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NOTE

DRAFT AND DRAWBAR POWER EQUIREMENT OF MOLDBOARD PLOW IN A CLAY LOAM SOIL[1]

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ABSTRACT

Draft and drawbar power requirement of a general purpose 3-bottom moldboard plow at four levels of soil moisture content (10-12%, 12-14%, 14-16% and 16-18% d.b.) and three levels of plowing depth (20, 25 and 30 cm) were evaluated and compared. The experimental design was a randomized complete block with a 3×4 factorial. The effect of plowing depth on draft and drawbar power was highly significant. Both total draft and drawbar power increased almost linearly with plowing depth. Also, an increasing trend of specific draft with plowing depth was observed, which was attributed to the higher soil bulk density at lower depths. The effect of soil moisture content was significant only on specific draft in such a way that its maximum value occurred at the moisture content of 10-12% and its minimum at 14-16%. Observation of soil condition following the plowing treatments showed better pulverization at higher moisture contents. An acceptable degree of soil clod size was obtained at the moisture range of 16 to 18% for the clay loam soil tested.

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مقاومت کششی و توان مالبندی مورد نیاز گاو آهن برگردان دار در یک خاک لوم رسی

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چکیده

تاثیر چهار دامنه رطوبت خاک (۱۲-۱۰، ۱۴-۱۲، ۱۶-۱۴و۱۸-۱۶ درصد وزنی) و سه عمق شخم (۲۰، ۲۵ و ۳۰ سانتی متر) بر مقاومت کششی، مقاومت ویژه و توان مالبندی مورد نیاز یک گاو آهن برگردان دار سه خیشه در یک آزمایش فاکتوریل در قالب بلوک های کامل تصادفی بررسی گردید. تاثیر عمق شخم بر مقاومت کششی و توان مالبندی بسیار معنی داربود، به طوری که هردو افزایشی تقریبا" خطی با عمق شخم داشتند. تاثیر عمق شخم بر مقاومت ویژه نیز روندی افزایشی داشت، که می تواند ناشی از افزایش جرم مخصوص ظاهری خاک با افزایش عمق باشد تاثیر رطوبت خاک فقط بر مقاومت ویژه معنی دار بود، به طوری که حد اکثر و حد اقل مقادیرمقاومت ویژه به ترتیب دردامنه های رطوبتی ۱۲-۱۰ درصد و۱۶-۱۴ درصدحاصل گردید. مشاهدات و بررسی های کیفی شرایط خاک پس از انجام عملیات خاک ورزی حاکی از خرد شدن

بهتر و یکنواخت تر خاک در رطوبت های بالاتر بود به طوری که دردامنه رطوبتی ۱۸ -۱۶ درصد میزان نرم سازی خاک توسط گاو آهن برگردان دار در حد قابل قبولی قرار داشت .

INTRODUCTION

Tillage is the mechanical manipulation of soil to provide a desirable soil structure and physical condition for seed germination and plant growth. However, it is the most costly operation in the budjet of a farmer because amongst all the agricultural operations, tillage machinery requires a tremendous amount of power for adequate seedbed preparation. It is estimated that tillage operations require over 60% of the mechanical power used in American farms (2).

Tractor sizes are better determined when reliable draft and power requirement data exist for desired tillage tools in the specific soil types and conditions. Also, it is very important for implement manufacturers to know the draft requirement of various tillage tools for designing and developing them in accordance with the size of tractors available.

The moldboard plow is one of the most widely used primary tillage implements consisting of a wrapped surface equipped with cutting edges that cut, crumble and invert the soil. The plow gives best residue coverage and superior pulverization under ideal conditions. Draft requirement and degree of soil pulverization are the two most important factors on which performance characteristics of moldboard plow are evaluated.

Soil type and conditions are by far the most important factors contributing to variations in specific draft of plows. Values of specific draft range from 1.4 to 2 N cm^{-2} for sandy soils up to 10 to 14 N cm^{-2} for heavy Gumbo soils (3).

Soil moisture content and depth of cut have considerable effects on plow draft and final soil conditions. At low moisture content, the soil is hard and very coherent because of cementation effect among the dried particles. As moisture content increases, water molecules are adsorbed on the surface of the particles and decrease coherence and impart friability to the soil mass (3). Nichols (4) divided soil moisture content into three phases: friction phase, adhesion phase and lubrication phase. In friction phase, adhesive forces are small and the coefficient of friction is essentially independent of moisture content. Moisture content in this phase is 0-10% in silt loams and 0-15% in silty clay loams. Soils in friable condition which are usually in good tilth, have moisture content in this range. In the adhesion phase, moisture films develop between the soil particles and the metal, thus creating adhesive forces that cause the apparent coefficient of friction to increase rapidly with moisture content. When the soil has enough moisture to act as a lubricant, the apparent coefficient of friction decreases as more water is added.

The specific draft of a plow generally decreases as the depth is increased to some optimum depth/width ratio and then increases as the depth is increased further (3). Randolph and Reed (5) observed that the minimum draft for a number of 36-cm bottoms was at depths of 13 to 18 cm.

ASAE standards provide draft and power requirement prediction equations for tillage tools in several soil types (1). Predicted draft of moldboard plow varies linearly with depth and with the square of speed. Summers *et al.* (7) investigated the effects of speed and depth on draft of moldboard plow on three different Oklahoma soils. They fitted to their data a series of equations which were similar to those presented in the ASAE standards (1). Draft was found to be a quadratic function of speed and a linear function of depth. Sheikh *et al.* (6) reported that the draft requirement of moldboard plows increased curvilinearly with plowing depth at constant travel speed.

The main objectives of this study were to determine total draft, specific draft and drawbar power requirement of moldboard plow at different levels of plowing depth and soil moisture content in a clay loam soil. This type of study can provide a design basis to the implement designer and a selection basis to the farmer.

MATERIALS AND METHODS

The experiment was conducted at the College of Agriculture Experimental Station, Shiraz University, located in Bajgah valley, 16 km north of Shiraz, Iran. The soil was clay loam (25.2% sand, 39.3% silt and 35.5% clay) of about 0.2% slope. Barley stubbles left from 1993 crop were picked up by a hay baler and the land was left fallow until the begining of the field experiment in September 1995.

A randomized complete block design was used with a 3x4 factorial. Three plowing target depths (20, 25 and 30 cm) and four ranges of soil moisture contents (10-12%, 12-14%, 4-16% and 16-18% dry weight basis, d.b.) were used in combination for 12 treatments. The blocks were replicated four times. The moldboard plow used was a mounted general purpose 3-30 cm bottom. Tests were conducted on plots of 90m length. The data recorded for each test run were implement draft, tractor forward speed, plowing depth and width and soil moisture content.

Draft of Moldboard Plow

A spring type recording drawbar dynamometer was attached to the front of a Massey Ferguson 285 tractor (53 kW engine brake power) on which the moldboard plow was mounted. Another auxiliary tractor (John Deere 4230 with 88 kW engine brake power) was used to pull the moldboard plow mounted tractor in neutral gear but with the implement in operating position. The draft force was recorded along a measured distance of 30 m as well as the time taken to traverse it. Along the next 20 m on each test plot, the moldboard plow was lifted out of the ground and the rear tractor was pulled to record the tractor rolling resistance. The net draft of the moldboard plow was determined by subtracting the amount of drawbar pull required by the front tractor in pulling the rear tractor without engaging the implement from the total drawbar pull exerted by the front tractor when the implement was engaged.

Operating Speed

The operating speed was calculated from the time required for the tractor and implement to cover a distance of 30m along each test run.

Drawbar Power

Drawbar power requirement of the moldboard plow for each test run was calculated by using the following equation:

$$Dbp = \frac{F.S}{3.6} \quad [1]$$

in which:

Dbp = Drawbar power, kW.

F = Net drawbar pull (draft), kN.

S = Tractor forward speed, km hr^{-1}

Working Width and Depth

The working width and depth of the implement were measured at three randomly selected locations in each plot following implement passes. The width was measured by using a steel tape from the furrow wall to the total tilled area. The cutting depth was measured from the bottom of the furrow to undisturbed soil surface adjacent to the tilled area.

Specific Draft

Specific draft is the draft force divided by the cross-sectional area of the furrow (tilled cross-section). The following formula was used to calculate the specific draft for each test run.

$$\text{Specific draft (N cm}^{-2}\text{)} = \frac{\text{Moldboard total draft (N)}}{\text{Plowing depth (cm)} \times \text{plowing width (cm)}} \quad [2]$$

Soil Moisture Content

Soil moisture content on dry weight basis was determined by taking core samples from 0-30 cm depth at five randomly selected locations on each test plot. The wet soil samples were weighed and then placed in a hot air oven maintained at 105° C for 24 h. The dried soil samples were reweighed and their moisture contents were calculated by using the formula:

$$\text{Soil moisture (\%)} = \frac{Ww - Wd}{Wd} \times 100 \qquad [3]$$

in which:

Ww = Weight of wet soil sample.

Wd = Weight of oven dried sample.

Soil Bulk Density

To measure the bulk density (g cm^{-3}) of the soil, samples were taken from 0-15 and 15-30 cm depths by a 5.5 cm diameter and 4 cm height core sampler at several randomly selected locations of the test plots. Samples were placed in a hot air oven maintined at 105 C for 24 h. The dried soil samples were weighed and the bulk density was determined by using the following formula:

$$\text{Bulk density} = \frac{M}{V} = \frac{4M}{\pi D^2 L} \qquad [4]$$

in which:

M = Oven dried soil mass contained in core sampler (g).

V = Volume of cylindrical core sample (cm^3).

D = Diameter of cylindrical core sample (cm).

L = Height of cylindrical core sample (cm).

Soil Pulverization

The effect of soil moisture content and plowing depth on soil pulverization by plowing treatments were investigated by observing the relative clod size grades of the test plots. Soil clod sizes were classified by visual inspection into six groups ranging from "very small"to"very large".

RESULTS AND DISCUSSION

Analysis of variance for the main effects of plowing depth, soil moisture content and their interactions on draft, specific draft and drawbar power requirement of moldboard plow are shown in Table 1. This table indicates that plowing depth had a highly significant effect on draft and drawbar power requirement, whereas it had no significant effect on the specific draft of moldboard plow in the range of plowing depths studied. Soil moisture content had no significant effect on the implement draft and drawbar power, but its effect on specific draft was significant. Also, plowing depth and soil moisture content had no interactive effect on any of the above mentioned parameters.

Table 1. Analysis of variance for the draft, specific draft and drawbar power requirement of moldboard plow.

Source	df	Mean squares		
		Draft	Specific draft	Drawbar power
Replications	3	3.53	0.61	9.13
Plowing depth, D	2	231.52**	0.39ns	314.27**
Moisture content, M	3	10.13ns	2.19*	8.52ns
D × M	6	0.30ns	0.13ns	0.60ns
Error	33	3.56	0.70	4.63

*, ** Significant at P= 0.05 and 0.01, respectively.

ns Nonsignificant.

Mean values of draft at different levels of plowing depth and soil moisture content are shown in Table 2. Comparison of treatment means using Duncan's multiple range test (DMRT) indicated that implement draft increased significantly as plowing depth increased. This is attributed to the larger volume of the soil being cut, lifted, disintegrated, inverted and displaced by the moldboard plow bottoms when operating at deeper level. Mean values of the implement draft at all three operating depths were consistently highest and lowest at 10-12% and 12-14 % soil moisture content, respectively, as shown in Table 2. This indicates that the clay loam soil tested has been in its most friable state at 12-14 % moisture content (d.b).

Table 2. Comparison of mean values of moldboard plow draft (kN) with respect to plowing depth and soil moisture content.

Soil moisture content	Plowing depth, cm			
(% d.b.[†])	20	25	30	Mean
16-18	13.75 a[§]	17.64 a	21.11 a	17.50 a
	C[¶]	B	A	
14-16	13.20 a	16.90 a	20.82 a	16.97 a
	C	B	A	
12-14	12.33 a	16.16 a	20.29 a	16.26 a
	C	B	A	
10-12	14.94 a	17.91 a	22.44 a	18.44 a
	B	B	A	
Mean	13.56	17.15	21.17	17.29
	C	B	A	

† Dry weight basis.

§ Means followed with the same lower case letter within each column are not significantly different at P = 0.01 (DMRT).

¶ Means with the same upper case letter within each row are not significantly different at P= 0.01 (DMRT).

Mean values of specific draft at different levels of plowing depth and soil moisture content are shown in Table 3. Comparison of the treatment means using DMRT did not show any significant difference, though, an increasing trend was observed in the specific draft values as plowing depth was increased. This phenomenon could be attributed to the larger soil bulk density at deeper soil layers. Average soil bulk densities of the test plots were measured 1.45 and 1.65 g cm^{-3} in 0-15 cm and15-30cm depths, respectively. Soil moisture content had a significant effect on the specific draft of the moldboard plow, in such a way that its mean value was a maximum at 10-12 % and minimum at 12-14 % moisture contents as shown in Table 3. This is also attributed to the friability of the soil at this moisture level. The overall average specific draft of the moldboard plow in the clay loam soil studied was 7.65 N cm^{-2}, which was in agreement with those reported by Kepner *et al.* (3).

Table 3. Comparison of mean values of moldboard plow specific draft ($N\ cm^{-2}$) with respect to plowing depth and soil moisture content.

Soil moisture content (% d.b.[†])	Plowing depth, cm 20	25	30	Mean
16-18	7.63 a[§] A[¶]	7.80 a A	7.82 a A	7.75 ab
14-16	7.33 a A	7.50 a A	7.70 a A	7.51 a
12-14	6.84 b A	7.17 a A	7.51 a A	7.17 b
10-12	8.31 a A	7.96 a A	8.30 a A	8.19 a
Mean	7.53 a A	7.61 a A	7.83 a A	7.65

† Dry weight basis.

§ Means followed with the same lower case letter within each column are not significantly different at P= 0.01 (DMRT).

¶ Means with the same upper case letter within each row are not significantly different at P = 0.01 (DMRT).

Mean values of moldboard plow drawbar power requirement with respect to plowing depth and soil moisture content are shown in Table 4. Comparison of treatment means using DMRT indicated that, drawbar power requirement had increased significantly with the depth of plowing. The effect of soil moisture content on drawbar power requirement was not significant, though it was minimized at 12-14% moisture content. Table 4 also shows that the average drawbar power requirement of a 3-bottom moldboard plow for tilling a clay loam soil at the usual moisture content range of 10-18% and cutting depths of 20, 25 and 30 cm are 16.23, 20.77 and 25.10 kW, respectively. considering a power transmission efficency of 85% from engine to drive axle and an optimum tractive efficiency of 70% on firm soil as suggested by Zoz (8), a tractor with at least 27.3, 34.9 and 42.2 kW power is needed for plowing a firm clay loam soil at 20, 25 and 30 cm depths, respectively. If for any reason the assumed tractor does not work at optimum tractive efficiency, the last three figures should be multiplied by the estimated ratio of optimum to actual tractive efficiency.

Table 4. Comparison of mean values of moldboard plow drawbar power requirement (kW) with respect to plowing depth and soil moisture content.

Soil moisture content	Plowing depth, cm			
(% d.b.†)	20	25	30	Mean
16-18	16.44 a§	21.42 a	25.82 a	21.23 a
	C¶	B	A	
14-16	16.18 a	20.95 a	25.27 a	20.80 a
	C	B	A	
12-14	14.92 a	19.37 a	24.16 a	19.48 a
	C	B	A	
10-12	17.05 a	21.32 a	25.14 a	21.29 a
	C	B	A	
Mean	16.23	20.77	25.10	20.70
	C	B	A	

† Dry weight basis.

§ Means followed with the same lower case letter within each column are not significantly different at P=0.01 (DMRT).

¶ Means with the same upper case letter within each row are not significantly different at P=0.01 (DMRT).

Table 5. The effects of soil moisture content and plowing depth on soil clod size.

Soil moisture content	Plowing depth, cm		
(% d.b.†)	20	25	30
16-18	very small	very small	small
14-16	small	medium	medium
12-14	medium	large	large
10-12	medium	large	very large

† Dry weight basis.

The effects of soil moisture content and plowing depth on soil pulverization are shown in Table 5. The results indicate that better soil pulverization can be achieved by shallower plowing at higher soil moisture content. An acceptable degree of soil clod size was obtained at the moisture level of 16 to 18% for the clay loam soil tested.

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