academicJournals

Vol. 10(11), pp. 1266-1272, 12 March, 2015
DOI: 10.5897/AJAR2014.8788
Article Number: FB262BC51444
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Fuel demand as a function of furrow opener and soil conditions in no-tillage system

Rafael Scabello Bertonha[1]*, Carlos Eduardo A. Furlani[1], Vicente Filho A. Silva[2] and Carlos Alessandro Chioderoli[3]

[1]Department of Rural Engineering, São Paulo State University - UNESP/FCAV – Brazil.
[2]Federal Rural University of Amazon – UFRA – Brazil.
[3]Department of Agricultural Engineering - Federal University of Ceará – UFC – Brazil.

Received 21 April, 2014; Accepted 11 March, 2015

In a no-tillage system, the timing of beginning to work with agricultural machines and tools is of great importance because it may be the key to the low cost of the operation. This study was conducted to evaluate the fuel consumption of a tractor and the effects of using different types of hoe-type openers on the soil disturbance at two soil moisture contents in a no-tillage system. The experiment was conducted in an area of the Department of Rural Engineering, UNESP/FCAV, Jaboticabal-SP-Brazil. The area was divided according to a randomized block design with a factorial scheme of 3 × 2 × 2 with four replications. The tractor used was a BH125i-model Valtra-AGCO with 91.9 kW of rated engine power and a pantograph planter with four rows. The treatments were three hoe-type furrow openers, two soil water content profiles (WCS1 and WCS2), and two working depths. The WCS2 profile consisted of a water content of 23.1% in the layer from 0.0 to 0.10 m deep and 23.8% in the layer from 0.11 to 0.20 m deep. The WCS1 profile consisted of a water content of 15.6% in the layer from 0.0 to 0.10 m deep and 21.3% in the layer from 0.10 to 0.20 m deep. The working depths were 0.10 and 0.15 m. Increasing the working depth provides greater tillage. The greater the working depth is and the lower the soil water content is, the better the operational fuel consumption. The combination of the rake angle and the thickness of the FO3 opener resulted in the lowest operational and hourly fuel consumption levels.

Key words: Soil mobilization, consumption, direct seeding, tractor performance.

INTRODUCTION

No-tillage seeding is one of the key operations of conservation agriculture (Baker et al., 2007). It is a system that minimizes soil disruption by leaving crop residue on fields after harvest, where it acts as a mulch to protect the soil from erosion and fosters soil productivity. To sow seeds, farmers use specially designed seeders that penetrate the residue and the undisturbed soil below,where the seeds can germinate and surface as new crops (Huggins and Reganold, 2008).

In Brazil, this technique has been used for approximately 30 years and is widely applied in the southern central region. Currently, more than 27 million ha in Brazil are cultivated under this system (Boddey et al., 2010), which makes Brazil the country with the

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*Corresponding author. E-mail: rafabertonha@hotmail.com, Tel: +55 16 3209-7289.

second-highest no-tillage cultivated area in the world, behind only the United States of America.

In a no-tillage system, the soil may be opened by coulters, row cleaners, disc openers, in-row chisels, hoe-type, or rototillers prior to planting the seed. All of these terms related to conservation tillage describe operational aspects of conservation agriculture (Ling-Ling et al., 2011).

The main functions of a hoe-type furrow opener in a no-tillage system are decompression and disturbance of the subsoil in depth and extension (Cepik et al., 2005). This decompression and disturbance of the subsoil reduces the bulk density of the soil and its mechanical resistance to penetration (Mello et al., 2003).

An important aspect of this type of mechanism is the tractive effort required by the opener, which depends on its physical characteristics, such as the angle of attack, tip width, tip shape, thickness, and angle of inclination (Sánchez-Girón et al., 2005).

Information on the results of evaluations of furrow-opening mechanisms for no-tillage planters helps companies in the sizing of soil-opening tools to reduce energy requirements (Mion et al., 2009).

The possibility of rupturing compacted surface soil layers, even in a localized manner, has induced famers to utilize shanks that can reach greater depths-in some cases, as great as 0.20 m. However, shanks with narrow points, such as the ones used in the majority of seed drill-fertilizers suitable for no-tillage, are limited in their ability to increase the operation depth because of soil–shank interactions and soil structure rupturing behavior (Conte et al., 2011; Godwin and O'Dogherty, 2007; Hemmat and Adamachuk, 2008).

Germino and Benez (2006) evaluated two types of hoe-type furrow openers for a no-tillage planter, working at four depths (0.12, 0.23, 0.28, and 0.33 m) in a distroferric red ultisol, and concluded that there was no difference in the performance of the two furrow openers when working at the recommended depth (0.13 m) but that the differences between the two types of furrow openers were accentuated when the working depth exceeded the critical working depth.

In a series of tests carried out on a sandy clay loam and loamy sand; Damora and Pandey (1995) found that furrow openers with lower drafts had smaller widths and wedges and rake angles of 40º or less. Soil disturbance is also affected by furrow opener design. The cross-sectional area of a furrow increases with increasing rake angle and wedge angle (Siemens et al., 1965; Abernathy and Porterfield, 1969). The rake angle also affects the working depth of a furrow opener and the variation in depth due to changes in the forward speed. Abernathy and Porterfield (1969) observed the furrow depth to be greater for openers with large rake angles and wedge angles.

Altuntas et al. (2006) evaluated the effects of three types of furrower mechanisms and reported that the design of the shank involves factors that affect its performance and the quality of the operation. Montanha et al. (2011) commented that the intensification of activities in mechanized agriculture results in higher energy costs for farms, mainly in fuel consumption by agricultural tractors.

Two conditions must be fulfilled before the start of field operations in the spring or after a rainy period: "The surface layer must be friable down to the intended tillage depth, and the underlying soil must have a sufficient bearing capacity for the machinery" (Heinonen, 1985). Soil friability is related to the soil water content and reaches a maximum at water contents close to the plastic limit (Utomo and Dexter, 1981; Watts and Dexter, 1998). To avoid compaction, field operations should not be carried out when the soil water content exceeds the lower plastic limit (Rounsevell, 1993).

This study was conducted to evaluate the fuel consumption of a tractor and the effects on the soil of three types of hoe-type furrow openers at two working depths and two soil water contents in a no-tillage system.

MATERIALS AND METHODS

The experiment was conducted in experimental area of the Department of Rural Engineering of São Paulo State University - UNESP/FCAV, Jaboticabal-SP-Brazil, in 2011 and 2012. The average slope of the area is 4%. The Köeppen classification of the climate is Aw climate (subtropical). The soil is classified as a eutroferric Red Latosol with 469 g kg^{-1} of clay, 307 g kg^{-1} of silt, and 224 g kg^{-1} of sand, managed for nine years under a no-tillage system. The soil's mechanical resistance to penetration was 0.8 and 2.7 MPa for the layers from 0.0 to 0.10 m deep and 0.11 to 0.20 m deep, respectively.

The experiment was conducted according to a completely randomized design with a 3 × 2 × 2 factorial scheme with four replications: three hoe-type furrow openers (FO1, FO2, and FO3) (Figure 1), two soil water contents (WCS1 and WCS2), and two working depths of the furrow openers (WD1 and WD2). The tractor used had 91.9 kW of rated engine power at 2300 rpm to pull a pantographic planter along four rows of corn, with a spacing of 0.90 m between rows. The average planting speed was 5.9 km h^{-1}.

To analyze the water contents of the soil, soil samples were collected from the layers 0.0 to 0.10 m deep and 0.10 to 0.20 m deep. A total of 20 soil samples per layer were collected from each plot. To permit planting at two soil water content levels, the experimental area was irrigated for approximately 12 h (6 h on one day + 6 h on the next day) at an average precipitation rate of 10 mm h^{-1}. The first planting was begun 36 h after the irrigation was completed. At that time, the WCS2 water content profile consisted of a water content of 23.1% in the 0.0 to 0.10 m layer and 23.8% in the 0.11 to 0.20 m layer. After 72 h, the second planting was conducted. At that time, the WCS1 water content profile consisted of a water content of 15.6% in the 0.0 to 0.10 m layer and 21.3% in the 0.10 to 0.20 m layer. The working depths were 0.10 m (WD1) and 0.15 m (WD2).

The soil area disturbed and the width and depth of the furrow were evaluated. The furrow was opened manually to make it possible to model the furrow. The furrow width (FW) and working effective depth (WED) were analyzed using a profile meter with 45 rods that are 30 cm high and spaced 1 cm apart (Figure 2). A piece of cardstock paper with horizontal lines spaced 0.5 cm apart was nailed to the back of the profile meter for precision and ease of reading. The positions of the upper ends of the rods reproduce the shape of the furrow. A digital camera was used to capture the

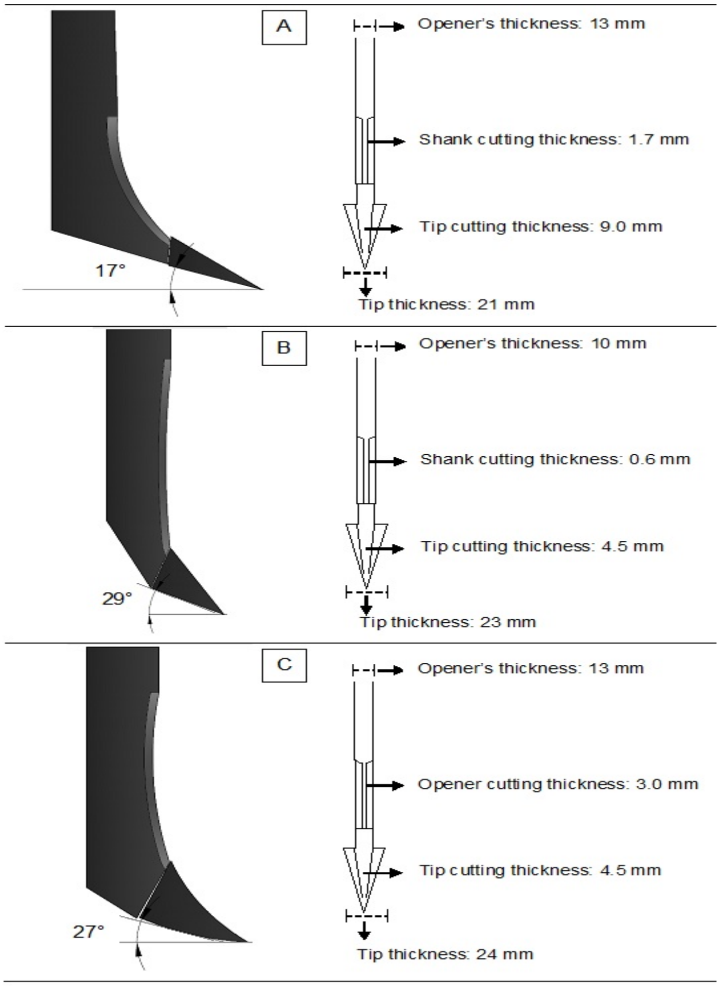

Figure 1. Characteristics of the furrow openers FO1 (a), FO2 (b), and FO3 (c).

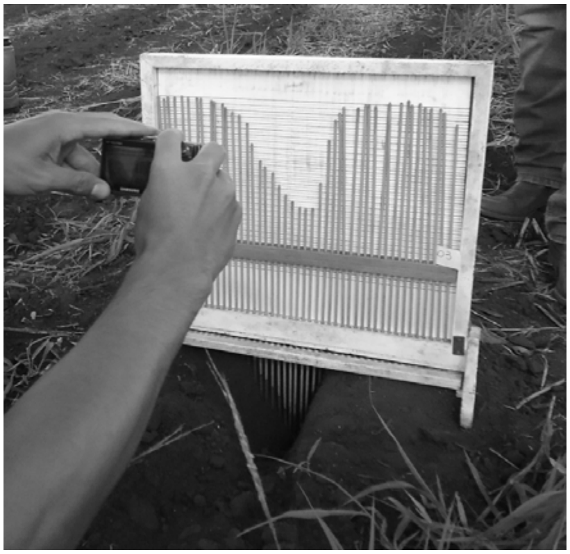

Figure 2. Profile meter used to analyze the furrow conditions after the passing of the opener.

Table 1. Analysis of variance for soil disturbance (SD), furrow width (FW), working effective depth (WED), hourly fuel consumption (FC - L h^{-1}), operational fuel consumption (FC - L ha^{-1}), and specific fuel consumption (SFC).

Factor	SD	FW	WED	--------- FC ----------		SFC
	(cm^2)	------- (cm) -------		(L h^{-1})	(L ha^{-1})	(ml m^{-3})
WCS						
WCS1	167.4	26.1	11.6	8.9	6.1^a	37.2^a
WCS2	155.9	26.6	12.3	8.6	5.7^b	33.0^b
Furrow openers (FO)						
FO1	149.9	26.5	12.6	9.6^a	6.8^a	40.0^a
FO2	156.8	25.4	12.2	9.1^b	6.0^b	33.9^{ab}
FO3	178.2	27.1	11.1	7.8^c	4.8^c	31.4^b
Working depth (WD)						
WD1	129.3^b	24.8	9.8^b	8.4^b	5.6^b	40.5^a
WD2	193.9^a	27.9	14.1 a	9.2^a	6.1^a	29.7^b
CV (%)	4.6	8.9	5.2	2.9	3.6	20.4

Means followed by the different letters are significantly different according to Tukey test at 95% confidence level. CV: coefficient of variation.

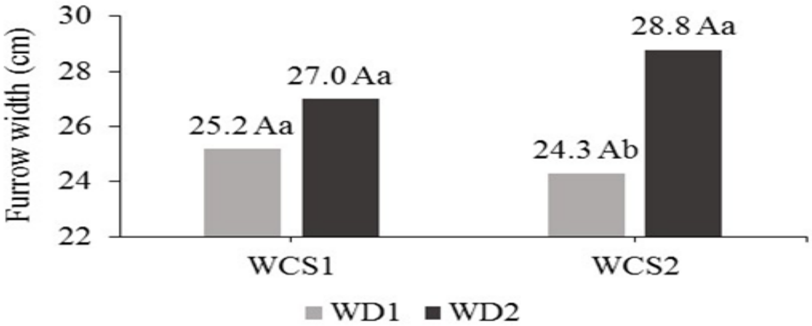

Figure 3. Interaction between water content of soil (WCS1 and WCS2) and working depth (WD1 and WD2) for furrow width. Means followed by the same letter (uppercase for WCS and lowercase for WD) are not significantly different according to Tukey test at 95% confidence level.

readings, which were analyzed using a computer. FW was defined with respect to the first rod that fell on the ground inside the furrow. WED was defined as the average of the heights of the two first rods with the highest values.

Soil disturbance was obtained by the transversal section of disturbed soil and the data were analyzed by the integral of the trapezoidal rule.

To determine the demand of fuel of the tractor, we obtained by the flow meter Oval-III model, with 0.01 ml of precision, installed in the tractor and collecting the difference between the measured amount of fuel in the input and return of the fuel injection pump. The values were stored in a "CR23X micrologger, Campbell Scientific Company".

Specific fuel consumption was evaluated. To calculate this variable, the area of disturbed soil data was transformed to volume of disturbed soil per hectare (m3 ha-1). Then, the data of fuel consumption was transformed from liters to milliliters and divided it per volume of disturbed soil (ml m-3).

The statistical programs used were the SISVAR (Ferreira, 2011) and ASSISTAT (Silva and Azevedo, 2006) to ANOVA, using F test of Snedecor and, when significant, applied the Tukey test (p<0.05). When the values presented asymmetric by Anderson-Darling test, applied the transformation [X=log(x)].

RESULTS AND DISCUSSION

An analysis of variance of the measurement obtained was conducted. The results are presented in Table 1 and Figures 3, 4, and 5 (which illustrate the interactions between factors). The coefficient of variation was low for most of the variables, which can be attributed to the logarithmic transformation of the data, performed on the basis of the asymmetry detected using the Anderson–Darling test. The asymmetry that was observed can be attributed to the natural variability of soil in an experiment

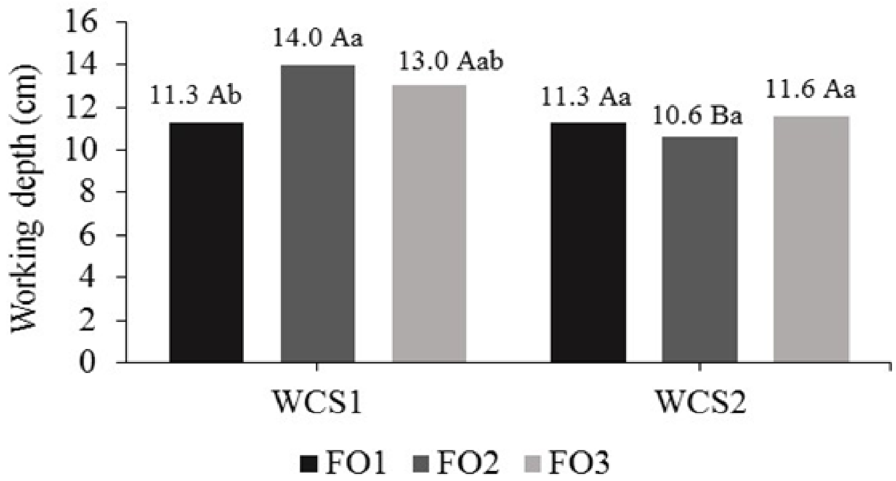

Figure 4. Interaction of water content of soil (WCS1 and WCS2) and furrow openers (FO1, FO2, and FO3) for working effective depth. Means followed by the same letter (uppercase for WCS and lowercase for FO) are not significantly different according to Tukey test at 95% confidence level.

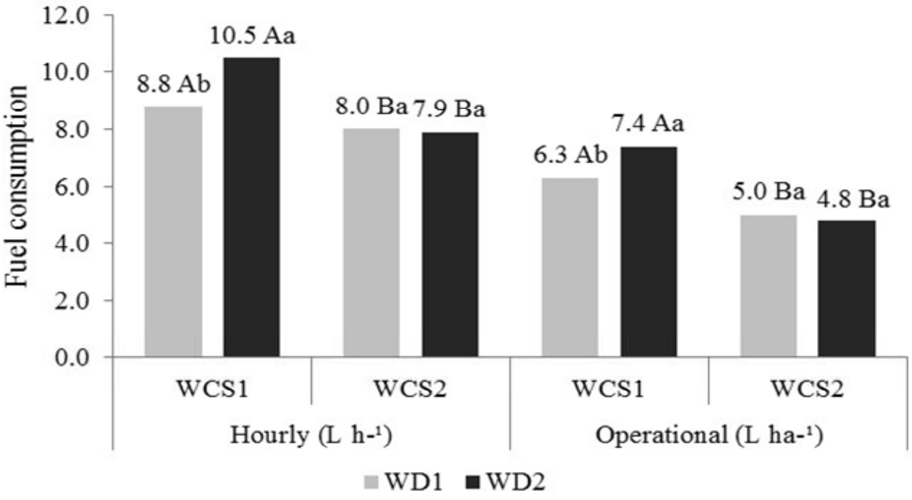

Figure 5. Interaction of the water content of soil (WCS1 and WCS2) and working depth (WD1 and WD2) for hourly (L h^{-1}) and operational fuel consumption (L ha^{-1}). Means followed by the same letter (uppercase for WCS and lowercase for WD) are not significantly different according to Tukey test at 95% confidence level.

of this type.

Despite the differences in the soil water content and the design characteristics (the thickness and tilt angle) of the openers, the degrees to which the soil was disturbed by the different openers were not significantly different (Table 1). The deeper the openers penetrated into the soil, the higher the disturbed area was. The soil disturbance increased by approximately 33% when the openers penetrated more deeply into the soil. According to Mion et al. (2009), the furrow opener achieves a greater depth due to the action of the opener's tip angle, which has a tendency to suck it down.

Use of the FO1 opener resulted in a higher fuel volume demand per hour and a higher consumption of fuel per hectare (Table 1) than the other openers. For example, use of the FO1 opener required 29% more fuel per hectare than the FO3 opener.

When the openers worked at a greater depth, the fuel consumption was higher because of the larger contact area of the openers with the soil and the greater resulting resistance of the soil to penetration.

A significant difference in the operational fuel consumption at WCS1 and WCS2 was observed. At lower water content, the fuel consumption was greater, which is consistent with the findings reported by Toro and Arvidsson (2003), who found in working in a clayey soil at different soil moisture contents that greater resistance to penetration was encountered when the soil contained less water.

Conte et al. (2011) commented that in evaluating the performance of furrow openers, it is very important to determine the soil mobilization index to make it possible to analyze the specific energy demand of the equipment used.

Although, there was no significant difference in fuel consumption with soil disturbance, when the amount of fuel consumed by the tractor was divided by the amount of soil disturbed, differences were observed in the real working conditions. This calculation makes it possible to assess the actual efficiency of the furrow opener mechanism.

When the tractor-seeder worked at WCS1, that is, under drier soil conditions, the fuel consumption per volume of disturbed soil was higher. Thus, WCS2 was more favorable because the amount of fuel consumed per volume of disturbed soil was smaller.

Although, the openers were not significantly different in terms of soil disturbance, use of the FO3 opener resulted in lower fuel consumption per volume of disturbed soil. The use of the FO1 resulted in the highest fuel consumption per volume of disturbed soil. This is an interesting finding because the geometries of these openers are completely different. The FO3 opener is larger than the FO1 opener, and the FO1 opener has a smaller angle of inclination.

The specific fuel consumption (SFC) for the WD2 was smaller than for the WD1 because the soil disturbance was higher and the fuel consumption was smaller. Kichler et al. (2011), working with a strip-tillage system, obtained values of 5.9 L h^{-1} per opener for openers operating at a depth of 30 cm (Table 1).

There was a significant interaction between the factors WCS and WD for the furrow width, as shown in Figure 3. In the interaction between WCS and WD for furrow width (Figure 3), there was an increase in width when the WD2 was utilized in the WCS2 soil because of the higher furrow opening angle promoted by the openers.

In the interaction between WCS and FO for the working effective depth (Figure 4), the FO2 opener resulted in greater depths than the FO1 opener in the WCS1 soil, but no differences were detected between the other openers when worked in the WCS2 soil. The reason for the difference observed is that the FO2 is thinner than the other openers. Another interesting characteristic of the FO2 is that it was able to penetrate the WCS2 soil but was not able to keep the furrow open, most likely because of the high soil moisture.

For Conte et al. (2009), the increasing depth of the FO action suggests a viable strategy for increase grain yield under conditions of water stress. Kichler et al. (2011) found a difference of 2 to 5 cm in the working depth between two subsoiling shanks and attributed this difference to differences in the geometries of the shank.

The interaction between WCS and WD for the variable hourly and operational fuel consumption (Figure 5) indicates that the tractor–planter set was better when working in the WCS2 soil. These results indicated that the WCS2 soil moisture content can be recommended for the soil studied, which has been managed for nine years under a no-tillage system. When the tractor–planter set worked under the drier soil conditions, the fuel demand was higher because of the amount of clay dried and the length of time for which the soil had been managed under a no-tillage system. In evaluating two planters with hoe-type furrow openers in a Red–Yellow Podzolic soil at four soil moisture contents under a no-tillage system, Reis et al. (2002) did not detect any significant differences in the hourly fuel consumption of the tractor. It is very important to study the characteristics of each mechanism because the tractor performance will vary depending on the texture, moisture, and physical attributes of the soil. This is particularly true in conservation agriculture systems.

Conclusions

Increasing the working depth achieves greater located tillage. A greater working depth together with a lower soil water content yields low operational fuel consumption. The combination of the rake angle and the thickness of the FO3 furrow opener resulted in the lowest operational and hourly fuel consumption.

Conflict of Interest

The authors have not declared any conflict of interest.

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