Application of Enamel-coating for Draught Reduction of a Mouldboard Plough

Ivan A. Loukanov[1], Jacek Uziak[2]

The effect of enamel-coating on the draught performance of an animal-drawn mouldboard plough was studied. A single furrow swing mouldboard plough-Maun Series, and the same type enamel-coated plough both ox-drawn, are compared under similar working conditions such as soil moisture content, depth and width of cut and approximately constant speed of ploughing. It was found that the enamel-coating reduces both the plough draught and the specific draught. The percentage reduction of the plough draught for enamel-coated plough compared to uncoated plough varied from 12.7% at 25% soil moisture content to 18.1% at 32% soil moisture content (dry basis). It was also found that the percentage reduction of the specific draught achieved with the enamel-coated plough in comparison with the uncoated plough varied from 20.3% at 32% soil moisture content to 25.7% at 25% soil moisture content (dry basis).

Keywords: uncoated plough, enamel-coated plough, plough draught, specific draught

1. Introduction

Animal traction is an affordable and sustainable technology, largely employed by the farmers for soil cultivation, transportation, irrigation and other agricultural activities in the developing countries of Africa, Asia and Latin America. The animal-drawn mouldboard plough is a widely used implement for primary tillage in these countries. It has been found that the modern plough draught requirements do not conform to the draught capacity of the work animals at different edaphic conditions (Betker and Kutzbach 1989). According to Inns (1990), when animals are used continuously for drawing implements they can provide a pull equal to approximately 10% of their weight.

This necessitated a modification of the plough design intended for animal traction in order to have reduced draught requirements and make them compatible with the draught capacity of work animals. This can be achieved either by reducing the weight of the plough and therefore providing less friction forces, or by optimising the shape of plough components. The latter approach has been already exhausted during the historical developments of this farm implement. Continuous investigations on tillage implements revealed that the draught performance of any plough is greatly affected by the type of soil, soil compaction, moisture content, working speed, depth and width of cut, as well as the apparent friction of the soil-engaged components, mainly the share, mouldboard and the landside. Soil that sticks to soil-metal interfaces of the plough bottom hampers proper ploughing and increases draught requirements. A direct method of overcoming such a phenomenon is to alter the surface properties of the tillage tool so that soil adhesion is reduced and sliding is enhanced (Shafer at al. 1975).

According to Kepner et al. (1982) the coefficient of friction of soil-to-metal surfaces was treated as apparent coefficient of friction being dependant upon the soil moisture content. Three phases were considered within which different values of the coefficient of friction are obtained. These are mainly the friction phase, adhesion phase and lubrication phase. *Figure 1* illustrates the above considerations and allows for interpretation of the values of the apparent coefficient of friction in terms of soil moisture. The graph can be used in the interpretation of experimental results of an implement performance obtained under specific moisture conditions. Other researches covered the soil-engaged surfaces of the plough bottom with teflon (tetrafluoroethylene) or polyethylene plastics (Cooper and McCreery 1961; Fox and Bockhop 1969). These provided a practical means of reducing soil sticking and therefore improved draught performance. Unfortunately, the research revealed that the life of wear of plastics is very limited compared to the wear capacity of steel. It was also concluded that the technology was expensive and difficult to implement.

The use of a polymer-water lubricant to mouldboard plough provides an alternative to plastic covers that are used in sticky soils (Schafer at al. 1975). Although the method reduced the draught requirements by as much as 40%, it turned out to be expensive and impractical to employ to animal-drawn ploughs, because of using PTO-driven pumps, heavy reservoirs, special distribution devices and nozzles.

Araya and Kawanishi (1984) explored another possibility for improving the plough scouring abilities and hence achieving a draught reduction, by employing a pressurized air, introduced between the soil-engaged parts of the plough and the soil slice. The compressed air served as a lubricant leading to better scouring and hence lower draught requirements. In this case an air compressor was used to develop the necessary pressure and flow rate. This method is also inapplicable to animal-drawn ploughs.

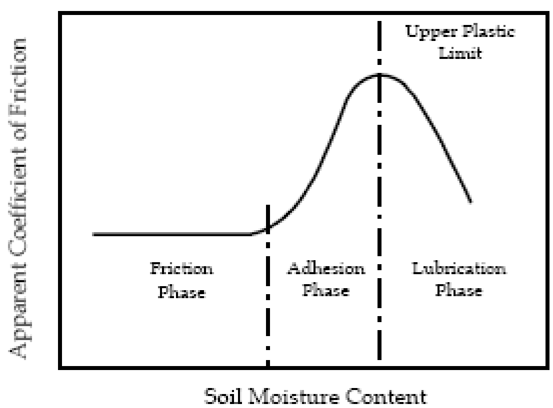

Figure 1. Apparent coefficient of friction (Kepner et al. 1982)

Salokhe et al. (1989) employed an enamel-coating to the share and mouldboard of a single plough bottom and conducted laboratory tests in a soil bin. A Bangkok clay soil was used at four levels of soil moisture content namely 21, 31, 51 and 58 percent (d.b.), and at three operating speeds: 1, 2 and 3 km/h. The results of this study showed a draught reduction of up to

26 percent depending on the soil moisture content and ploughing speed. Also Salokhe and Shirin (1990) applied the enamel-coating on a disc plough. They found that the enamel-coating reduced the draught requirements of the disc plough. The reduction of the specific draught due to enamel-coating was found to vary in the range of 4 to 21% depending upon the disk angle and soil moisture content. They concluded that the observed effects were due to low adhesion of enamel-coating to soil and low soil-enamel friction angle. In fact the coefficient of friction was determined and the above conclusions were based on the experimental results obtained. Apart from these two studies there were no further investigations reporting on enamel-coated mouldboard plough tested under field conditions.

1.1. Objective

Considering the importance of the draught reduction, particularly for tillage implements drawn by a limited power source such as animals, it was assumed that the enamel-coating might be the appropriate technology for draught reduction in the developing countries of Africa. Therefore, the objective of this study was to evaluate the effect of enamel-coating on the draught performance of an animal-drawn mouldboard plough at different moisture and field conditions.

2. Materials and Methods

A single furrow swing mouldboard plough Maun Series manufactured by Zimplow Limited, Zimbabwe, was used in this study as shown in *Figure 2*. It is a standard plough designed and manufactured to operate with oxen, cows, and donkeys. It is fitted with depth and cross clevis attachment and a 150-mm depth gauge wheel with adjustable supporting arm. The Maun plough was compared to a modified plough of the same type, the major soil-engaged components of which were enamel-coated. These components were: the share, mouldboard, and the landside surface. An enamel-coating technique intended for domestic kitchenware was employed as being cheap and readily available. The enamel-coating process was done at TECO Enamelware PVT (Ltd) Company in Harare, Zimbabwe.

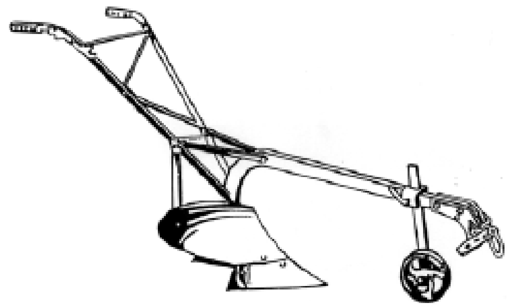

Figure 2. The Maun plough

The process of enamel-coating was preceded by sand blasting of the mouldboard, share and the landside surfaces engaged with the soil during ploughing. The purpose of using the sand blasting techniques was to roughen the soil-to-metal surfaces in order to achieve increased surface area and hence improved adhesion between the metal and the enamel-coating. Two coatings were applied within an interval of 20 to 30 minutes. The first coating was done by spraying and the second coating by dipping the parts into enamel paint bath. Then the components were heated in a large electric furnace at a temperature of 820°C for about 30 minutes. The parts were hanged on a conveyer chain passing through the furnace. Since the weight of every part was much heavier than of the kitchenware usually heated in that furnace it was necessary to heat the enamel-coated parts longer than usual. This was achieved by passing the parts several times through the furnace. As a result of the heating process a strong bond was achieved between the enamel-coating and the parts' surfaces.

Let us consider the steady ploughing motion of the Maun plough; therefore the plough can be regarded as being in the state of equilibrium. *Figure 3* shows the main forces acting on the plough along with the chain angle α. These forces are, as follows:

P – pull applied to the plough by the draught animals,

H– draught force of the plough, which is the sum of the horizontal force components acting on the plough by the soil and the operator, *V* – effective vertical force; this force is composed of all vertical force components acting on the plough due to its weight, generated by the soil, and the operator.

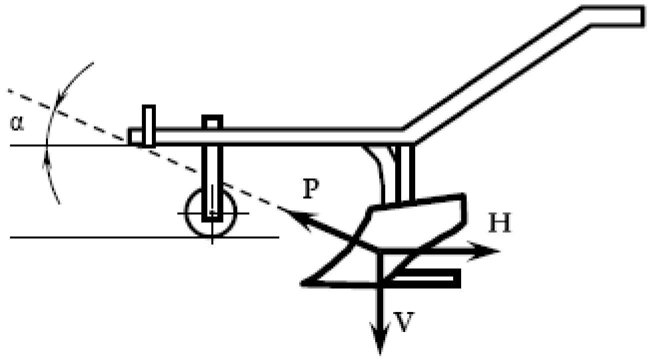

Figure 3. Main forces on the plough

From the basic static principles a body subjected to three forces is in equilibrium whenever these forces are coplanar (that is they are in the same plane), concurrent (their lines of action intersect at a point), and the force polygon formed is closed or that the sum of horizontal and vertical forces is zero. For the system of three forces acting on the plough bottom the following two equations of equilibrium are necessary and sufficient:

$$\sum_{n=1}^{n=3} F_h = 0, \quad H - P\cos\alpha = 0\,, \tag{1}$$

$$\sum_{n=1}^{n=3} F_v = 0, \quad P\sin\alpha - V = 0\,, \tag{2}$$

where α is the angle between the pull and the horizontal, usually called the chain angle. Solving Equations (1) and (2) the draught force and the effective vertical force are determined:

$$H = P\cos\alpha \tag{3}$$

$$V = P\sin\alpha. \tag{4}$$

The draught force on the plough can be estimated from Equation (3) by substituting the value for the pull and the chain angle.

In this regard the experimental setup was designed to measure the pull in the chain and the angle that the chain closes to the horizontal. A load cell of 2000 N maximum load capacity was attached between the plough and the chain. The load cell was connected by means of a shielded flexible cable to a portable battery-operated electronic amplifier fitted with a processor and digital display. The amplifier was calculating the mean values of the pull at the preset time interval and providing the results on the digital display. During the trials the values of the pull were continuously measured and the mean values of the pull simultaneously calculated within the preset interval of 2.25 seconds. The results for the mean values of the pull were displayed and recorded. The amplifier was set to deliver approximately 10 readings per run.

The experiments were done at the Institute of Agricultural Engineering, Borrowdale, Harare, Zimbabwe. During the trials both ploughs were set to operate at a nominal depth of 150 mm corresponding to a width of cut of 250 mm. The frame of the ploughs was kept in a horizontal position by adapting the position of the chain on the hitch point, so that the three forces were in equilibrium when the preset depth of 150 mm was maintained.

The trials for each test were replicated five times maintaining approximately the same plough settings and the operating speed. They were run on three horizontal plots of 20 by 10 meters on a red clay soil having 35% sand, 10% silt and 55% clay.

Prior to each test the average soil moisture content, soil bulk density and soil penetration resistance were measured. An Eijelkamp cone penetrometer with 12.7 mm cone diameter was used to measure the soil penetration resistance. Readings were taken at three locations within each plot at five different levels of depth, which included the depth of ploughing. Soil physical properties including the soil bulk density were obtained by taking soil samples from three locations of each plot on the field.

Figures 4 and *5* show the variation of soil bulk density and penetration resistance corresponding to the depth profiles at which the samples were taken in the field, and for a soil moisture content of 25% and 32% (d.b.) respectively.

From *Figure 4* it can be seen that the variation of the soil bulk density is within the usual limits suggesting that the plots of land allocated for the tests were approximately of uniform density. During each trial the pull in the chain was measured and periodically recorded along the 20 m long furrows. The preset depth and width of cut for both ploughs were maintained as much as it was possible although the ploughs were fluctuating from the straight furrow, and deviating from the preset depth of ploughing. The reason is that the operator has to control the position of the plough on the field manually, at the same time making effort to maintain the furrow size in the horizontal and vertical direction. Any increase in the depth, or/and the width of cut contributes to an increase of the furrow cross section and therefore increases the plough draught.

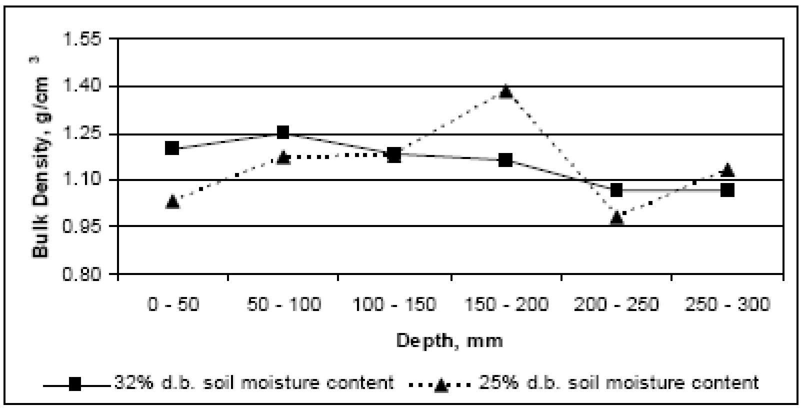

Figure 4. Variation of soil bulk density as a function of depth

On the other hand the specific draught being the force acting on unit area of the furrow cross section should remain almost unchanged if it is calculated under the same moisture content, furrow cross section, and speed of ploughing. It is for this reason that in this study the specific draught was used as the only comparable parameter to obtain the specific draught reduction of the enamel-coated plough with respect to the uncoated plough. If for any reasons the difference in cross section of the furrows of both ploughs has increased at definite moisture content level and constant speed of operation, then the specific draught of the enamel-coated plough would reduce giving misleading information on the plough performance.

In this study the values for the depth and width of cut on the field were measured by a measuring tape and later the cross section of the furrow was calculated. Since the experiments were conducted within the same day with both enamel-coated and uncoated ploughs the soil moisture content was assumed to be the same within the trials. The experiments with enamel-coated and uncoated ploughs were conducted at 25% and 32% soil moisture content (d.b.). The average speed of the ploughs was also measured by recording the time taken for the implement to travel a distance of 20 m and then calculated dividing that distance by the time taken. For all trials the average speed of the plough was estimated to be approximately 0.8 m/s and this was assumed to be the ploughing speed for each plough.

It should be noted that *Figure 5* exhibits an interesting trend of variation of the soil penetration resistance within the working depth of 200 mm. It is shown in the graphs that the soil penetration resistance increases very steeply for the two moisture levels within the depth range of 75–150 mm. In fact this range coincides with the possible variation of the working depth of the tested ploughs. Also it should be noted that the increase of soil penetration resistance directly correlates to the draught forces induced on the plough and this effect should be considered whenever forces on the plough are analyzed.

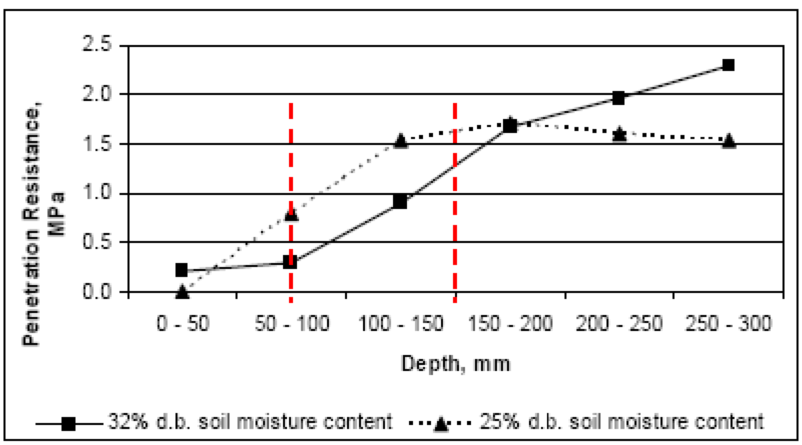

Figure 5. Variation of the soil penetration resistance with depth

It was also found that the variation of the chain angle during the trials was very small and the mean value was estimated to be $\alpha = 19.5°$. Later this result was used in the force analysis.

To obtain the specific draught H_{sp} the plough draught H is related to the cross sectional area of the furrow

$$H_{sp} = \frac{H}{dw}, \tag{5}$$

where d is the depth and w is the width of the furrow.

The percentage reduction of the draught force of enamel-coated plough compared to uncoated plough is obtained from equation (6).

$$\%, reduction\ \ H^{c} = \left(\frac{H_{m}^{unc} - H_{m}^{c}}{H_{m}^{unc}} \right) \times 100\% \tag{6}$$

The percentage reduction of the specific draught of the enamel-coated plough with respect to uncoated plough is calculated from equation (7).

$$\%, reduction\ \ H_{sp}^{c} = \left(\frac{H_{sp,m}^{unc} - H_{sp,m}^{c}}{H_{sp,m}^{unc}} \right) \times 100\% \tag{7}$$

where H_{m}^{unc} – mean value of the draught of the uncoated plough,

H_{m}^{c} – mean value of the draught of the enamel-coated plough,

$H_{sp,m}^{unc}$ – mean value of the specific draught of the uncoated plough,

and

$H_{sp,m}^{c}$ – mean value of the specific draught of the enamel-coated plough.

3. Results and Discussion

From the statistical analysis of the experimental data it was found that the results of the plough draught and the specific draught obtained for both types of ploughs were of normal distribution regardless of soil moisture content and soil properties. As an illustration of this fact the frequency distribution of the specific draught for both types of ploughs at 32% soil moisture content is presented in *Figures 6* and *7*.

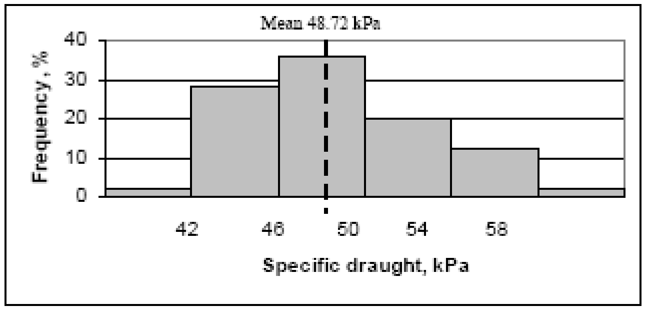

Figure 6. Specific draught distribution for uncoated plough at 32% soil moisture content

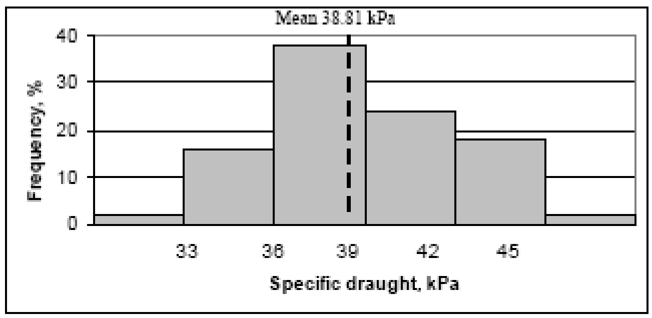

Figure 7. Specific draught distribution for enamel-coated plough at 32% soil moisture content

The results for the specific draughts shown in *Figures 6* and *7* indicate that the mean value of the uncoated plough is considerably larger than the mean value of the enamel-coated plough. It was calculated that the specific draught of the enamel-coated plough at 32% moisture content was 20.3% smaller then that of the uncoated plough, suggesting that the coefficient of friction of soil to enamel-coating is much smaller than that of the soil to steel for the uncoated plough. The variation of the plough draught and the specific draught for both types of ploughs along the furrow at 25% and 32% soil moisture content (d.b.) and the corresponding mean values is shown in *Figures 8* and *9*.

Figure 8 presents the variation of the plough draught H for both ploughs along the furrow at 25% and 32% moisture content for five replications. By employing Equation (6) the percentage reduction of the plough draught for the enamel-coated plough in comparison with uncoated plough was estimated to be 12.7% at 25% moisture content, (d.b.) and 18.1% at 32% (d.b.) soil moisture content (d.b.), respectively.

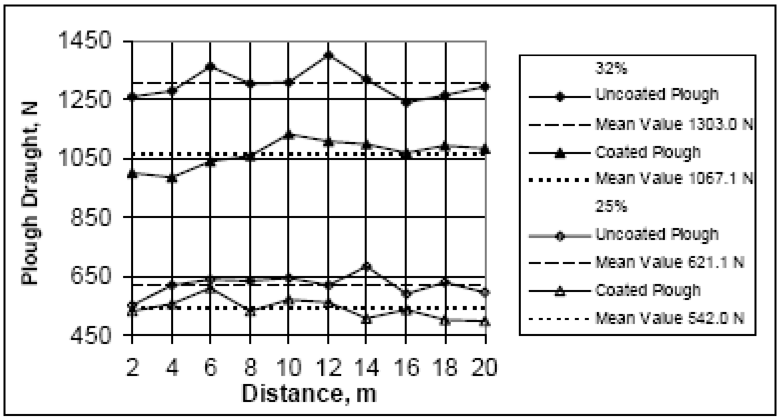

Figure 8. Variation of plough draught as a function of the distance

Figure 9 shows the variation of the specific draught H_{sp} for both ploughs along the furrow at 25% and 32% moisture content for five replications. By using Equation (7), the percentage reduction of the specific draught for enamel-coated plough as compared to uncoated plough was calculated to be 25.7% at 25% and 20.3% at 32% soil moisture content (d.b.), respectively. The reasons for the above variation of the specific draught reduction may be explained with the variation of the apparent coefficient of friction as this is shown in *Figure 1,* and most likely with the larger average cross section of the furrow at 25% moisture content relative to that at the 32%.

Possibly the soil penetration resistance may also be a contributing factor to the above effect within the ploughing depth of 75–150 mm as previously noted in *Figure 5*. The statistical analysis also revealed that the moisture content considerably affects the draught requirements of both uncoated and enamel-coated ploughs at the 95% level of significance. When the soil moisture content increases (*Figure 1*) this leads to an increase in the soil adhesion to the working surfaces of the plough (adhesion phase), therefore increasing the apparent coefficient of friction, and hence there is an increase in plough draught. This effect is well demonstrated in *Figure 8*, where at 32% moisture content the average plough draught for uncoated plough was measured to be 1303 N, while that for the enamel-coated plough it was 1067.1 N. The same trend is observed at 25% moisture content, where 621.1 N was the average draught measured for uncoated plough and 542 N for enamel-coated plough.

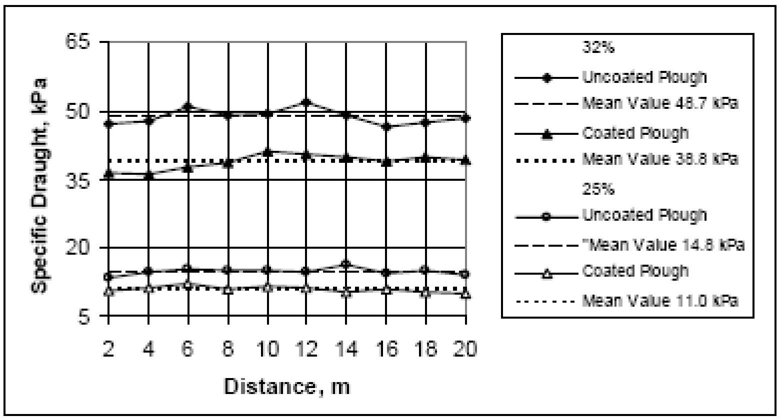

Figure 9. Variation of specific draught as a function of the distance

Analyzing the experimental data for the cross section of the furrow it was found that the percentage difference between the average cross sections of the furrows for enamel-coated and uncoated plough at 25% moisture content appears to be 16.7% larger than the furrow cross section of the uncoated plough. This is found to be much greater than the difference in the furrow cross section at 32% moisture content being only 2.6%, again in favour of the coated plough. The above results suggest that the higher value of the specific draft reduction at 25% moisture content was benefited not only because of the use of the enamel-coating on plough but also by the increase in the average furrow cross section of the enamel-coated plough. Nevertheless, our findings on the percentage reduction of the plough draught and the specific draught agreed with the results obtained by Salokhe (1989) conducted under strictly controlled conditions in a soil bin.

In addition to the above study a cost estimate for the enamel-coating process of the share, mouldboard and landside of the coated plough was conducted. It was found that cost of the sandblasting, enamel-coating and the heating process was amounting approximately 7–8% of the total cost of a new plough. At the time when the study was conducted a new plough was sold out at a market price of approximately US$ 240.0. The above cost estimate was based on the prices estimated by TECO Enamelware Pvt. (Ltd) in year 2000. This made the net expenses for the three enamel-coated parts: the share, the mouldboard and land slide of approximately US$ 20. These expenses were found to be reasonable and affordable as compared to the benefits provided by the enamel-coated plough itself.

Furthermore observations were made for scratches and/or damages on the coated surfaces of the plough bottom but none were seen. Since the test observations were based on short-term and relatively short trials they cannot provide conclusions on the strength wear and durability of the enamel-coating.

Durability tests should be based on one or more ploughing seasons to be able to conclude with confidence on the durability of the kitchenware enamel-coating employed in this study. In addition to the improved draught performance the enamel-coated plough showed much better scouring abilities in comparison to the uncoated plough. This can be attributed to the reduction of the apparent coefficient of friction between the soil slice and the enamel-coating at the estimated soil moisture content. Unfortunately, so far the apparent coefficient of friction for enamel-coating to soil has not been measured by us and such result has not been published in the literature by other researchers.

4. Conclusions

Based on the above findings it can be concluded that the application of kitchenware enamel-coating technique for draught reduction of low speed tillage implements, such as animal-drawn ploughs has a remarkable positive effect on both plough draught and specific draught. The percentage reduction of the plough draught for the uncoated plough varied from 12.7% to 18.1% at 25% and 32% moisture content, (d.b.) respectively. The percentage reduction of the specific draught for enamel-coated plough varied from 25.7% at 25% and to 20.3 % at 32% soil moisture content (d.b.). The above results were found to be statistically significant at the 95% level of significance. It could be concluded that the percentage reduction of the plough draught and the specific draught for the enamel-coated plough were considerable and these may be attributed to the low adhesion of the soil to the enamel-coating as well as reduced soil to enamel apparent coefficient of friction. It was also found that the value of 25.7% percentage reduction of the specific draught of the enamel-coated plough at 25% moisture content was not only due to the application of the enamel-coating but also owing to 16.7% increase in the furrow cross section of the enamel-coated plough as compared to the furrow cross section of the uncoated plough.

On the other hand comparing the results for the plough draught with the available continuous draught of an ordinary pair of oxen (Inns 1990), it was found that the draught requirements of the enamel-coated plough appear to be 12.7%–18.1% lower than that of the uncoated plough, therefore meeting the draught capacity of the ordinary farm animals. Also taking into account that the modification cost of the enamel-coated plough amounts to approximately 7–8% of the total cost of a new mouldboard plough, it could be concluded that the results obtained in this study could justify economically the application of the enamel-coatings. Therefore, the durability test of the enamel-coated animal drawn mouldboard plough is recommended.

References

Araya, K. and Kawanishi, K. (1984) Soil Failure by Introducing Air under Pressure. *Transactions of the ASAE*, 27:1292–1297.

Betker J. R. and H. D. Kutzbach (1989) The Working Performance of Animal-drawn Implements for Soil Tillage in Western Africa. *Agricultural Engineering* Vol. 3: 1517–1522. Land and Water Use, Dodd & Grace (eds.), Balkema, Rotterdam.

Cooper, A. W. and W. F. McCreery (1961) Plastic Surfaces for Tillage Tools. *ASAE Paper* No. 61–649, ASAE, St. Joseph, Michigan 49085.

Fox W. R. and C. W. Bockhop. (1969) Characteristics of a Teflon-covered Simple Tool. *Transactions of the ASAE* 8 (2): 227–229.

Inns F. M. 1990. The Mechanics of Animal-draught Cultivation Implements. *The Agricultural Engineer* 45(1): 13–17.

Kepner R. A., Bainer R. and E. L. Barger (1982) Principles of Farm Machinery, AVI Publisher, Connecticut.

Salokhe V. M., D. Gee-Clough and A. I. Mufti (1989) Performance Evaluation of an Enamel-Coated Mouldboard Plough. *Agricultural Engineering* Vol. 3, pp. 1633–1638, Land and Water Use, Dodd & Grace (eds.), Balkema, Rotterdam.

Salokhe V.M. and A.K.M. Shirin, (1990) Effect of Enamel-coating on the Performance of a Disc Plough, *Journal of Agricultural Engineering Research*, 53, 71–80.

Schafer R. L., W. R. Gill and C. A. Reaves, (1975) Lubrication of Soil-Metal Interfaces. *Transactions of the ASAE* 18 (5): 848–851.