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Studies on draft requirements of bullock drawn mouldboard ploughs in sandy loam soil of coastal Odisha

MK Ghosal and N Mahapatra

Abstract
The draft requirements of four types of mouldboard ploughs namely CAET, Downsize, Implement factory and Heavy soil mouldboard ploughs in sandy loam soil at two depths (100 mm and 150 mm), two speeds (1.25 kmph and 2.0 kmph), soil moisture conditions (in the range 10-11 %, wet basis) and soil resistance (in the range of 800-1000 kPa) were studied in OUAT, Bhubaneswar during 2016. The Downsize mouldboard plough was evaluated only at 100 mm depth due to its small size. The results indicated that ploughing depth had more pronounced effect on the draft of the above ploughs than the forward speed. The Downsize OUAT MB plough was found suitable for a pair of bullocks of body weight of about 400-450kg i.e. for small size bullocks which can develop a draft of 400-450N. The other three test ploughs were found suitable for the bullock pair with total body weight of about 700kg i.e. for medium size bullocks developing a draft of 600-650 N.

Keywords: Mouldboard plough, tillage, draft, draft bullock, sandy loam soil, test soil bin

Introduction

Tillage is an energy intensive farm operation consuming about 40 percent of the total energy input required for crop production (Yadav *et al*., 2006) [13]. Accurate knowledge of draft and energy requirement of implement used for tillage is essential for appropriate matching of the implements with available power sources along with the selection of the optimum operating conditions (Ademosun, 1990) [1]. The draft required for a given implement is also affected by the soil condition and the geometry of tillage implement (Olatunji *et al*., 2009) [7]. It is also a function of soil properties, tool geometry, working depth, travel speed and width of the implement (Manuwa, 2009 and Naderloo *et al*., 2009) [5, 6]. Lift angle of the mouldboard plough also contributes significant effects on the mean draft requirement of the plough (Owende and Ward, 1999) [8]. Soil properties that contribute to tillage energy are moisture content, bulk density, soil texture and soil strength (Sahu and Raheman, 2006) [9]. The ASAE standard (1999) describes tillage draft as a function of implement type, implement width, depth and speed. However, depth of operation was found to be most significant factor while speed was often significant. Therefore, draft is an important parameter to evaluate the performance of a specific tillage implement for energy requirement in order to select the matching power sources for its efficient operation.

Animal drawn mouldboard plough is one of the most prevailing primary tillage implements used in the Indian farms (Srivastava and Kalra, 2005) [12]. The size of mouldboard plough varies from region to region as per the pulling capacity of the local draft animals. In Odisha also, various sizes of bullock drawn mouldboard ploughs are still used by for tillage operation in majority of the cultivable land (Anonymous, 2008) [4]. The bullocks in the state of Odisha are mostly small (pair weight ranging from 300 to 500 kg) and medium (pair weight ranging from 501 to 700 kg) categories. Information on the draft requirement of tillage implements is limited. The lack of information compels the farmers to rely mostly on the past experience for selecting the implements. The farmers' experience may be of little value in selecting the efficient tillage system if accurate information on the draft requirement of specific tillage implement with respect to a particular farming situation, soil parameters and power sources is not available. The proper selection and use of appropriate matching equipment can enhance the effective utilization of the power source which is more important in case of animal power.

Draft animal power still continues to be an important source of power in Indian agriculture due to small holdings, hill agriculture, socio economic conditions of farmers etc (Singh, 1994). It is estimated that at present about 75 percent of total energy put into Indian farming is contributed by animals, 15 percent by human beings and the rest 10 percent by fossil fuels and electric power (Singh and Singh, 2013) [10]. In view of shortage of commercial sources of energy, especially in rural sector, draft animal power is going to play an important role in future also. It is therefore advisable to continue utilizing the power of the present availability of about 55 million draft animals in our country with better output, increased annual utilization and overall system efficiency. In the state of Odisha, bullocks are also the main source of draft power in agriculture. Thus availability of data on the draft requirements of bullock drawn tillage implements, mostly of mouldboard ploughs is an important factor while selecting tillage implement for its effective and efficient use. Hence considering draft as an important parameter, the present study has been taken up with the following objectives;

1. To study the effect of various operating and soil parameters for the draft requirement of various mouldboard ploughs namely CAET plough, Downsize OUAT MB plough, Implement Factory plough and Heavy Soil plough.
2. To determine the operating and soil parameters best suited to the above ploughs under study.

Materials and Methods

The experiments for the study were conducted in the soil bin set up of the Department of Farm Machinery and Power, OUAT, Bhubaneswar, Odisha, India. The study was limited to one soil type (sandy loam) and one soil moisture content as well as normal soil resistance level usually prevail in the field condition for operation of bullock drawn tillage implements. Four types of ploughs such as CAET plough, Downsize OUAT mouldboard plough, Implement factory plough and Heavy soil plough are selected for the study on the basis of their use under different farming situation. The effects of speed and depth of operation of all four ploughs on their draft requirement have been studied for tillage in sandy loam soil of soil bin in laboratory condition.

Soil Bin

The soil bin comprised of a stationary bin, a tool carrier to attach desired implement, soil processing trolley, test trolley, power transmission system, control unit and data acquisition system for recording and display of the collected data in the computer. The bin was 15.0 m long, 1.8 m wide and 0.6 m deep. The two rails, one on top of each side of the bin wall were used for supporting the soil processing as well as implement trolleys. The test soil bed was of 12.0 m long and 1.2 m wide over which all test ploughs are operated for draft measurement. The soil processing trolley consists of a frame, rotary tiller, leveling blade and roller for tilling, leveling and compacting the soil respectively to obtain the desired soil strength. A water sprayer provided in the processing trolley is used for spraying water on the soil to maintain the desired average moisture level. The different speeds of operation were obtained by choosing suitable gear of a gear reduction unit coupled to the input shaft of the revolving drum, which was attached to the soil processing trolley with stainless steel rope. A control unit placed outside the soil bin controlled the direction of movement of the soil processing trolley. The testing implement was mounted on the frame of the implement trolley where screw jack arrangements were provided to vary the depth of operation.

The test trolley consists of an extended octagonal ring transducer (EORT) of 1000 N capacity for draft measurement, cone penetrometer with 1 kN load cell with cone diameter of 19 mm for measuring soil resistance and a linear voltage displacement transducer with linear displacement range of 0-200 mm. the data acquisition is done by HBM Spider 8 data logger with provision for 8 channels recorder for interpretation of data in the computer. The photograph of experimental soil bin is shown in Fig. 1.

Fig 1: Experimental soil bin

Soil description and Soil bed preparation

Experiments were conducted under laboratory conditions in a sandy loam soil for which the physical properties are given in Table-1. The soil was collected from one of the fallow agricultural lands of the Central Farm of Orissa University of Agriculture and Technology, Bhubaneswar, Odisha, India, which is situated between 17^0 $50^/$ and 22^0 $30^/$ N latitude and 81^0 $21^/$ to 87^0 $38^/$ E longitude and 27 m elevation from mean sea level. The climate of the place is warm and humid with an average rainfall of 1410 mm, concentrated over the months of June-September. The soil is partly eroded due to high intensity of rainfall in the area during monsoon season. In order to quantify the soil conditions of field, bulk density, moisture content and cone index data were obtained with core sampler and hand operated soil cone penetrometer.

To get a similar condition of field soil in the laboratory, the collected soil from the farm was filled in the bin up to a depth of 0.6 m with separation in layers of 15 cm each. Each layer of soil in the bin was compacted with roller to achieve the similar bulk density as prevailed in the field condition. After filling the soil in the bin, the bulk densities of the soil were again measured with core sampler at soil depth of 15 cm interval at four locations. It was found that the differences between the bulk densities of the soil in the field and in the soil bin were comparable. The water was sprayed in the bin to get moisture content close to the field condition. Some physical properties of the top 15 cm soil in the bin are also mentioned in Table-1.

Before starting the experiments, the soil bed was prepared to achieve the desired cone index and bulk density. In order to get this, the tiller was initially used to pulverize the soil after spraying water to achieve the required moisture content. Then the soil was leveled with the leveling blade and compacted by the roller to the desired cone index and bulk density in each layer. At the end of each soil preparation, soil cone penetrometer provided in the soil bin set up was used for measuring the soil resistance to a depth of 15 cm in three locations in the soil bin at the interval of 2.5 m, following the procedures outlined in the ASAE Standards (ASAE, 2000).

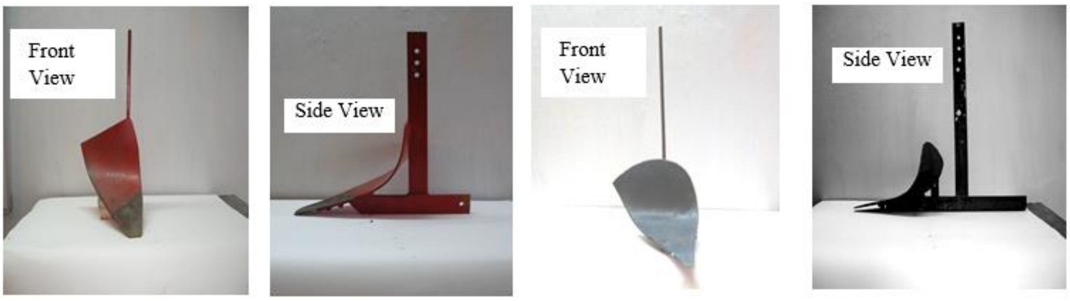
The locations were chosen so as not to interfere the actual tillage tests. To get the soil uniformity, the soil bed preparation was repeated if cone indices and bulk densities were significantly different from each other.

Table 1: Physico-chemical properties of soil sample collected from the field

A.		**Mechanical composition**	
	i)	**Particle size distribution**	
		Sand	81.24%
		Silt	7.80%
		Clay	10.96%
	ii)	Textural class	Sandy loam
B.		Physical properties	
	i)	Bulk density (g/cm^3)	1.54
	ii)	Particle density (g/cm^3)	2.63
C.		Chemical properties	
	i)	Organic matter (%)	0.935
	ii)	Organic carbon (%)	0.56
	iii)	Available N (kg/ha)	295
	iv)	Available P_2O_5 (kg/ha)	20
	v)	Available K_2O (kg/ha)	150
	vi)	p^H	5.1

Test Ploughs Used

The description of mouldboard ploughs under test and their front as well as side views are mentioned in Table-2 and in Figure-2 respectively. The four types of moldboard ploughs like CAET plough, Downsize OUAT mouldboard plough, Implement factory plough and Heavy soil plough were selected for the study because of their wide prevalence among the majority of the farmers in the state of Odisha. These are all right turning ploughs and all are bullock drawn tillage implements. The draft requirements of the above four ploughs were studied in the laboratory conditions in the soil bin at different depths and speeds usually chosen for bullock drawn tillage implements in the field conditions. The width of cut at a particular depth was measured between the projected horizontal distance of the two extreme points at the frontal plane by keeping it in the horizontal position at that depth. Similarly, the depth of operation of test ploughs was maintained by moving the plough bottom up and down along with EORT and noting the vertical distance with the help of a measuring scale provided in the test trolley.



CAET Mouldboard Plough　　　　Downsize OUAT Mouldboard Plough

Fig 2: Photographs of four types of mouldboard ploughs used for study

Table 2: Specifications of four types of mouldboard ploughs used for study

Sl. No	Plough Type	Width of cut at different Depth (mm)		Plough Height (mm)	Plough Length (mm)	Lift Angle (degree)	Weight of plough bottom (kg)
		Depth 100mm	Depth 150mm				
1	CAET Plough	195	205	210	377	19.8	4.06
2	Downsize OUAT MB Plough	175	-	135	340	10.8	3.5
3	Implement Factory Plough	168	175	240	328	21.8	3.6
4	Heavy Soil Plough	175	190	230	355	16.7	5.7

Experimental Layout

Laboratory experiments in the soil bin were conducted with four test ploughs to determine the effects of speed and depth of operation on draft requirements in a reference soil condition. The experiment for each tillage implement in sandy loam soil was conducted with the moisture contents maintaining within 10-11 % (wb). Soil strengths were maintained between 800 kPa to 1000 kPa. Two speeds of operation (1.25 kmph and 2.0 kmph) and two depths (100 mm and 150 mm) were selected for the study except Downsize OUAT mouldboard plough which was tested at only 100 mm as it could not be used beyond 100 mm depth and at the second depth of 150 mm because of its size.

After maintaining the desired moisture level and soil strength in the soil bin and fixing the required depth, the implement was moved at a particular speed by selecting the proper gear and keeping the pulling arm horizontal to the soil bed. With the help of the calibrated EORT, the data for draft of test implement were continuously acquired in the data acquisition system. Simultaneously the time to cover a fixed distance of

10 m was recorded using a mechanical stop watch to calculate the speed of operation.

Results and Discussion

The results of the different experiments on draft requirement of four types of mouldboard ploughs with the change of depth and speed of operation have been mentioned and compared among themselves. In the beginning, the EORT has been calibrated from the known weights in Newton applied to the test ploughs and observed electrical strain in mV/V. The best fit equation has been developed to know the drafts on the ploughs from the recorded data of electrical stains during the course of experimentation. Results obtained during the study are presented in the following sub-heads.

- Calibration of EORT to know the best fit equation between draft and electrical strain
- Effect of depth on the draft requirement of test ploughs
- Effect of speed of operation on the draft requirement of test ploughs

Calibration of Extended Octagonal Ring Transducer (EORT)

The EORT was calibrated by applying known weight to it and recording of respective electrical strains in the data logger. Getting a series of data, graphs were plotted between the electrical strains and known weights and from the curve, the calibration equation was developed. The data of weight versus electrical strains have been mentioned in Table-3 and their calibration curve has been shown in Fig. 3. From the graph between the electrical strain and the load on the EORT, it was observed that the straight line curve represents best fit with high value of coefficient of determination i.e. R^2 be 0.9987 which can be satisfactorily used to determine the draft experienced on the test ploughs at various operational conditions.

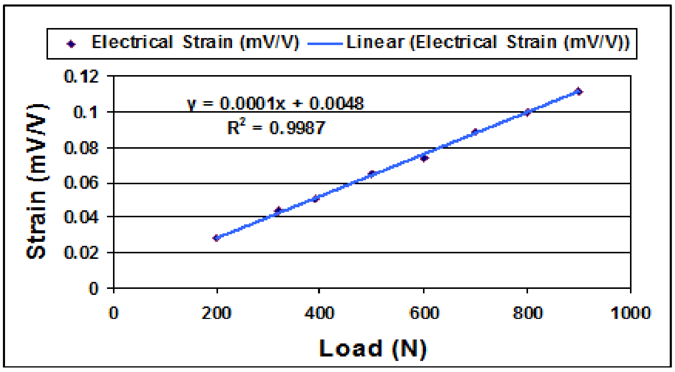


Fig 3: Calibration curve of the EORT

Table 3: Calibration of EORT

Load, N	mV/V
200	0.028
320	0.044
390	0.051
500	0.065
600	0.074
700	0.089
800	0.1
900	0.112

Effect of depth on the draft requirement of test ploughs

The drafts observed at two depths of 100mm and 150mm and at two different speeds of 1.25 km/h and 2.0 km/h are presented in Table 4 and are shown graphically in Figs 4 and 5. This represents the effect of variation of depth on draft. The data reveals that the draft requirement of the Downsize OUAT MB plough is minimum among all but it can be used up to 100mm depth due to its size. Among the other three ploughs, the draft requirement of Heavy soil plough is least at both the speeds and depth. The increase in draft requirement at 150mm depth compared to that at 100mm depth was found to be 11.88% for CAET plough, 11.39% for Implement Factory plough, and 16.31% for Heavy Soil plough at speed of 1.25 km/h. Similarly, the increase in draft was 6.74% for CAET plough, 6.65% for Implement Factory plough and 11.88% for Heavy Soil plough at speed of 2.0 km/h. The least value of draft in case of heavy soil plough may be attributed to the least value of lift angle compared to the other two ploughs. The increase in the draft requirement of tillage implement with the increase in depth and speed of operation may be because of the higher soil resistance and more volume of soil handled at higher depth and higher force required accomplishing the soil acceleration at a higher speed of operation.

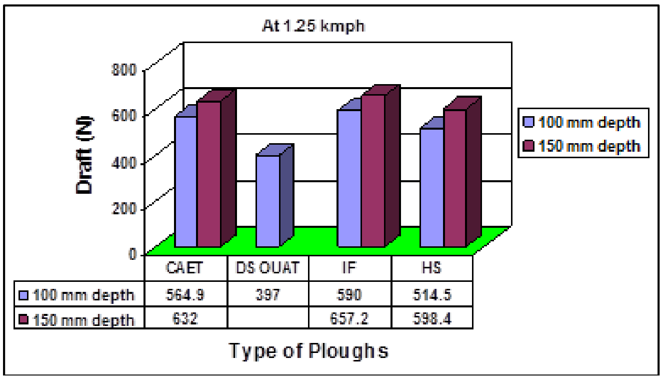


Fig 4: Drafts of test ploughs at 100 mm and 150 mm depth at a speed of 1.25 kmph.

Table 4: Draft requirements of test ploughs with the change of depth

Sl. No	Plough Type	Draft (N) of Ploughs at different speed and depth					
		Speed 1.25 km/h			Speed 2.0 km/h		
		Depth 100mm	Depth 150mm	% increase	Depth 100mm	Depth 150mm	% increase
1	CAET Plough	564.9	632	11.88	623.6	665.6	6.74
2	Downsize OUAT MB Plough	397	-	-	422.2	-	-
3	Implement Factory Plough	590	657.2	11.39	632	674	6.65
4	Heavy Soil Plough	514.5	598.4	16.31	564.9	632	11.88

Effect of speed of operation on the draft requirement of test ploughs

The effect of speed on the draft requirement of the test ploughs is presented in the Table-5 and is shown graphically in Figs 6 and 7. From the data it was observed that draft requirement increased with increase in speed of operation from 1.25km/h to 2km/h. This is mainly because of acceleration of the soil. Accelerated soil exerts more reaction force on the plough causing more draft. The increase in draft at 100mm depth was found to be 10.39% for CAET plough, 6.35% for Downsize OUAT MB plough, 7.12% for Implement Factory plough and 9.8% for Heavy Soil plough at 2.0 km/h compared to 1.25 km/h speed. However, the increase in draft requirement at 150mm depth was found to be 5.32% for CAET plough, 2.56% for Implement Factory plough and 5.61% for Heavy Soil plough at 2.0 km/h compared to 1.25 km/h speed. The above results can be attributed to the fact that the Downsize OUAT MB plough is the smallest plough in dimension and among the other three ploughs, the lift angle is minimum (16.7^0) in case of Heavy Soil plough. Higher lift angle in case of Implement Factory plough lifts the cut furrow to greater heights thereby increasing the draft requirement. Further it was also observed that the effect of depth of operation had pronounced effect on the draft requirement than that of speed. The draft requirement increased in the range of 6.65% to 16.31% when the depth was increased from 100mm to 150mm, compared to that of 2.56% to 10.39% when the speed was increased from 1.25km/h to 2 km/h for the test ploughs.

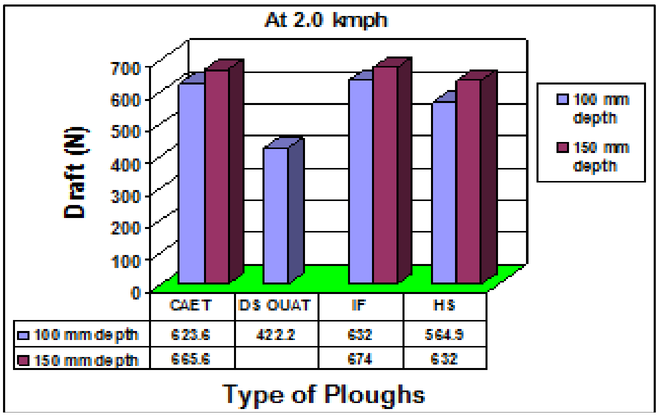


Fig 5: Drafts of test ploughs at 100 mm and 150 mm depth at a speed of 2.0 kmph.

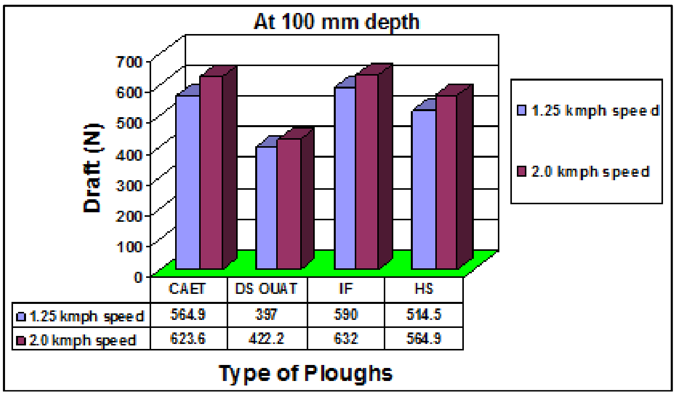


Fig 6: Drafts of test ploughs at 1.25 km/h and 2.0 km/h at a depth of 100 mm.

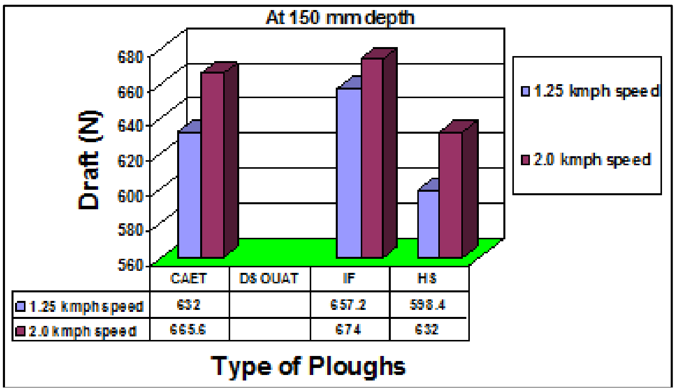


Fig 7: Drafts of test ploughs at 1.25 km/h and 2.0 km/h at a depth of150 mm.

Table 5: Draft requirements of test ploughs with the change in speed of operation

Sl. No	Plough Type	Draft (N) of Ploughs at different speed and depth					
		Depth 100mm			Depth 150mm		
		Speed 1.25 km/h	Speed 2.0 km/h	% increase	Speed 1.25 km/h	Speed 2.0 km/h	% increase
1	CAET Plough	564.9	623.6	10.39	632	665.6	5.32
2	Downsize OUAT MB Plough	397	422.2	6.35	-	-	-
3	Implement Factory Plough	590	632	7.12	657.2	674	2.56
4	Heavy Soil Plough	514.5	564.9	9.80	598.4	632	5.61

Conclusions

1. The major conclusions drawn from the present study are as follows.
2. The draft requirement of Downsize OUAT MB plough was found to be 397N and 422.2N at the operating speed of 1.25 km/h and 2 km/h respectively at 100mm depth of operation.
3. For the other three ploughs namely CAET plough, Implement Factory plough and Heavy Soil plough, draft requirements were found to be in the range of about 500 to 600N at depth of 100mm and in the range of about 600 to 650 N when the depth of operation was increased to 150 mm at the speed of operation of 1.25 km/h,
4. Similarly, the draft requirements of CAET plough, Implement Factory plough and Heavy Soil plough were found to be in the range of 550 to 650 N at depth of 100 mm and in the range of 630 to 670 N at 150 mm depth at the speed of 2.0 km/h.
5. The Downsize OUAT MB plough is suitable for a pair of bullocks of body weight of about 400-450kg i.e. for small size bullocks which can develop a draft of 400-450N. The other three test ploughs are found suitable for the bullock pair with total body weight of about 700kg i.e. for medium size bullocks.

The research findings presented above provide useful information in selection of bullock drawn ploughs most suitable to the different size of bullocks available in the state of Odisha. This will also help in increasing the efficiency of bullocks for ploughing operation.

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