plow which was covered with rows of ultra-high molecular weight polyethylene (UHMW-PE), as the material with low viscosity and friction, and its draft force was compared with steel moldboard plow in the adhesive soil. The results indicated that the draft force of the moldboard plow with a UHMWPE coating was 36% less than that of the moldboard plow. Barzegar *et al*. (2016) covered a furrower with ultra-high molecular weight polyethylene (UHMW-PE) and examined on the blade the draft force and adhesive. Their results showed that the UHMW-PE coating reduced the draft force and adhesion.

Recent studies on comparing plow types, changing the blade's material, and finding the best performance in the tillage operations indicated that the researchers are seeking the best performance with the lowest cost and power consumption in the tillage operation. The purpose of this research was to evaluate the performance of the Fiber Reinforced Polymer (FRP) composite blade compared to conventional steel ones. The factors of this research were including draft force, fuel consumption, soil disturbance area, and cone index. Performance comparison such as draft force, soil disturbance area, etc. of the FRP composite blade and conventional steel one (considering the effect of the blade properties, such as weight, adhesion, etc., but without considering the abrasive wear blade) was carried out in the field. The purpose of this research is to present the FRP composite blade and compare it to the steel blade in terms of impact on the mentioned factors.

Materials and Methods

Tillage site

Field experiments were conducted in farm No. 10 of Agriculture school (29°43′41″N 52°34′51″E) of Shiraz University, located in Bajgah zone of Fars province, Iran. The soil texture at the experimental site was clay loam with 38% clay, 30% sand, and 32% silt. To do experiments, a total of 27 plots were selected at a predetermined size (30 × 15 m) in the field. Soil moisture content was measured at 10 random locations of each plot prior to the tests. Initial soil moisture content was 7.2 ± 1.3 (d.b %). Also, to measure the soil bulk density, a standard cylinder with a diameter of 5 cm and a height of 10 cm was used, and the bulk density of 1.8 ± 0.4 (g.cm^{-3}) was obtained.

Tractor and tillage implement specifications

In this research, a 4WD tractor (model: ITM-399) was used that produced in the Iran Tractor Manufacturing Company. The plow used in this research was the mounted type chisel plow, constructed by Oztoprac Company in Turkey. The plow had a shank and two gauge wheels on both sides. Also, a mechanism was installed on it for adjusting the rake angle (Fig.1).

Fig.1. Mechanism for adjusting the rake angle

Blades

In this research, two chisel blades made of steel (controlling factor) (Fig.2C) and FRP composite (Fig.2B) were compared. The reason to use the FRP composite instead of steel in the chisel blades is due to its similarity or superiority at some mechanical factors over steel (Zhou *et al*., 2019). FRP materials are more resistant than steel in terms of the tensile strength (Jauharia *et al*., 2016). Also, the specific weight of the FRP composite is less than that of the steel (Biscaia and Chastre, 2018), such as the specific weight of FRP composites is one-third that of steel. The ultimate tensile strength for steel and FRP composite is 390 and 1200 MPa, respectively. Also, the young's modulus for the steel and FRP composite is 200 and 55 GPa, respectively (Mazaheri *et al*., 2015). In FRP materials, the volume fraction, size, and cross-sectional area of the FRP fibers used essentially affect their resistivity (Biscaia and Chastre, 2018). FRP composite blade used in this study, was prepared from FRP composite pipes manufactured by Farassan Company (Fars province, Iran). The FRP composite blade was cut off by using a laser cutting technique, according to steel blade pattern, with the same curvature and width (5 cm) (Figures 2B and 2C). The FRP composite toughness is less than steel (Mazaheri *et al*., 2015), therefore, to strengthen the composite blade against impact and better soil cutting, a steel plate (thickness of 8 mm and length of 250 mm) was installed as a base under the FRP composite blade (Fig.2A). For comparison of two blades with the same conditions, the surface area of the FRP composite blade with its support was the same as the surface area of the steel blade.

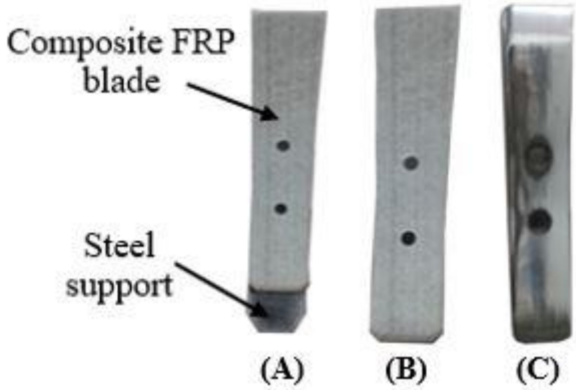

Fig.2. Blades used in this research, (A)- FRP composite with steel support installed below, (B)- FRP composite blade, and (C)- Steel blade (control)

To measure the friction between blades and soil, the adhesion index and external friction angle were used. For this purpose, in this study, a device similar to the devices of Gill and Van Den Berg (1968) and Kepner *et al.* (1972) was used to measure the adhesion and angle of external friction. To measure cohesion, the shear and vertical stresses of the soil at the desired moisture contents were measured by using a direct shear test machine manufactured by the Azmoon Company, Iran. Then, by using the Mohr-Coulomb theory, the cohesion, adhesion, and external friction angle for FRP composite and steel blades were obtained (Table 1). The blades' weight, shank weight, and total weight of the plow were affected the draft force and fuel consumption of the tractor (Karparvarfard and Rahmanian-Koushkaki, 2015). Therefore, the weight of the blades in this research was measured. For this purpose, weights were obtained by using a digital scale (model: MDS15000AP) with the accuracy of ±2g, manufactured by Mahak Company, Iran. Net weight of the steel and the FRP composite blades, net weight of the support, total weight of the FRP composite blade, and its support were obtained 1.355, 0.230, 0.830 and 1.065 kg, respectively.

Table 1- Mechanical and physical properties of farm soil

Moisture content (%)	Soil cohesion (kPa)	Steel chisel blade		FRP composite chisel blade	
		Soil adhesion (kPa)	Angle of external friction (°)	Soil adhesion (kPa)	Angle of external friction (°)
9.3	2.23	1.01	24.20	0.78	23.10
13	3.26	1.40	22.90	1.09	20.60
16.7	4.37	2.14	20.40	1.89	18.20

Field tests

The experimental variables in this research were forward speed (3, 5, and 7 $km.h^{-1}$), rake angle (20°, 30°, and 40°), and soil moisture content (9.3, 13, and 16.7%). The depth of tillage in all experiments was 25 cm. Tests were based on the split-split plot in a completely randomized design. To obtain the tillage depth of 25 cm, several trials were performed by using the desired plow. Several times, for measure tillage depth by using a laser ruler, from the plowed furrow floor to the surface soil was measured. This work was done to fine-tune the tillage depth of the plow in the tillage operation. After reaching a tillage depth of 25 cm, the depth of tillage was fixed using gauge wheels on both sides of the chisel plow.

To obtain the desired moisture content in the field, the whole farm was irrigated using a flooding irrigation system. Then, on a daily basis, soil moisture was measured, and by observing the desired moisture content (from the highest moisture to the lowest moisture), experiments related to those desired moisture content were performed.

Draft force and fuel consumption

A digital system was employed to measure the draft force and the fuel consumption of the tractor (Rahmanian-Koushkaki *et al*., 2015). This digital system had 11 ports. Two encoder shafts, two fuel transducers, and one load cell were used and connected to it to measure the draft force and fuel consumption (Fig.3). By using the RS232 cable the data was transformed to a Laptop and displayed and saved (Fig.3).

Draft force is the force applied from the soil on the blade and shank of the plow. The RNAM test code was used to measure the reaction force from soil to blade (RNAM Standard, 1995). For this purpose, a traction dynamometer (S type) was used (Table 2). Actual forward speed was measured using two shaft encoders (Fig.3). They were mounted on the center of the fifth wheel and right rear wheel of the tractor for measuring the actual and theoretical forward speed, respectively (Karparvarfard and Rahmanian-Koushkaki, 2015).

Two turbine flow transducers were also used to measure fuel consumption (Table 2). One of them was installed between fuel filters and injector pump of the tractor and the other between the injectors and the fuel tank were placed (Fig.3) (Shafaei *et al*., 2018). The difference between values measured by two turbine flow transducers indicates the actual fuel consumption.

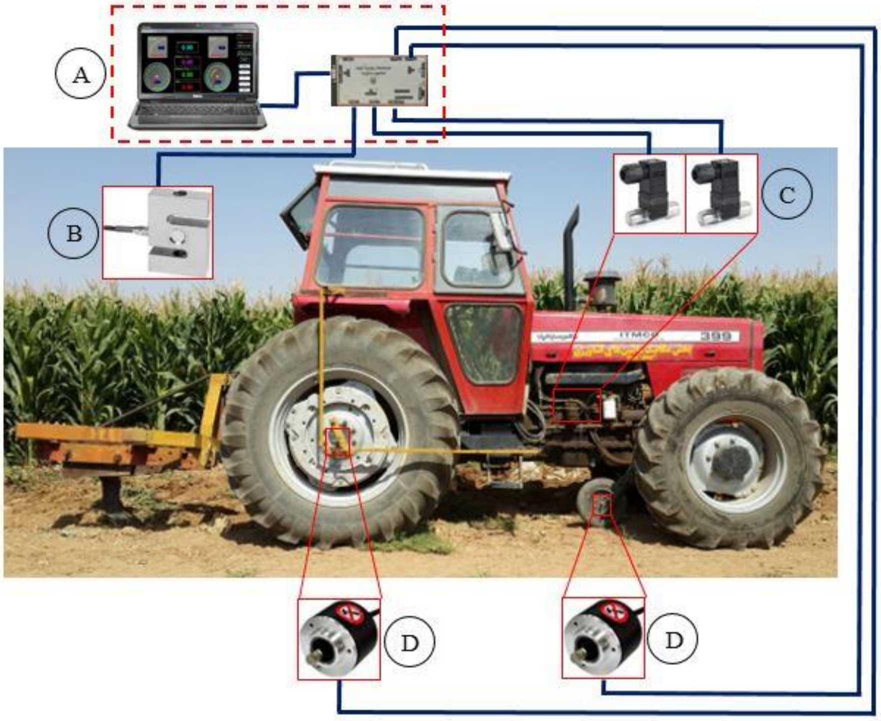

Fig.3. (A) Package of the laptop and data acquisition; (B) Load cell; (C) Turbine flow transducer; (D) Rotary shaft encoder. (Dark blue line is the connection wire).

Table 2- Specification of equipment used

T. No.	Name of the transducer	Specification	Manufacturer
1	Vision-1000, Turbine flow transducer (2 Nos.)	0.1-2.5 $l.min^{-1}$ (22,000 $pulse.l^{-1}$), ±3%	Remag, Switzerland
2	E50S8-500-3-N-24, Shaft encoder (2 Nos.)	500 $pulse.revolution^{-1}$, ±5%	Autonics, South Korea
3	DEE-5t, Traction dynamometer	S type, range 0-50 kN, precision grade: C_3	Keli, China

Soil disturbance area and cone index

For measuring the soil disturbance area in each plot, a transverse cut equal to the size of the soil disturbance, was created in the soil. After drawing out the soil, the profilometer was placed on the soil surface. The distance between the profilometer rods was 2 cm. Thus, several points of soil disturbance area were obtained by profilometer (Conte *et al*., 2011; Hang *et al*., 2017). Then, by using these points and Simpson's rule (Eq. 1), the soil disturbance area in each plot was computed.

$$\int_a^b f(x)dx \approx \frac{h}{3}\left[f(x_0) + 2\sum_{j=1}^{N/2-1} f(x_{2j}) + 4\sum_{j=1}^{N/2} f(x_{2j-1})) + f(x_N) \right] \quad (1)$$

Where a and b are the minimum and maximum values among the points obtained by the profilometer, respectively. N is the number of used data points and h is $(b-a)/2N$.

Cone index was used to measure the amount of soil softness. The soil cone index was measured according to the ASABE standard (ASABE, 2006a) and by using the penetrometer (SP-1000) manufactured by Findly Irvine, Scotland. For this purpose, the cone index was randomly measured at several points in the field before doing the experiments. Also, after each experiment, the cone index was measured with 5 replications in each plot.

Results and Discussions

Draft force and fuel consumption

The draft force value for the steel and FRP composite blades at different levels of soil moisture content, rake angle, and forward speed are shown in Figures 4, 5, and 6. Based on these results, the amount of draft force of the FRP composite blade is less than that of the steel one at different levels of soil moisture content, rake angle, and forward speed. The reduction of the draft force of the FRP composite blade compared to the steel blade in the moisture content of 9.3, 13, and 16.7% were obtained at 11.94% (0.56 kN), 23.40% (1.43 kN), and 11.67% (0.77 kN), respectively (Fig.4). This reduction was also reported at the rake angle of 20°, 30°, and 40° as 10.67% (0.57 kN), 18.50% (1.11 kN), and 14.00% (0.87 kN), respectively (Fig.5), and the reduction of the draft force at the forward speed of 3, 5 and 7 km.h^{-1} were 16.64% (0.91 kN), 10.70% (0.59 kN) and 17.24% (1.16 kN), respectively (Fig.6). According to Table 1, the adhesion value of the FRP composite blade is lower than the adhesion of the steel blade. Therefore, the soil movement on the FRP composite in different levels of the rake angle, forward speed, and moisture content has been flowing and consequently, the required draft force was reduced (Raper and Sharma, 2004; Sanchez-Giron *et al*., 2005). Also, the weight of the plow can be a factor in decrease and increase the draft force and fuel consumption (Karparvarfard and Rahmanian-Koushkaki, 2015). Due to the less adhesion (Table 1) and also the lower weight of the FRP composite blade than the steel one, the draft force of the FRP composite blade in different levels of moisture content, rake angle, and forward speed was less than that of the steel blade.

In Fig.4, with increasing the soil moisture content from 9.3 to 16.7%, the draft force for both FRP composite and steel blades was increased. With increasing moisture content, the cohesion and adhesion (Table 1), the soil bulk density also increases (Raper and Sharma, 2004; Hemmat *et al*., 2007; Chaplain *et al*., 2011). Consequently, with increasing the cohesion and soil bulk density, more draft force is needed to overcome the cohesion between the soil particles, which finally cause to increase the draft force (Qian and Zhang, 1984; Natsis *et al*., 1999; Chaplain *et al*., 2011; Manuwa, 2012). Also, with increasing adhesion between blade and soil, the soil movement speed on the blade is reduced and causes to increase the soil volume in the front of the blade, which requires more force for the displacement of this soil volume that this increases the draft force (Raper and Sharma, 2004; Sanchez-Giron *et al*., 2005).

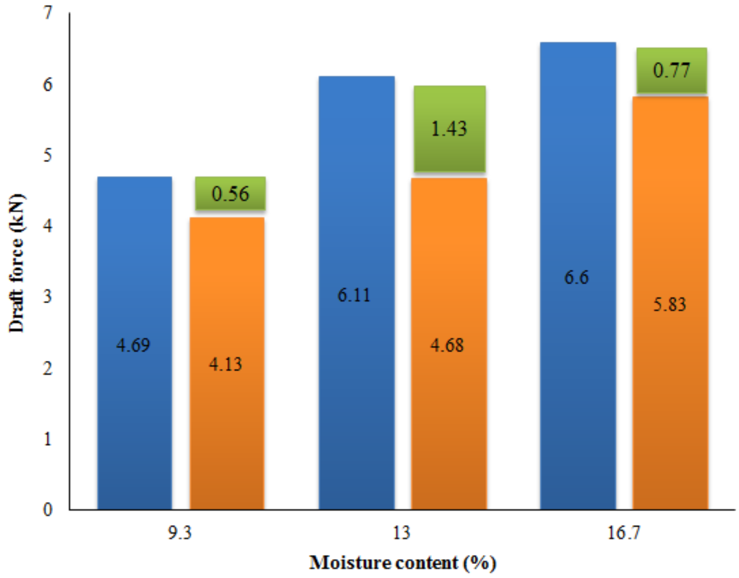

Fig.4. Comparison between the draft force of steel blade and FRP composite blade at different moisture content levels (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

In Fig.5, by increasing the rake angle, the draft force of two FRP composite and steel blades was increased. By increasing the rake angle, the projected area of the blade increases for contact with intact soil (Aluko and Seig, 2000). Therefore, by increasing the blade contact surface at the initial impact to the intact soil, more force is applied to the blade from the soil, and draft force increases. Thus, with increasing rake angle, the draft force increases (Aluko and Seig, 2000; Godwin, 2007).

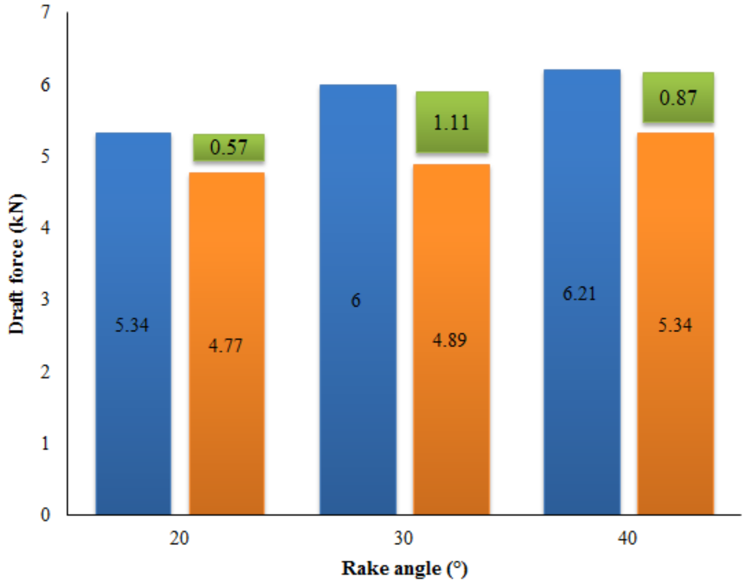

Fig.5. Comparison between the draft force of steel blade and FRP composite blade at different rake angles (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

In Fig.6, it is revealed that with increasing the forward speed, the draft force of the FRP composite and steel blades increased. As the forward speed increases, the blade movement acceleration increases in the soil. According to Newton's second law, with increasing the acceleration of the blade movement in the soil, the force applied to the soil particles increases, and consequently, the soil particles applied more reaction force to the blade, and the draft force increases. Therefore, with increasing forward speed, the draft force increases (Akbarnia *et al*., 2014; Ibrahmi *et al*., 2015).

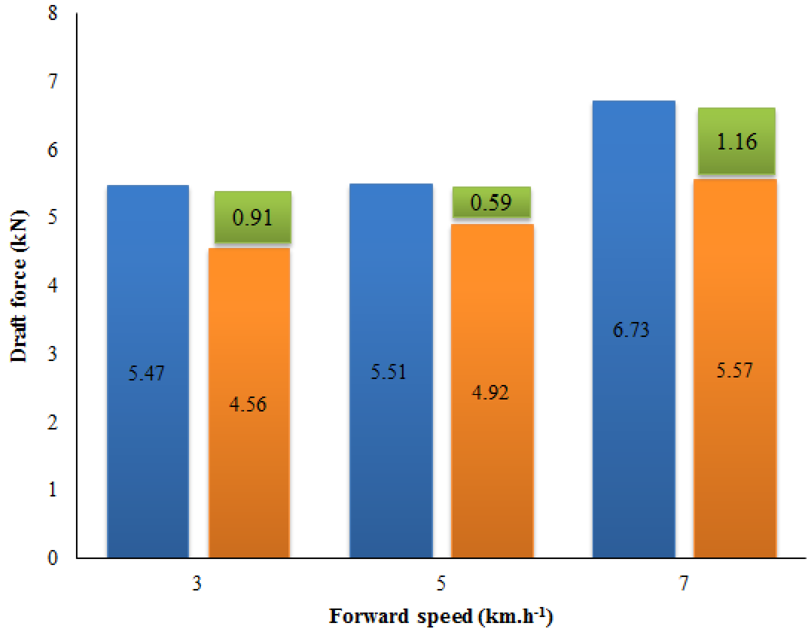

Fig.6. Comparison between the draft force of steel blade and FRP composite blade at different forward speeds (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

Figures 7, 8, and 9, show fuel consumption values of FRP composite and steel blades at different levels of moisture content, rake angle, and forward speed. These figures indicated that the fuel consumption of the FRP composite blade is reduced than the steel blade. Since the fuel consumption is directly related to draft force (Shafaei *et al*., 2017; Shafaei *et al*., 2018), with increasing draft force, the fuel consumption increases. Due to the less draft force of the FRP composite blade than the steel blade at different levels of moisture content, rake angle, and forward speed (Figures 4, 5, and 6), the fuel consumption of the FRP composite blade was lower than that of the steel blade.

The reduction of the fuel consumption related to the FRP composite blade compared to the steel blade in the moisture content of 9.3, 13, and 16.7% were obtained as 11.36% (0.05 $l.min^{-1}$), 12.77% (0.06 $l.min^{-1}$), and 17.65% (0.09 $l.min^{-1}$), respectively (Fig.7). This reduction was also reported at the rake angles of 20°, 30°, and 40° were obtained as 23.08% (0.12 $l.min^{-1}$), 20.75% (0.11 $l.min^{-1}$), and 21.82% (0.12 $l.min^{-1}$), respectively (Fig.8) and the reduction of the fuel consumption at the forward speed of 3, 5, and 7 $km.h^{-1}$ were obtained as 16.67% (0.07 $l.min^{-1}$), 16.00% (0.08 $l.min^{-1}$), and 9.62% (0.05 $l.min^{-1}$), respectively (Fig.9).

Figures 7, 8, and 9 show that fuel consumption is increased with increasing the moisture content, rake angle, and forward speed. With increasing draft force at different levels of moisture content, rake angle, and forward speed (Figures 4, 5, and 6), the tractor should consume more power to move the blade in the soil and overcome the draft force. Increasing the power consumption by the tractor leads to an increase the fuel consumption. As a result, with increasing moisture content, rake angle, and forward speed, the fuel consumption also increases (Zhang *et al*., 2016; Shafaei *et al*., 2018).

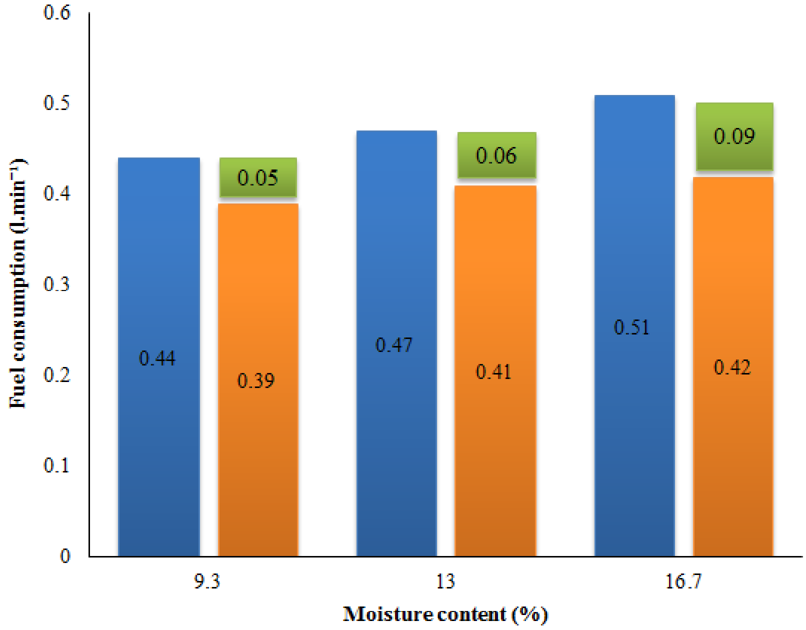

Fig.7. Comparison between the fuel consumption of steel blade and FRP composite blade at different moisture content levels (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

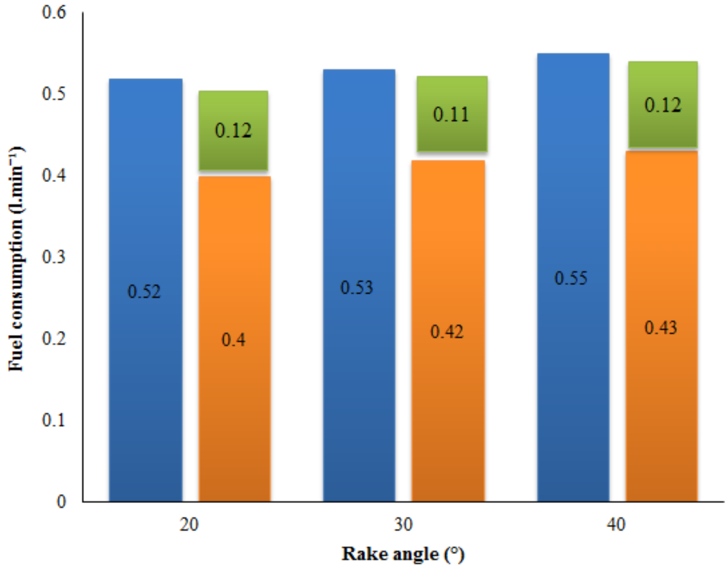

Fig.8. Comparison between the fuel consumption of steel blade and FRP composite blade at different rake angles (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

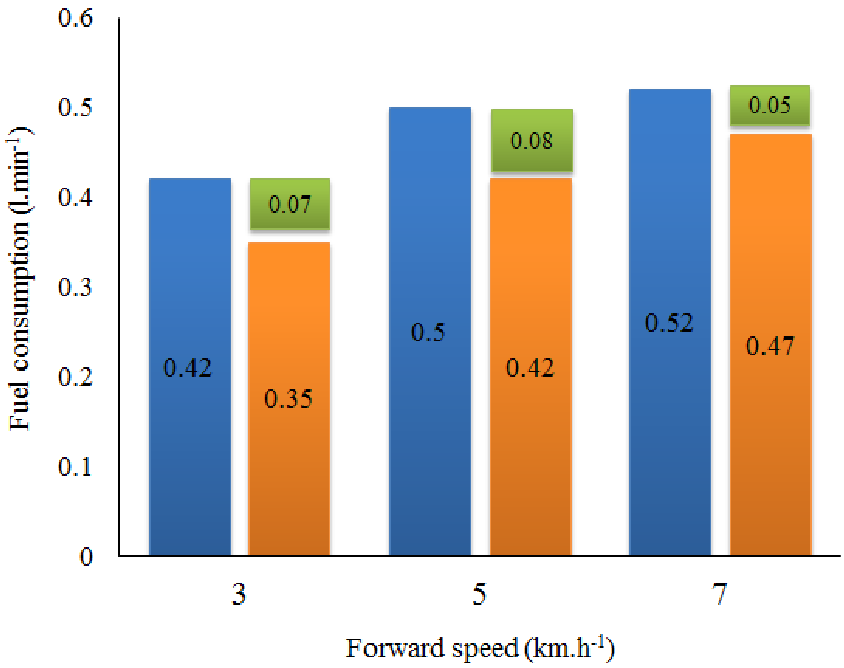

Fig.9. Comparison between the fuel consumption of steel blade and FRP composite blade at different forward speeds (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

Soil disturbance area and cone index

The soil disturbance area shows the soil failure area (Solhjou *et al*., 2014; Hang *et al*., 2017). Due to the less adhesion of the FRP composite blade than the steel blade (Table 1), the soil particles can move easily on the blade and leads to more displacement of soil particles. With these explanations and according to figures 10, 12, and 13, it can be concluded that the soil disturbance area created by the FRP composite blade is more than the steel blade.

The soil disturbance area of the FRP composite blade than the steel blade in the moisture content of 9.3, 13, and 16.7% were increased which obtained as 4.52% (23.17 cm^2), 5.16% (25.93 cm^2), and 5.08% (24.74 cm^2), respectively (Fig.10). Also, this increase was reported at the rake angle of 20°, 30°, and 40° as 4.39% (21.67 cm^2), 5.96% (30.37 cm^2), and 6.22% (32.24 cm^2), respectively (Fig.12). The increase of soil disturbance area of the FRP composite rather than steel blade at the forward speed of 3, 5, and 7 $km.h^{-1}$ were obtained as 3.68% (18.05 cm^2), 3.66% (18.19 cm^2), and 5.71% (28.99 cm^2), respectively (Fig.13).

According to Table 1, with increasing the soil moisture content, cohesion value increases. The high value of soil cohesion leads to the formation of a strong bond among soil particles. Also, by increasing soil moisture content, the soil adhesion was increased (Table 1), which caused slower movement of the soil on the blade. With these explanations, it can be concluded that with increasing the soil moisture content, soil particles movement has been decreased and the soil disturbance area also decreased (Fig.10) (Rahmatian *et al*., 2018).

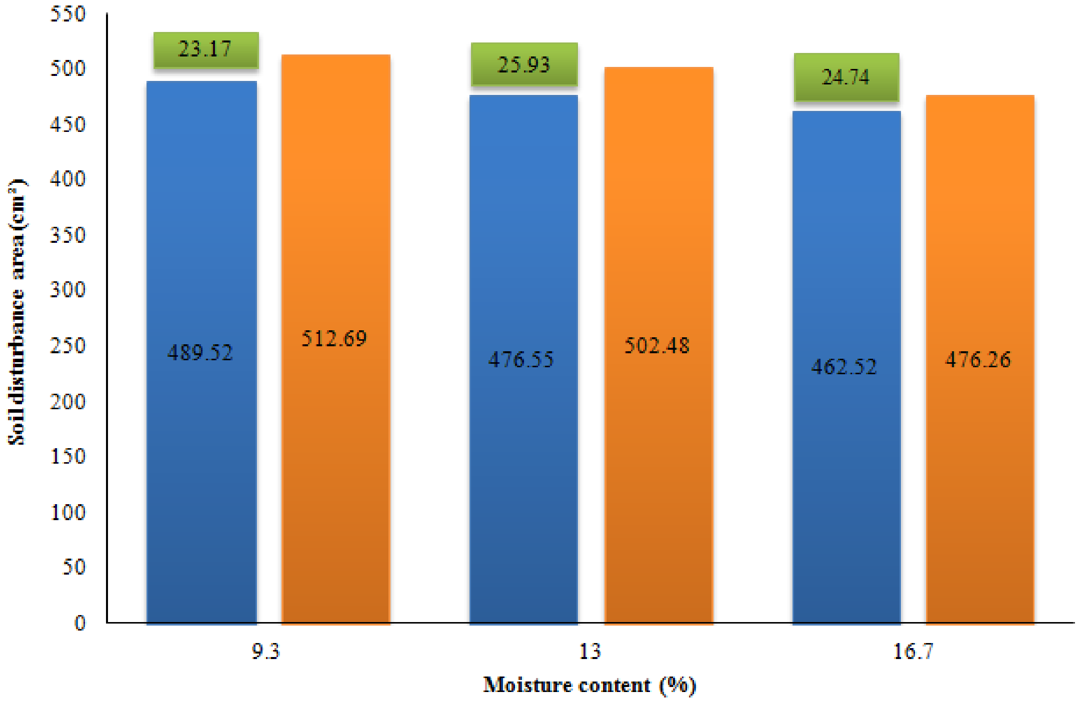

Fig.10. Comparison between the soil disturbance area of steel blade and FRP composite blade at different moisture content levels (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

Fig. 2, shows that the soil disturbance area increased by increasing the rake angle. By increasing the rake angle blade, the projected area of the blade on the intact soil has been increased and at one time, the more surface of the blade hits with the soil and leads to displacement of more soil particles in the soil (Fig.11). For this reason, with increasing the rake angle blade, the soil disturbance area increases (Jafari *et al*., 2011).

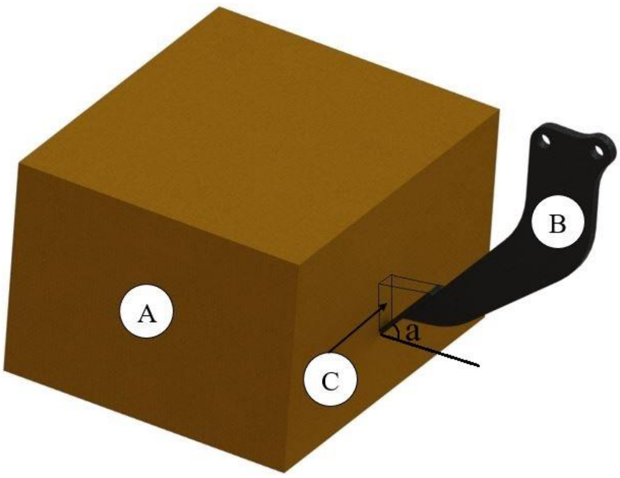

Fig.11. Schematic project blade on the soil: (A) soil, (B) tillage tool, (C) project blade on the soil, and (a) rake angle

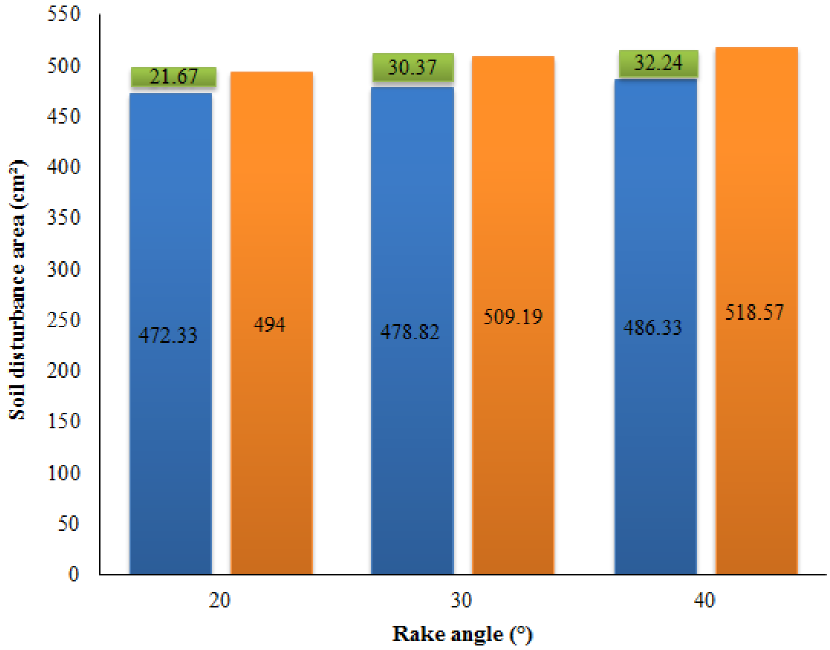

Fig.12. Comparison between the soil disturbance area of steel blade and FRP composite blade at different rake angles (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

Fig.13, shows the effect of the forward speed on the soil disturbance area. According to Fig.13, with increasing the forward speed, the soil disturbance area has been increased (Manuwa, 2009; Jafari *et al.*, 2011). With increasing forward speed, the displacement of soil particles increases, and consequently, the soil disturbance area increases.

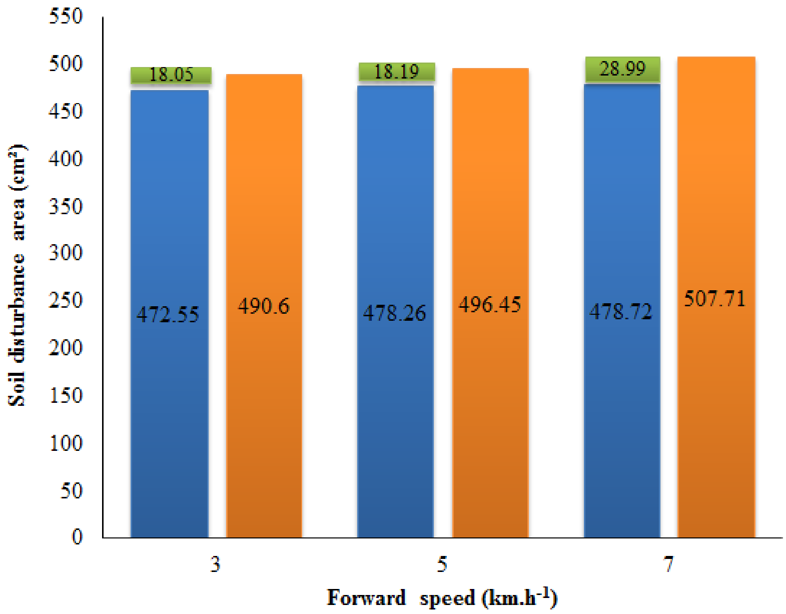

Fig.13. Comparison between the soil disturbance area of steel blade and FRP composite blade at different forward speeds (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

The cone index of the soil is an indicator for measurement soil softening for water and root penetration in soil (Goodin and Priddy, 2016; Pillinger *et al.*, 2018). By increasing the soil disturbance area, the soil is softened and the penetration becomes easier. For this reason, the soil cone index decreased (Figures 14, 15, and 16) with increasing soil disturbance area at different levels of moisture content, rake angle and forward speed in this study (Figures 10, 12, and 13) (Tagar *et al.*, 2014; Goodin and Priddy, 2016). The reduction amount of soil cone index of the FRP composite blade than the steel blade in the moisture content of 9.3, 13, and 16.7% were obtained 37.12% (1.21 MPa), 34.29% (1.20 MPa), and 30.23% (1.20 MPa), respectively (Fig.14). This reduction was also found at the rake angle of 20°, 30°, and 40° as 31.58% (1.26 MPa), 33.51% (1.24 MPa), and 38.94% (1.18 MPa), respectively (Fig.15) and at the forward speed of 3, 5, and 7 km.h^{-1} were obtained 26.55% (1.24 MPa), 41.46% (1.31 MPa), and 42.07% (1.22 MPa), respectively (Fig.16).

In Fig.14, it has been shown that with increasing soil moisture content, the value of the cone index increases (Patel *et al.*, 2013; Lin *et al.*, 2014). Due to the increase of moisture content, the cohesion between soil particles is increased (Table 1). Therefore, the soil disturbance area has been decreased (Fig.10), which causes less soil softening, and the soil cone index increases. In figures 13 and 14, with the increase of the rake angle and forward speed, the soil cone index decreased (Tagar *et al.*, 2014) that this reason is due to the reduction of soil disturbance area when increasing the rake angle and the forward speed (Figures 12 and 13).

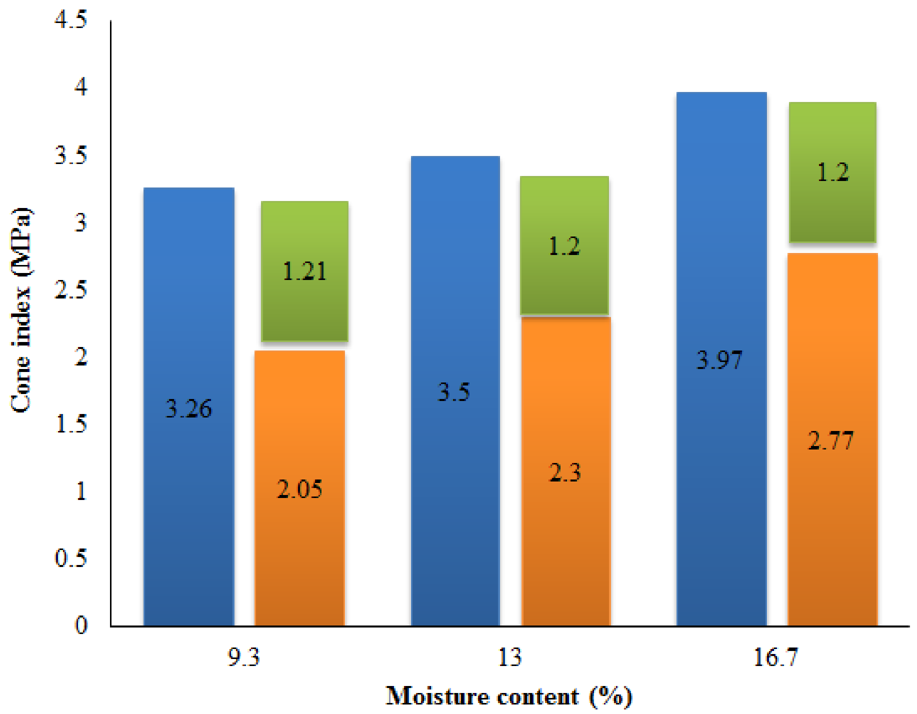

Fig.14. Comparison between the cone index of steel blade and FRP composite blade at different moisture content levels (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

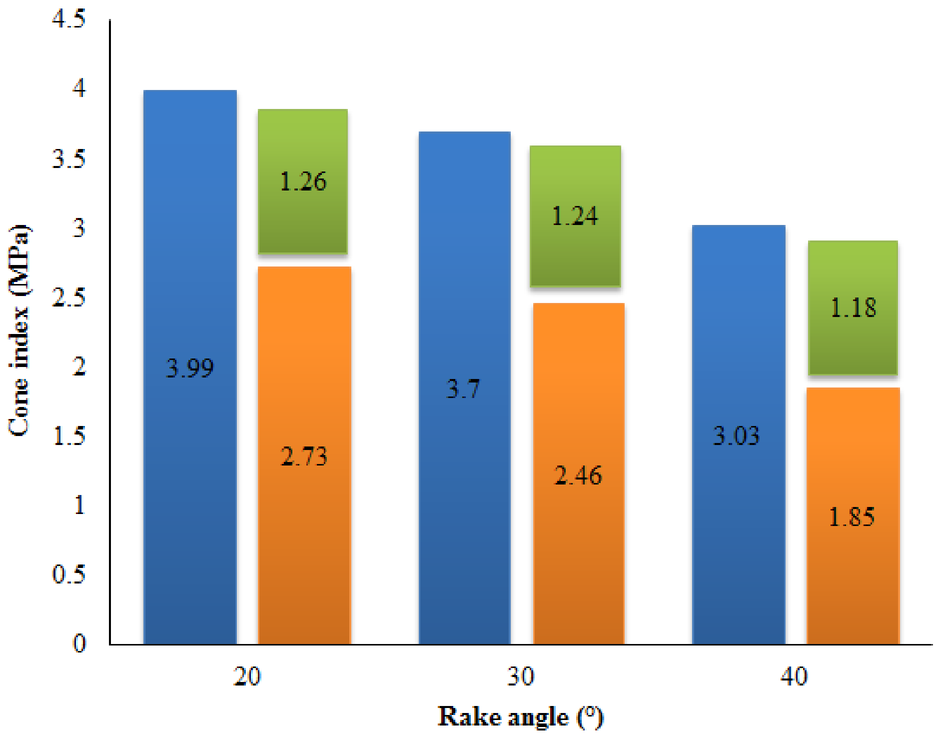

Fig.15. Comparison between the cone index of steel blade and FRP composite blade at different rake angles (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

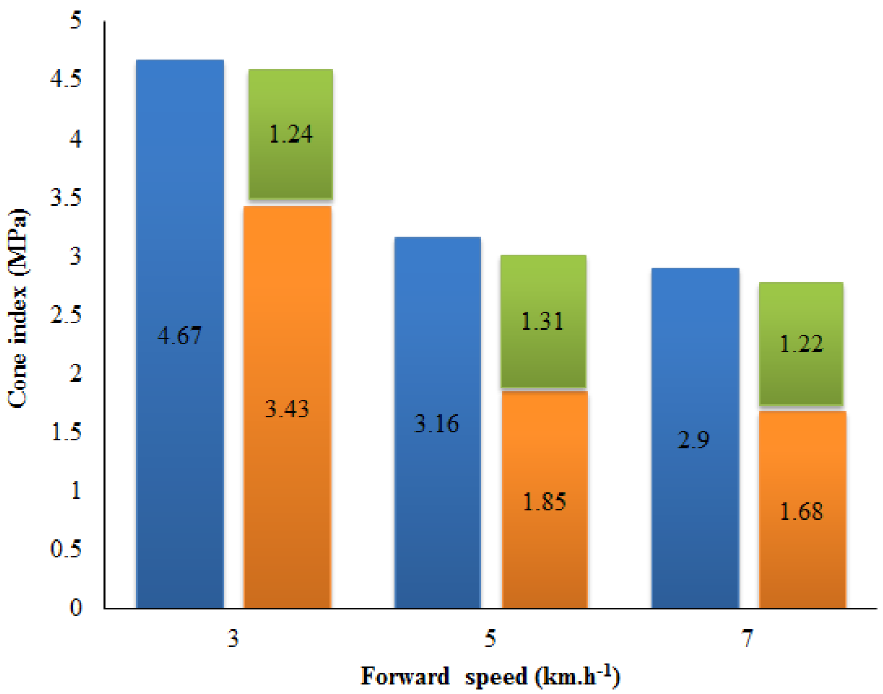

Fig.16. Comparison between the cone index of steel blade and FRP composite blade at different forward speeds (blue rectangle: steel blade; orange rectangle: FRP composite blade; green rectangle: difference between steel blade and FRP composite blade)

Economic comparison

Economic issues, one of the important stages in the engineering design that must be considered (Stanic *et al*., 2016). According to the prices presented by the New York Stock Exchange (NYSE) for steel and FRP composites in 2018 and 2019, it is observed that FRP composites have lower prices on the world market than steel (Fig.17). Also, according to section blades, the FRP composite specific weight is less than that of the steel. Therefore, more blades can be produced with larger volumes of FRP composites per kilogram than steel. According to this information, the use of FRP composite instead of steel for making the chisel blade in terms of economical is affordable. The high production of FRP composite blades with lower cost than steel blades leading to reduce the cost of blade manufacturers and also increases profitability. Of course, due to fluctuations in the world market for gold and oil had a great impact on the price of steel and FRP composite, which in 2018 and 2019 cause to rise or fall in the price of steel and FRP composites in dollar terms (Fig.17), but the price of FRP composite is still lower than steel prices.

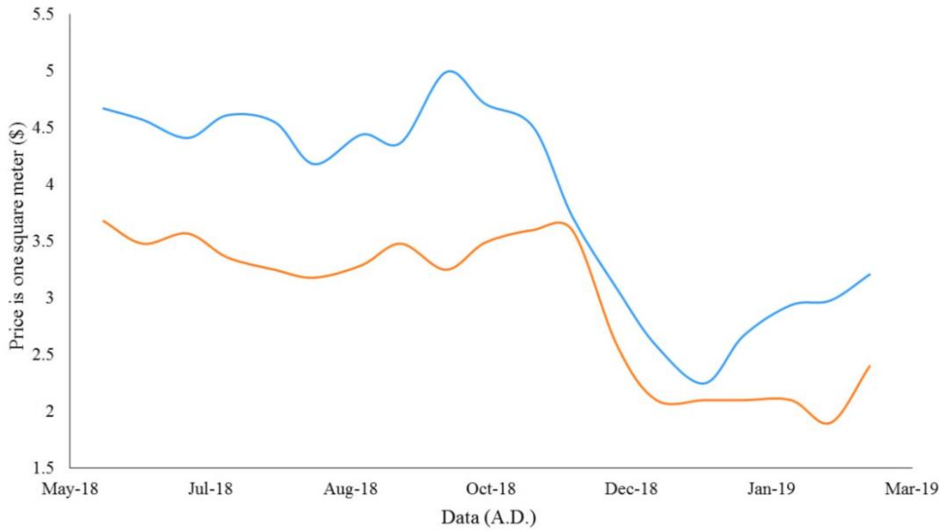

Fig.17. Price comparison in dollar terms between steel and FRP composite in 2018 and 2019 retrieved from New York Stock Exchange (NYSE) site (blue line: steel price; orange line: FRP composite price)

Conclusion

The obtained results from field tests showed that the FRP composite blade (on average in the desired range for variables) has reduced the draft force, fuel consumption, and soil cone index, 14.97%, 16.63%, and 35.08%, respectively, than the steel blade. The soil disturbance area created by the FRP composite blade was 4.93% higher than the steel blade. According to the comparison of FRP composite blade and steel blade in terms of draft force, fuel consumption, soil disturbance area, and cone index in the experimental field, and economic comparison between these two blades, FRP composite blade operation was better and more suitable. According to the results of this research in terms of tillage and economic, the use of the FRP composite blade is recommended to farmers and blade manufacturing. It is suggested that the FRP composite blade checking at different tillage depths and in the subject of abrasive wear, so that information on the characteristics of the FRP composite blade in the tillage operation to be complete.

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مقاله پژوهشی

جلد ۱۲، شماره ۱، بهار ۱۴۰۱، ص ۱۹-۱

مقایسه عملکرد تیغه کامپوزیت پلیمر تقویت شده با الیاف (FRP) با تیغه فولادی مورد استفاده در گاوآهن قلمی

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چکیده

در سراسر دنیا، کشاورزان ادوات مختلفی را برای خاک‌ورزی انتخاب می‌کنند که این به نوع محصول، نوع خاک، میزان باقی‌مانده گیاه از محصول قبلی و غیره بستگی دارد. انتخاب ابزار خاک‌ورزی نیز تحت تأثیر در دسترس بودن ابزارآلات، توان مصرفی، هزینه‌های کارگری و سرمایه‌های موجود است. در این تحقیق، نیروی کششی، سطح مقطع به‌هم خوردگی خاک، شاخص مخروط خاک و مصرف سوخت در نظر گرفته شد. اثرات زاویه حمله، سرعت پیشروی و رطوبت خاک بر پارامترهای نام برده بررسی شد. در این تحقیق، مقایسه‌ای بین عملکرد تیغه کامپوزیت پلیمر تقویت شده با الیاف (FRP) و تیغه فولادی معمولی انجام شد. آزمایش‌ها بر اساس آزمایش کرت‌های دو بار خرد شده بر پایه‌ی طرح کاملاً تصادفی، انجام شد. عوامل رطوبت خاک، زاویه حمله و سرعت پیشروی در سه سطح گنجانده شد. سه سطح برای رطوبت خاک (۹/۳، ۱۳، ۱۶/۷٪)، زاویه حمله (۲۰، ۳۰، ۴۰ درجه) و سرعت پیشروی (۳، ۵، ۷ کیلومتر در ساعت) در نظر گرفته شد. تیغه کامپوزیت FRP به‌طور متوسط در محدوده مورد نظر برای متغیرها باعث کاهش نیروی کششی، مصرف سوخت و شاخص مخروط خاک به‌ترتیب ۱۴/۹۷٪، ۱۶/۶۳٪ و ۳۵/۰۸٪ نسبت به تیغه فولادی شده است. همچنین، سطح به‌هم خوردگی خاک ایجاد شده توسط تیغه کامپوزیت FRP، ۴/۹۳٪ بیشتر از تیغه فولادی بود. با توجه به نتایج این مطالعه، مشخص است که تیغه کامپوزیت FRP عملکرد بهتری نسبت به تیغه فولادی معمولی برای متغیرهای آزمون فوق دارد. با توجه به این‌که کامپوزیت FRP از فولاد ارزان‌تر است، این امر منجر به صرفه‌جویی قابل‌توجهی در تولید تیغه کامپوزیت FRP مورد استفاده در گاوآهن چیزل و ابزارهای خاک‌ورزی مرکب می‌شود که از نظر اقتصادی برای کشاورز و تولیدکننده مقرون به صرفه است.

واژه‌های کلیدی: تیغه کامپوزیت FRP، تیغه فولادی، زاویه حمله، سرعت پیشروی، میزان رطوبت خاک

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