Draught requirements of enamel coated animal drawn mouldboard plough

I. A. Loukanov[1], J. Uziak[1], J. Michálek[2]

[1]Department of Mechanical Engineering, University of Botswana, Gaborone, Botswana
[2]Department of Applied Mathematics and Informatics, Masaryk University, Brno, Czech Republic

ABSTRACT: The power requirement of tillage implements is an important design consideration particularly for animal-drawn implements where the power is limited. The paper presents the possibility of reduction in the draught requirements of animal-drawn mouldboard plough by using enamel coating on the soil-engaged components such as the mouldboard, share and the landside. Trials were conducted to compare enamel-coated Maun Series single mouldboard plough (manufactured by Zimplow Limited, Bulawayo, Zimbabwe) with similar uncoated plough, both animal-drawn, under comparable working conditions. Experiments were done at 25% and 32% d.b. soil moisture content on a red clay soil in Zimbabwe. The parameters measured in evaluating the draught performance of both ploughs were the tractive effort (pull), speed of ploughing, depth and width of ploughing, and soil conditions (i.e. soil moisture content, soil bulk density and soil penetration resistance). It was found that for similar working conditions the enamel coating reduced the specific draught by 20 to 26% depending upon soil moisture content.

Keywords: enamel coating; uncoated plough; enamel-coated plough; actual draught and specific draught

The mouldboard plough has always been the basic tillage implement on the farm. Although historic, it is still useful and widely employed for primary tillage. It cuts the soil slice, lifts it over the surface of the mouldboard and inverts it, burying the surface growth and crop residues to leave a clear surface for subsequent cultivation (Brassington 1987). Animal traction is an appropriate, affordable and sustainable technology that is still important throughout Eastern and Southern Africa. Therefore, animal traction technology in terms of draught power requirements is a crucial area of research and development. The animal-drawn mouldboard plough is widely used for primary tillage in the developing counties of Africa. This is due to its low cost and the availability of working animals such as oxen, cows, donkeys, horses and mules. Generally the mouldboard plough works well as a low speed soil inverting implement and improvements in the design can be obtained mainly by reducing draught and wear. It was estimated that the friction component of draught contributes about 30% of the total draught for ploughs working at a speed of 3 km/h (O'Callaghan, McCoy 1965). According to Betker and Kutzbach (1989) draught forces in animal-drawn ploughs vary from 850 N to 2,000 N depending upon the type of the soil and its moisture content. On the other hand the continuous pull available from work oxen is usually taken to be 10% of animal's body weight (Inns 1990). So that a pair of oxen with a combined body mass of 800 kg would produce a pull of about 800 N. Consequently continuous operation of an implement would be beyond the capacity of an ordinary draught animal pair. In this regard an investigation was undertaken to evaluate the draught requirement of enamel-coated animal-drawn mouldboard plough and compare its performance with similar uncoated plough under comparable working conditions.

LITERATURE REVIEW

The draught requirements of an animal drawn mouldboard plough is affected by the following factors: the type of soil, soil moisture, speed of ploughing (which normally does not vary significantly), depth and width of the furrow slice, type of the mouldboard used, as well as soil-to-metal friction characteristics of the soil-engaged components. By reducing the soil-to-metal friction, the draught requirement of the plough can be reduced considerably. Kepner et al. (1982) found that the values of the specific draught vary from 1.4 to 2 N/cm^2 (14–20 kPa) in sandy soils and from 10 to 14.4 N/cm^2 (100–144 kPa) in heavy clay soils. Various attempts have been made to reduce friction and adhesion of soil on tillage implements by using coatings, such as glass, Teflon, special paints and other low friction materials. These efforts were usually unsuccessful due to poor wear resistance, complicated coating techniques or cost limitations. According to Wismer et al. (1968), friction on mouldboard plough may represent as much as 30% of the total draught. They found that covering the plough bottom with Teflon reduced the draught by 23%, but Teflon showed low wearing resistance and the technique was expensive. Fox and Bockhop (1969) also found that Teflon wears much faster than steel. Salokhe and Gee-Clough (1988) tried different coating materials in investigating the soil adhesion on cage wheel lugs. They found that enamel coating on a cage wheel lug reduced the soil adhesion considerably. Later Salokhe et al. (1989) employed enamel coating to mouldboard plough, mainly to mouldboard and share, and conducted laboratory experiments in a soil bin using Bangkok clay soil under variety of working conditions. They have investigated the draught variation at four different soil moisture levels 21%, 31%, 51% and 58% (d.b.), and three speeds 1, 2 and 3 km/h. It was found that enamel coating was the best material to reduce friction and plough draught requirements. The results obtained show a draught reduction by up to 26% depending upon soil moisture content and speed. Salokhe and Shirin (1992) employed similar technique to a disc plough. They found that the overall percentage reduction in the specific draught was in the range of 4 to 21%, depending upon the soil moisture content, disc angle, tilt angle and ploughing speed. They also concluded that this was due to both low adhesion property of soil to enamel, and low soil-enamel friction coefficient.

Considering that the enamel coating technique is cheap and readily available in the industry, and with the promising results obtained so far, it was decided to carry out similar tests of enamel coating for an ox-drawn moulboard plough in field conditions.

MATERIALS AND METHODS

Experiments were conducted at the Institute of Agricultural Engineering, Borrowdale, Harare, Zimbabwe, on a red clay soil. The soil classification is USKALF with average contents of sand, silt and clay 35, 10 and 55 percent respectively.

A single furrow mouldboard plough – Maun Series and a similar enamel-coated plough, both ox-drawn, were used to plough three test plots of 20 m by 10 m. The uncoated-Maun plough is a standard plough manufactured by Zimplow Limited at Bulawayo, Zimbabwe and is designed to operate with oxen or donkeys. The plough does not have a coulter but is fitted with depth and cross clevis attachment, as well as a 150 mm wheel with a supporting arm. It is light, robust easy to handle walk behind plough intended for normal width and depth of the furrow. The Maun Plough has been tested and approved in design and performance by the Institute of Agricultural Engineering in Harare, Zimbabwe, Agritex – Zimbabwe and Silsoe Research Institute U.K. Fig. 1 shows the Maun Plough used in the trials.

The modification of the standard mouldboard plough by means of enamel coating was based on the baked on technique intended for kitchenware. The process first involved pre-treatment by sand-blasting of the soil engaged components, such as the mouldboard, share and landside. This is to roughen and therefore to increase the surface area to which the enamel coating is to be applied. First a primer-coat was applied on the metal surfaces by spraying, and after being dried for 20 minutes, a second coat was laid on by dipping the components into a pool with enamel paint. Then the components were baked in an electric furnace at 820°C for about 30 minutes in order to achieve a strong bond and improved wear resistance.

For the experiments both ploughs were set to operate at a nominal depth of 150 mm and width of 250 mm. The trials for each test were replicated five times maintaining approximately the same working conditions. Before any tests were carried out, the average soil moisture content was determined by

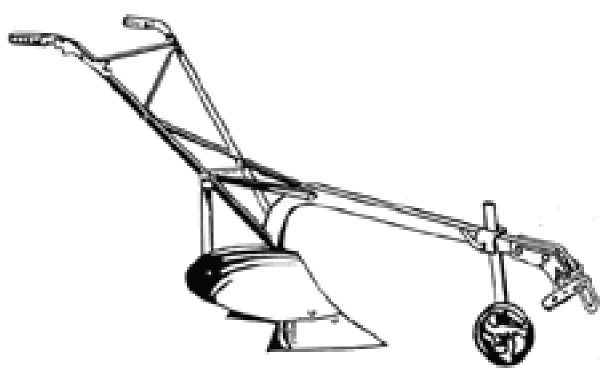

Fig. 1. Maun Plough

Table 1. Soil moisture content (% d.b.) on dry weight basis

	Trials 7. 4. 2000	Trials 27. 4. 2000
Average	31.8	24.8
St. dev.	3.6	3.6

using an electronic moisture meter. It was designed to measure organic moisture content and mineral moisture content as well as to provide a voltage output proportional to the respective moisture content. The mineral moisture content, which approximates the gravimetric moisture content, was measured and the corresponding voltage output recorded.

The procedure of taking readings for the soil bulk density involved taking soil samples up to 300 mm profile depth by means of plastic rings, each having a depth of 50 mm. This enabled 'undisturbed' samples of soil to be obtained from the soil profile, which were accurately weighed later. The samples were taken at three different stations located diagonally along the plots. Finally the data were processed using software developed by the Silsoe Research Institute U.K., to determine the bulk density and moisture content on dry bases (d.b.). The approach employed avoids taking samples to the laboratory and hence shortens the processing time. Results obtained are listed in Tables 1 and 2.

An Eijelkamp cone Penetrometer with 12.7 mm (½″) cone diameter was employed for measuring the soil penetration resistance. The readings were taken at three independent stations on each plot and the results are listed in Table 2.

During each trial the actual draught was measured by recording the tractive effort (pull) employing a load cell and portable electronic amplifier fitted with a processor and giving average readings at preset intervals of 2 seconds. This provided approximately 10 readings per run. The actual draught was calculated in accordance with the equation

$$\text{Actual Draught} = \text{Pull} \times \cos\alpha \qquad (1)$$

where: α – the angle of inclination of the chain to the horizontal (α = 19.5°).

The load cell was attached between the plough and the chain and connected to the amplifier by means of a shielded cable. At the other end the chain was attached to the yoke of the oxen. During each trial time taken for ploughing 20 m length was measured in order to estimate the average speed. On each day of the trials both enamel-coated and uncoated ploughs were tested, maintaining approximately the same working conditions such as soil moisture content and the preset depth and width of cut. The depth of cut was measured at various points along the furrow, while the width of cut was taken as the distance between successive furrow edges. Experiments were conducted at two levels of 25% and 32% d.b. soil moisture content and at average working speed of 0.8 m/s. The plough was modified on the field by using two sets of interchangeable plough bottom components, which included enamel-coated and uncoated components namely the share, mouldboard and landside. The specific draught was calculated in accordance with the equation

$$\text{Specific Draught} = (\text{Actual Draught})/(\text{Cross Sectional Area of the Furrow}) \qquad (2)$$

RESULTS AND DATA ANALYSIS

In general the variation of the ploughing speed was found to be within the range 0.7–0.9 m/s giving an average of 0.8 m/s or 2.88 km/h.

Specific draught results

The results of specific draught obtained for enamel-coated and uncoated plough at 25% d.b. soil moisture content (experiments conducted on

Table 2. Soil bulk density and soil penetration resistance

Depth (mm)	Trials 7. 4. 2000		Trials 27. 4. 2000	
	Bulk density[a] (g/cm³)	Penetration resistance[a] (MPa)	Bulk density[a] (g/cm³)	Penetration resistance[a] (MPa)
0–50	1.20	0.2	1.03	0.0
50–100	1.25	0.3	1.17	0.8
100–150	1.18	0.9	1.18	1.5
150–200	1.16	1.7	1.38	1.7
200–250	1.07	2.0	0.98	1.6
250–300	1.07	2.3	1.13	1.5
Mean (0–300)	1.154	1.22	1.147	1.19

[a]Each value is the mean of three replications

27. 4. 2000) and at 32% d.b. soil moisture content (experiments conducted on 7. 4. 2000) are shown in Table 3.These include also the mean values and standard deviations of the pull, actual draught, depth and width of cut, and the furrow cross-sectional area. From Table 3 it is evident that at 25% d.b. soil moisture content the values of the specific draught for the coated plough are lesser than that for uncoated plough. The mean values of specific draught for the enamel-coated and uncoated plough were found to be 11.0 kPa and 14.8 kPa respectively. Similar trend is observed at 32% d.b. soil moisture content. The difference is only in the higher values of the specific draught obtained. The mean values of the specific draught for enamel-coated and uncoated plough are 38.8 kPa and 48.7 kPa respectively.

Comparison between the specific draughts

Based on the results listed in Table 3 a comparison is made between enamel-coated plough and uncoated plough in terms of their specific draughts and the results are shown in Fig. 2. It was noted that the specific draughts at both moisture levels were smaller for enamel-coated plough compared to uncoated plough. The decrease in specific draught for enamel-coated plough was estimated to be 25.7% at 25% d.b. soil moisture content and 20.3% at 32%. This can be attributed to the greater difference in soil-to-metal friction on the ploughs. In addition to that it was noticed that there was a significant difference in the mean values of the specific draught at both levels of soil moisture content, the latter being attributed to the increased soil-to-metal adhesion at higher levels of moisture content. As found by Fox and Bockhop (1969) the apparent coefficient of friction between the soil and the tillage tool depends upon the type of the soil, the tool material, and soil moisture content. Furthermore an increase in soil moisture content up to a certain level leads to a significant increase in friction due to an increased soil-to-metal adhesion. Presumably similar situation occurred in reported experiments, where the specific draught was measured at 25% and 32% d.b. soil moisture contents, and its values for both ploughs at 32% d.b. soil moisture content has increased considerably. However, the percentage reduction of the specific draught agreed closely to those reported by Solokhe et al. (1989).

As seen from Table 3 it is evident that the values of the specific draught for enamel-coated plough are always lesser than the respective values of the specific draught for uncoated plough regardless of the soil moisture content. This indicates that the enamel coating when employed on mouldboard plough provides lower draught requirements.

Statistical analysis

The statistical analysis performed in this paper was based on the analysis of variance (ANOVA) (Searle 1971, 1987; Schabenberger, Pierce 2002). The main attention was given to the specific draught as a response variable depending on the experimental conditions expressed by two factors. The factors were: Plough (with two categories; Uncoated Plough coded by $P = 1$ and Enamel Coated Plough coded by $P = -1$), and Moisture Content (with two categories; 32% and 25%, coded by $MC = 1$ and $MC = -1$, respectively). The categories for the second factor were associated with two different trial dates (7. 4. and 27. 4.) corresponding to the values of the above soil moisture content.

Table 3. Pull, actual and specific draughts, depth and width of cut, and cross-sectional area of furrow

	Moisture content (% d.b.)							
	25				32			
	uncoated plough		enamel-coated plough		uncoated plough		enamel-coated plough	
	mean	standard deviation	mean	standard deviation	mean	standard deviation	mean	standard deviation
Pull (N)	659	24.7	575	18.5	1,382	52.7	1,132	30.0
Actual draught (N)	621	23.3	542	17.4	1,303	49.7	1,067	28.2
Depth of cut (m)	0.150	0.020	0.170	0.009	0.112	0.010	0.114	0.008
Width of cut (m)	0.283	0.004	0.291	0.006	0.241	0.008	0.243	0.008
Cross-sectional area (m^2)	0.043	0.006	0.050	0.003	0.027	0.003	0.028	0.001
Specific draught (kPa)	14.8	1.83	11.0	0.51	48.7	3.06	38.8	2.39

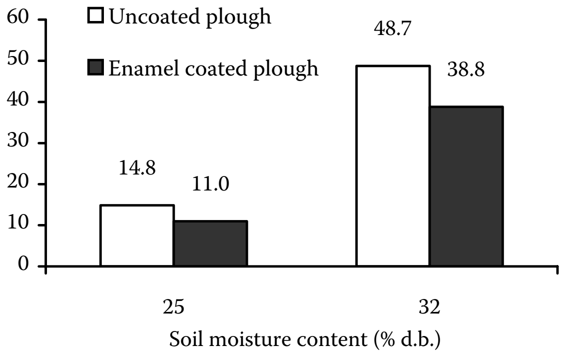

Fig. 2. Specific draught (kPa)

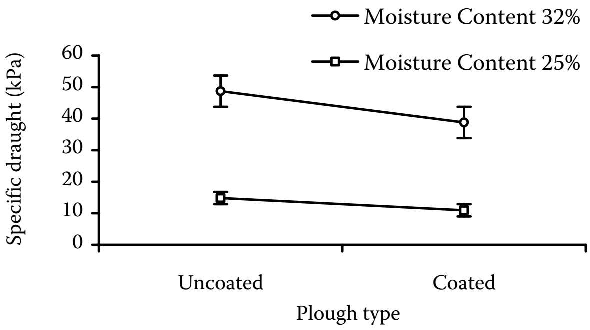

Fig. 3. Comparison of Plough and Moisture Content Effects (error bars show one standard deviation)

The ANOVA model for the response *SD* (the specific draught) with sigma-restricted parametrization was assumed (Searle 1987) in the following form

$$SD = \mu + \alpha \times P + \beta \times MC + \gamma \times P \times MC + E \tag{3}$$

where: μ – the average effect,

$\alpha \times P$ – the main effect of the factor *P* (Plough) – equal to α for $P = 1$ and equal to $-\alpha$ for $P = -1$,

$\beta \times MC$ – the main effect of the factor *MC* (Moisture Content) – equal to β for $MC = 1$ and equal to $-\beta$ for $MC = -1$,

$\gamma \times P \times MC$ – the interaction term of *P* and *MC* and it is equal to γ or $-\gamma$ when the $P \times MC$ product is equal to 1 or -1,

E – the error term.

From the ANOVA results (obtained by using a standard software package STATISTICA), it could be seen that ANOVA model fitted the data very well. The multiple correlation coefficient is equal to 0.988171 and it is highly statistically significant at significance level 1%. Its second power is 0.976481 which means that about 97.65% of variability of specific draught can be explained by the variability of factors Plough and Moisture Content and by their interactions.

Information provided in Table 4 makes possible to draw the following conclusions about the main effects of factors Plough (*P*) and Moisture Content (*MC*).

The effect of plough (factor *P*) is statistically significant at the level 1% ($p = 0.000002$) and it can be concluded that the difference in measurements of the specific draught obtained for uncoated plough and enamel coated plough is statistically significant at 1% significance level. The values of specific draught for enamel-coated plough are statistically significantly lower then the values of specific draught for uncoated plough at 1% significance level. The results are presented in Fig. 3.

Similar results were obtained for the other factor, Moisture Content (factor *MC*), which has statistically significant influence on specific draught ($p = 0.00000$). Also interaction term (factor $P \times MC$) is statistically significant ($p = 0.06602$). Thus, it is possible to conclude that the interaction between Plough and Moisture Content is highly significant as well. It means that the combination of high soil moisture content with the type of plough leads to the non-linear effects on specific draught. Higher moisture content leads to lower values of specific draught for enamel coated plough (the lines connecting the means in the Fig. 5 are not parallel to each other).

Table 4. Univariate tests of significance for specific draught using ANOVA analysis

Effect	SS Sum of squares	D Degree of freedom	MS Mean sum of squares	*F* Test Statistics	*p* *p*-value
Intercept	160.40	1	160.40	3,423.4	0.000000
P	2.38	1	2.38	50.81	0.000002
MC	47.69	1	47.68	1,017.58	0.000000
P × *MC*	0.46	1	0.46	9.73	0.006602
Error	0.75	16	0.05		

Table 5. Means, standard errors of the means, 95% confidence intervals for specific draught

Plough	Soil moisture content (% d.b.)	Specific draught		95% confidence intervals	
		mean (kPa)	standard error (kPa)	lower limit (kPa)	upper limit (kPa)
Uncoated	32	48.72	1.376	44.89	52.54
Uncoated	25	14.82	0.818	12.54	17.09
Enamel coated	32	38.80	1.064	35.84	41.75
Enamel coated	25	10.94	0.224	10.31	11.56

The detail results of ANOVA analysis with means in the categories, standard errors of means and 95% confidence intervals for specific draught in each category can be found in Table 5.

DISCUSSION

The enamel-coated plough is cheap and affordable innovation in the tillage practice. Observations were also made for any scratches or damages on the coated surfaces of the plough, but none were found. Since these were preliminary observations based on short-term applications we could not conclude about the strength and durability of the enamel coating. Further investigations are needed to find out its wear resistance, reliability and applicability in practice.

Apart from the improved draught characteristics the enamel-coated plough showed improved scouring abilities as compared to uncoated plough. These were observed particularly at 32% d.b. soil moisture content, where the soil-engaged surfaces were always free of stuck soil clods. Therefore, the application of the enamel coating contributed not only to improved plough draught requirements but also to better scouring properties.

CONCLUSIONS

Results show that enamel coating has a significant influence on the working performance of animal-drawn mouldboard plough. It was found that enamel coating reduced considerably both the specific draught and the actual draught. As compared to uncoated plough the specific draught was reduced by as much as 25.7% at 25% d.b. soil moisture content and by 20.3% at 32% d.b. soil moisture content. Based on the considerable specific draught reduction as well as lower values of the actual draught it may be concluded that the draught requirements of the enamel-coated plough are compatible with the draught capacity of an ordinary pair of oxen.

References

BETKER J.R., KUTZBACH H.D., 1989. The working performance of animal-drawn implements for soil tillage in Western Africa. Agricultural Engineering, *3*: 1517–1522. In: DODD V.A., GRACE P.M. (eds.), Land and Water Use. Balkema, Rotterdam.

BRASSINGTON T.J.M., 1987. Re-examination of the plough. Agricultural Engineer, *5*: 53–57.

FOX W.R., BOCKHOP C.W., 1969. Characteristics of a Teflon-covered simple tool. Transactions of the ASAE, *8*: 227–229.

INNS F.M., 1990. The mechanics of animal-draught cultivation implements. The Agricultural Engineer, *45*: 13–17.

KEPNER R.A., BAINER R., BAGNER E.L., 1982. Principals of Farm Machinery. Westport, CT, AVI Publishers.

O'CALLAGHAN J.R., MCCOY J.G., 1965. The handling of soil by mouldboard ploughs. Journal of Agricultural Engineering Research, *10*: 95–100.

SALOKHE V.M., GEE-CLOUGH D., 1988. Coating of cage wheel lugs to reduce soil adhesion. Journal of Agricultural Engineering Research, *33*: 21–27.

SALOKHE V.M., GEE-CLOUGH D., MUFTI A.I., 1989. Performance evaluation of an enamel coated mouldboard plough. Agricultural Engineering, *3*: 1633–1638. In: DODD V.A., GRACE P.M. (eds.), Land and Water Use. Balkema, Rotterdam.

SALOKHE V.M., SHIRIN A.K.M., 1992. Effect of Enamel Coating on the Performance of Disc Plough. Journal of Agricultural Engineering Research, *53*: 71–80.

SCHABENBERGER O., PIERCE F.J., 2002. Contemporary Statistical Models for the Plant and Soil Sciences. Boca Raton, CRC Press.

SEARLE S.R., 1971. Linear Models. New York, J. Wiley and Sons.

SEARLE S.R., 1987. Linear Models for Unbalanced Data. New York, J. Wiley and Sons.

WISMER R.D., WEGSCHOEID E.L., LUTH H.L., RANING B.E., 1968. Energy Application in Tillage and Earth Moving. SAE Transactions, *77*: 2486–2496.

Received for publication March 3, 2005
Accepted after corrections May 10, 2005

Potřeba síly vynaložené tažnými zvířaty k orbě svrchní vrstvy ornice pomocí pluhů se smaltovanou radlicí

ABSTRAKT: Potřeba tažné síly při orbě je důležitým faktorem při konstrukci pluhů pro orbu ornice především při orbě tažnými zvířaty, jejichž tažná síla je omezená. Článek shrnuje možnosti snížení energetické náročnosti orby tažnými zvířaty povrchovou úpravou radlice smaltováním v závislosti na vlastnostech půdy, jako je struktura ornice, sklon a poloha brázdy. V polních pokusech byly porovnávány pluhy se smaltovanou radlicí série Moun, vyráběné firmou Zimplow Ltd. (Bulawayo, Zimbabwe) s obdobnými nesmaltovanými pluhy, taženými zvířaty ve srovnatelných pracovních podmínkách. Červená jílová půda v Zimbabwe měla v době orby 25% a 32% vlhkost. Při hodnocení pokusu byly uplatněny následující měřené parametry: tažný výkon obou pluhů a trakční úsilí (pull), rychlost orby, hloubka a šířka brázdy, půdní podmínky jako vlhkost půdy, hustota půdních agregátů i odolnost proti pronikání. Bylo zjištěno, že při podobných pracovních podmínkách může smaltovaná radlice ušetřit 20–26 % práce, potřebné k orbě ornice v závislosti na vlhkosti půdy.

Klíčová slova: smaltování; nepotažená radlice; smaltem potažená radlice; aktuální a specifický tah

Corresponding author:

Doc. RNDr. Jaroslav Michálek, CSc., Ekonomicko-správní fakulta Masarykovy univerzity, katedra aplikované matematiky a informatiky, Lipová 41a, 602 00 Brno, Česká republika
tel.: + 420 549 496 075, fax: + 420 549 491 710, e-mail: michalek@econ.muni.cz