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Effect of Soil Moisture Content, Tillage Depth and Forward Speed on Draft Force of Double Action Disc Harrow

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Abstract: This study was conducted on the effect of soil moisture content (SMC), tillage depth (TD) and forward speed (FS) of the implement on draft force of double action disc harrow (pull-type). Two SMC (11.27 and 22.87%), four TD (4, 8, 12 and 16 cm) and four FS (3.05, 4.30, 5.89 and 7.15 km/h) were investigated. A factorial experiment was laid out in a randomized complete block design (RCBD) with three replications. The data collected were subjected to analysis of variance (ANOVA). Also, Duncan's Multiple Range Test (DMRT) at 1% probability was performed to compare the means of different treatments. The statistical results of the study showed that SMC, TD and FS significantly ($P \leq 0.01$) affected draft force. Results of the study also indicated that draft force decreased by increasing SMC and increased by increasing TD and FS. Additionally, TD and FS had less influence on draft force with increasing SMC, whereas FS had more influence on draft force with increasing TD.

Key words: Draft force · Double action disc harrow · Soil moisture content · Tillage depth · Forward speed · Machinery management · Iran

INTRODUCTION

Tillage involves the movement of soil from one place to another [1, 2]. In conventional farming tillage may consume a major portion of the farm's energy budget. The most convenient method to estimate a given implement's energy requirement is to measure the force required to pull the tillage implement at a desired forward speed [3-5]. The force required to pull a tillage implement through the soil is called draft force. When a tillage implement is pulled through the soil, the power unit (usually a tractor) must overcome draft forces created by soil resistance. The direction of the draft force is in the direction of travel [6].

Accurate knowledge of draft force is useful for optimal matching of power unit to tillage implement [7]. However, draft force varies greatly due to numerous factors that influence it. Since a large number of factors influencing draft requirement and various potential combinations of tillage devices exist, it is prohibitively expensive to test all implements in all conditions for every soil type. Therefore, determining which variables have the greatest influence on the draft requirement for tillage with the most common tillage tools would greatly enhance the process of matching power units to tillage implements [8].

The objective of a large body of existing work has been to study the draft force of a given tillage implement under certain soil conditions and/or operating parameters [3-5, 9-19]. The ASAE standard D497.4 describes draft force as a function of implement type, soil type, implement width, tillage depth and forward speed [6]. A number of other properties such as static and dynamic component of soil shear stress, soil-metal friction coefficient, soil density and implement geometry are also necessary to consider when analyzing draft force [8, 10, 12, 20]. However, most work that has been done on draft force in the past was focused on specific draft and has concluded that tillage depth is the primary determinant of the amount of force required to pull an implement through soil, with speed often having a significant effect [8, 12, 15, 16, 19].

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In this paper, effect of soil moisture content (SMC), tillage depth (TD) and forward speed (FS) of the implement on draft force of a double action disc harrow (pull-type) is reported.

MATERIALS AND METHODS

Experimental Site: Experiments were conducted at the Agricultural Research and Experimental Farm of Shahid Beheshti Technical School at Sari, Mazandaran Province, Iran. The experimental site was located at latitude of 36° 31' N and longitude of 53° 25' E and was 16.4 m above mean sea level.

Soil Sampling and Analysis: A composite soil sample from 32 points was collected from 0-20 cm depth and analyzed in the Laboratory for particle size distribution (sand, silt and clay). The soil in the experimental site was clay. The clay soil was consisted of 49.5% clay, 35.0% silt and 15.5% sand.

Tillage Implement: One commercial double action disc harrow (pull-type) with width of 255 cm was used in this study (Fig. 1). This implement was representative of the standard secondary tillage implement most commonly used for seedbed preparation in Iran. It consisted of four groups with 28 discs, each 36 cm in diameter.

Fig. 1: Double action disc harrow (pull-type) used in this study

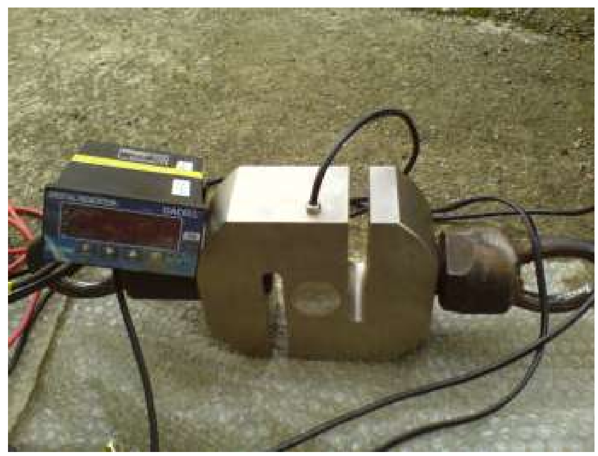

Fig. 2: Towed linkage load cell used in this study

Field Methods: There was no crop growth and the field was left fallow. Prior to performing the experiments, the field was irrigated by using a sprinkler irrigation system. Soil samples were collected and weighed during the experiments to determine soil moisture content. The samples were placed in an electric oven maintained at 110° C for 48 hours. The dried soil samples were reweighed and the soil moisture contents were calculated on a dry weight basis. A factorial experiment based on randomized complete block design (RCBD) with three replications was used to evaluate the effect of soil moisture content (SMC), tillage depth (TD) and forward speed (FS) of the implement on draft force of double action disc harrow (pull-type). Two SMC (11.27 and 22.87%), four TD (4, 8, 12 and 16 cm) and four FS (3.05, 4.30, 5.89 and 7.15 km/h) were used in a combination resulting in a total of 32 treatments. The treatments were randomly distributed in the field test. An experimental block 75 m long by 5 m wide was used for each treatment. A small block of approximately 15 m long by 5 m wide in the beginning of each tested block was used to enable the tractor and implement to reach the required tillage depth and forward speed. Tillage depth was measured as the vertical distance from the top of the undisturbed soil surface to the implement’s deepest penetration. During field operations, the tractor was operated at the same tillage depth but at different forward speeds. A Universal 650 tractor with 48.5 kW and in good condition was used in all the experiments. The implement draft force, tillage depth and forward speed during field operations were measured and recorded by an onboard data logger in the tractor cab.

Data Acquisition System: The data acquisition system consisted of a data logger, a towed linkage load cell (Fig. 2), a depth position transducer and a fifth wheel. The towed linkage load cell used to measure implement draft force was calibrated prior to the experiments using a specially built calibration rig. A performance test program was developed and documented for the data logger to scan the transducers every second during field operation.

Therefore, the number of readings made in each treatment depended on the forward speed of the tractor. To begin the field tests, the depth wheels lever was adjusted to lower the implement corresponding to the tillage depth. Then the tractor was accelerated to the required forward speed with a known gear range before entering the first test block. Data acquisition was activated by pressing the push button switch on the activity unit as the tractor passed the flag marking the beginning of the first test block. Data acquisition continued until the end of the test block. After finishing the first test block, the tractor was again driven straight toward the second test block with a different forward speed and the process was repeated. Similar procedure was repeated for other treatments.

Statistical Analysis: The effect of soil moisture content (SMC), tillage depth (TD) and forward speed (FS) of the implement on draft force of double action disc harrow (pull-type) were determined by analysis of variance (ANOVA). All of the collected data were subjected to the ANOVA following Gomez and Gomez [21] using SPSS 12.0 statistical computer software. Moreover, means of the different treatments were separated by Duncan's Multiple Range Test (DMRT) at 1% probability.

RESULTS AND DISCUSSION

Results of study indicated that soil moisture content (SMC), tillage depth (TD) and forward speed (FS) of the implement significantly (P = 0.01) affected draft force of double action disc harrow (pull-type). Moreover, different interactions, i.e. SMC × TD, SMC × FS, TD × FS and SMC × TD × FS showed significant effect (P = 0.01) on draft force (Table 1).

The highest draft force of 484 kgf was observed in 11.27% SMC and lowest (427 kgf) in 22.87% SMC and draft force decreased with increasing SMC (Table 2). These results are in agreement with those of Bowers [4], Collins and Fowler [12], Grisso *et al.* [14], Al-Suhaibani and Al-Janobi [17], Al-Janobi and Al-Suhaibani [18], McLaughlin and Campbell [19] and McKyes and Maswaure [20] who concluded that a dry soil would have a much greater draft force and therefore require more power to plow, than a moist soil. This is due to the lubricating effect of moisture films surrounding soil particles and also to a decrease in soil strength imparted by the moisture.

In addition, the highest draft force of 502 kgf was observed in 16 cm TD and lowest (408 kgf) in 4 cm TD and draft force increased with increasing TD (Table 2).

Table 1: Analysis of variance for draft force of double action disc harrow

Source of variation	Df	Mean square
Replication	2	28.227 NS
Soil moisture content (SMC)	1	78147.094 **
Tillage depth (TD)	3	35994.594 **
Forward speed (FS)	3	52825.094 **
SMC × TD	3	607.844 **
SMC × FS	3	2575.844 **
TD × FS	9	1358.177 **
SMC × TD × FS	9	152.594 **
Error	62	13.023

** = Significant at 0.01 probability level

NS = Non-significant

Table 2: Means comparison for draft force of double action disc harrow under different studied treatments using DMRT at 1% probability

Treatment		Draft force (kgf)
Soil moisture content (%)	11.27	484 a
	22.87	427 b
Tillage depth (cm)	4	408 d
	8	454 c
	12	460 b
	16	502 a
Forward speed (km/h)	3.05	407 d
	4.30	442 c
	5.89	456 b
	7.15	519 a

Means in the same column with different letters differ significantly at 0.01 probability level according to DMRT

Table 3: Means comparison for draft force of double action disc harrow under different combinations of soil moisture content (SMC) and tillage depth (TD) using DMRT at 1% probability

SMC (%) × TD (cm)		Draft force (kgf)
11.27	4	424 f
	8	482 c
	12	489 b
	16	544 a
22.87	4	392 g
	8	425 f
	12	431 e
	16	461 d

Means in the same column with different letters differ significantly at 0.01 probability level according to DMRT

These results are in line with the results reported by Nicholson *et al.* [3], Upadhyaya [7], Collins and Fowler [12], Glancey *et al.* [13], Grisso *et al.* [14], Al-Suhaibani and Al-Janobi [17] and McLaughlin and Campbell [19] that draft force increased by increasing tillage depth.

Moreover, the highest draft force of 519 kgf was observed in 7.15 km/h FS and lowest (407 kgf) in 3.05 km/h FS and draft force increased with increasing FS (Table 2). These results are in agreement with those of Nicholson *et al.* [3], Bashford *et al.* [5], Glancey and Upadhyaya [11], Collins and Fowler [12], Glancey *et al.* [13], Grisso *et al.* [14], Kushwaha and Linke [15], Wheeler and Godwin [16], Al-Suhaibani and Al-Janobi [17] and McLaughlin and Campbell [19] who concluded that forward speed was a significant determinant of draft force. They concluded that draft force increased in a linear manner and/or quadratically with forward speed.

SMC × TD interaction was significant. The study of SMC × TD combinations on draft force showed that in each SMC, draft force had the highest value in 16 cm TD and lowest value in 4 cm TD. Also, in each SMC, draft force increased with increasing TD. The maximum mean value for draft force (544 kgf) was observed in 16 cm TD and 11.27% SMC and minimum mean value for draft force (392 kgf) was observed in 4 cm TD and 22.87% SMC (Table 3). A similar outcome was reported by Collins and Fowler [12] who found that TD had less influence on draft force with increasing SMC.

SMC × FS interaction was also significant. Mean comparison for SMC × FS combinations on draft force indicated that in each SMC, draft force had the highest value in 7.15 km/h FS and lowest value in 3.05 km/h FS. Moreover, in each SMC, draft force increased with increasing FS. The maximum mean value for draft force (555 kgf) was observed in 7.15 km/h FS and 11.27% SMC and minimum mean value for draft force (383 kgf) was observed in 3.05 km/h FS and 22.87% SMC (Table 4). Similar result has been reported by Collins and Fowler [12] who concluded that FS had less influence on draft force with increasing SMC.

TD × FS interaction was significant as well. The study of TD × FS combinations on draft force showed that in each TD, draft force had the highest value in 7.15 km/h FS and lowest value in 3.05 km/h FS. In addition, in each TD, draft force increased with increasing FS. The maximum mean value for draft force (547 kgf) was observed in 7.15 km/h FS and 16 cm TD and minimum mean value for draft force (370 kgf) was observed in 3.05 km/h FS and 4 cm TD (Table 5). This result is in agreement with the finding of Collins and Fowler [12] who reported that FS had more influence on draft force with increasing TD. A similar result was observed by McLaughlin and Campbell [19] as well.

Table 4: Means comparison for draft force of double action disc harrow under different combinations of soil moisture content (SMC) and forward speed (FS) using DMRT at 1% probability

SMC (%) × FS (km/h)		Draft force (kgf)
11.27	3.05	430 d
	4.30	469 c
	5.89	484 b
	7.15	555 a
22.87	3.05	383 f
	4.30	415 e
	5.89	429 d
	7.15	483 b

Means in the same column with different letters differ significantly at 0.01 probability level according to DMRT

Table 5: Means comparison for draft force of double action disc harrow under different combinations of tillage depth (TD) and forward speed (FS) using DMRT at 1% probability

TD (cm) × FS (km/h)		Draft force (kgf)
4	3.05	370 g
	4.30	398 fg
	5.89	412 efg
	7.15	452 cde
8	3.05	393 fg
	4.30	436 def
	5.89	451 cde
	7.15	535 a
12	3.05	399 fg
	4.30	442 de
	5.89	457 cd
	7.15	542 a
16	3.05	464 cd
	4.30	492 bc
	5.89	507 ab
	7.15	547 a

Means in the same column with different letters differ significantly at 0.01 probability level according to DMRT

CONCLUSIONS

Soil moisture content (SMC), tillage depth (TD) and forward speed (FS) significantly (P = 0.01) affected draft force of double action disc harrow (pull-type). Moreover, draft force decreased by increasing SMC and increased by increasing TD and FS. Additionally, TD and FS had less influence on draft force with increasing SMC, whereas FS had more influence on draft force with increasing TD.

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