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# Soil reactions of selected bullock drawn ploughs in two extreme soils

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**Abstract :** Establishing relations between the plough reactions and the soil constituency help in designing better soil working tools. It leads to minimized energy cost in tillage operations. A hydraulic six cell dynamometer was developed and used in a standard soil bin to compare the mechanics of four bullock drawn tools, namely country plough, iron plough, Tenkasi plough and semi digger. The trials were conducted in two extreme soils namely black cotton and sand, at three levels of soil moisture content and three operating depths. The measurements yielded the complete picture of plough mechanics. The country plough had substantially lesser horizontal reaction of 250 to 460 N in black soil and 165 to 270 N in sand. The iron plough had the maximum horizontal reaction of about 1000 N in black soil and 750 N in sand. But the unit drafts were 3.5 to 4.8, 5.3 to 6.6, 4 to 6.1, and 2.65 to 4.25 N $cm^{-2}$ for the iron, semi digger, Tenkasi and country ploughs respectively in black soil. This indicated that the semi digger demanded the maximum specific draft among the ploughs tested. The vertical soil reactions were all downward indicating a suctional force and they generally increased with depth of operation in both the soils. Clock-wise couples were present only for the iron plough and the semi digger. In the semi digger, it increased non-linearly from 4000 Nm at 8 cm depth to 5000 Nm at 16 cm.

*Key words: Bullock drawn plough, Horizontal reaction, Vertical reaction, Lateral reaction, Couple*

## Introduction

The fact that soil working tools influence farm production is undeniable. Research on soil working tools date back to the years of Clyde, Tullinger and Randolph in the thirties. In spite of the rapid advances in technology, tillage is still far from being an exact science. The importance of optimizing tillage tool performance is of utmost importance considering the lion's share of tillage cost in overall crop production. The establishment of relations between the plough reactions and the soil constituency is helpful in understanding the tool mechanics towards designing better tillage tools. This is particularly so in the case of indigenous animal drawn tools, which are still in existence in the Indian agricultural scenario.

Clyde (1936) designed and developed a six cell dynamometer to experiment and analyze the mechanics of different tillage tools. The device consisted of a frame with diaphragm type hydraulic load cells to measure the reactions at six degrees of freedom. Since then, various six cell dynamometers have been designed and used mainly on tractor drawn tillage tools. (Perumpral *et al.* 1980; Orleanda *et al.* 1983; and Durairaj *et al.* 1998).

Hussain *et al.* (1985) compared a desi plough with a mould board plough and reported that the latter with an 18 cm operating width at 11 cm depth had a draft of 4800 N. Tajuddin and Karunanithi (1987) developed an animal drawn iron plough as an alternative to the country plough. They found that it had a draft of about 600 N while operating in black and red soils at a depth of 15 cm. Senapati and Satpathy (1989) evaluated seven types of bullock drawn ploughs in terms of their draftability. They reported that these ploughs having an operating width of 18 cm demanded a draft of about 746 to 834 N in lateritic soils, while operating at a depth of 12 cm. Mohanty *et al.* (1991) incorporated rollers on the surface of conventional animal drawn mould board ploughs towards reducing the draft requirement. The draft of the 15 cm wide plough was 490 N, while operating at a depth of 10 cm in a soil having 8% moisture (d.b).

In all these studies mentioned, the draft was measured with a single dynamometer and hence did not provide the complete mechanics of the ploughs. This work was taken up with the objectives of selecting four popular designs of indigenous tools, assess and compare their soil reactions in two extreme soils as influenced by the soil moisture and depth of operation. The study intended to instrument the tools with a six cell dynamometer so as to acquire a complete picture of the tool mechanics including the couples.

## Materials and Methods

The development of force measurement system was conceived on the basis of the pioneering work of Clyde (1936) in designing and developing a six cell dynamometer, which could measure the forces acting on any plough at six degrees of freedom. He used hydraulic force sensing cells to compute the soil reactions of ploughs in all the three planes as well the couple if any. The dynamometer used in this study was much similar to that design, but much simplified, and consisted of the following parts:

i. A main trailed frame with a pair of castor wheels at the back

ii. A sub frame restrained on to the main frame through six hydraulic load cells

The main frame (Fig. 1) was hitched integrally to the soil bin trolley available in the Department of Farm Machinery laboratory, Tamil Nadu Agricultural University, Coimbatore, so that the tail wheels could support it at the back by rolling on the concrete sidewalk. The soil bin has two parallel compartments each of 30 m length and 3 m width, one with black cotton soil and the other with sand. Using the bin, soil working tools were tested in two extreme soils. The main frame was provided for supporting the sub-frame and to tow it along with the soil bin. The sub frame was of a triangular construction and had provisions for mounting the plough beam at its centroidal location. The apex points of the frame had hooks welded and accommodated the hydraulic load cells. Hooks were correspondingly welded on the main frame to suspend the sub-frame on the mainframe through the load cells (Fig. 1). Three load cells ($V_1$, $V_2$, $V_3$) hence restrained the vertical freedom of the sub-frame. Similarly two load cells oriented horizontally ($H_1$, $H_2$) restrained the freedom in that direction. One more load cell ($S_1$) was connected between the lateral side of the sub frame and the main frame towards restraining the side-wise freedom. This arrangement provided for measurement of these six forces on the tool in three directions. Applying simple principles of mechanics, these forces were used to calculate the resultant soil reaction vector and the magnitude of the couple. The resultant was then used to derive the reaction components in the horizontal, vertical and lateral directions.

Using the developed dynamometer and the soil bin facility, experiments were conducted during 1996 at Department of Farm Machinery, TNAU, Coimbatore, on the following four indigenous animal drawn ploughs each with an operating width of 15 cm.

a) Country plough

b) Iron plough (beam type)

c) Tenkasi plough- similar in construction to the country plough, but constructed of mild steel plates.

d) Semi digger plough

The force measurements were done on all the four tools in both the types of soil, namely black cotton and sand. The soil moisture was varied at three levels of 6, 10 and 13 per cent (d.b) and the depth of operation at three levels of 8, 12 and 16 cm.

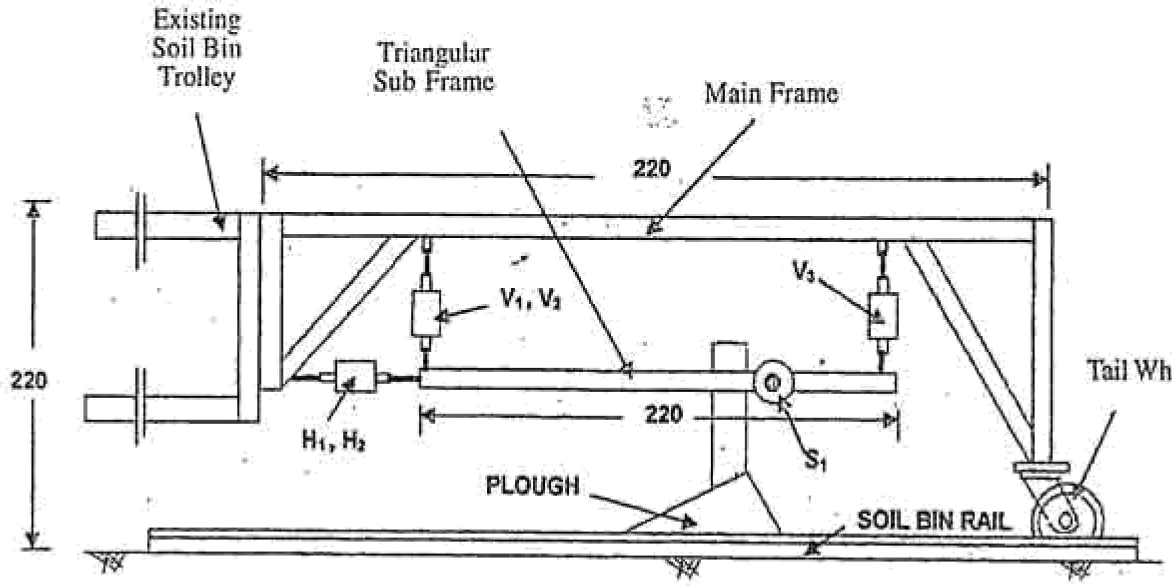
## Results and Discussion

*a. Effect of depth of operation on the horizontal reactions*

In all the cases (Fig. 2) the horizontal reactions were found to increase with an increase in depth of operation, which is quite obvious since that the reacting area increased with depth. The country plough had substantially lesser horizontal reaction. It was 250 to 460 N in black soil and 165 to 270 N in sand. Iron plough had the maximum horizontal reaction of about 1000 N in black soil and 750 N in sand. This is obvious because it made a rectangular furrow, whereas the other three made triangular furrows. The unit drafts of the ploughs were 3.5 to 4.8, 5.3 to 6.6, 4 to 6.1, and 2.65 to 4.25 N $cm^{-2}$ for the iron, semi digger, Tenkasi and country ploughs respectively in black soil. This indicated that the semi digger demanded the maximum specific draft among the ploughs tested. The semi digger, Tenkasi and the country ploughs being similar to inclined plates indicated an uniform increase in reactions relative to depth as governed by the fundamental inclined tool analogy. However, the iron plough also showed a similar linear trend with respect to depth. The semi digger, that can be assumed to be a combination of an inclined plane and mould

Table 1. Lateral reactions as influenced by the type of plough

| Type of plough | Lateral reaction, N | |
|---|---|---|
| | Black cotton soil | Sand |
| Iron plough | 167 to 196 | 108 to 137 |
| Semi digger | 108 to 137 | 49 to 69 |
| Tenkasi plough | Nil | Nil |
| Country plough | Nil | Nil |




HYDRAULIC LOAD CELLS: $H_1$, $H_2$ - Measuring Horizontal Reactions
$V_1$, $V_2$, $V_3$ - Measuring Vertical Reactions
$S_1$ - Measuring Lateral Reactions

**Fig.1** Construction of the dynamometer frame as attached to the soil bin

board plough, has an abrupt twist at the tail end of its mould board. This contributed higher horizontal reactions (400 to 750 N) than the Tenkasi and country ploughs in both the soils (150 to 600 N). Generally the horizontal reactions were very minimal in sand for all the ploughs at all moisture levels and depths. The sand being purely frictional, contributed its resistance only to the projected area and hence this result.

*b. Effect of depth of operation on the vertical reactions*

The vertical soil reactions were all downward indicating a suctional force. These forces generally increased with the depth of operation (Fig. 3) in both the soils. Iron plough had the highest vertical soil reactions of 400 to 600 N, whereas the country plough recorded the least of 299 to 380 N in black soil. The vertical reactions had proportionate values to horizontal reactions, which meant that the H/V ratios were similar for all the ploughs. However, the semi digger indicated a relatively lesser H/V ratio in black soil, especially at higher depths of operation.

*c. Effect of depth of operation on the lateral reactions*

Table 1 shows the lateral reactions as measured on these ploughs. The Tenkasi and country ploughs being symmetrical did not have

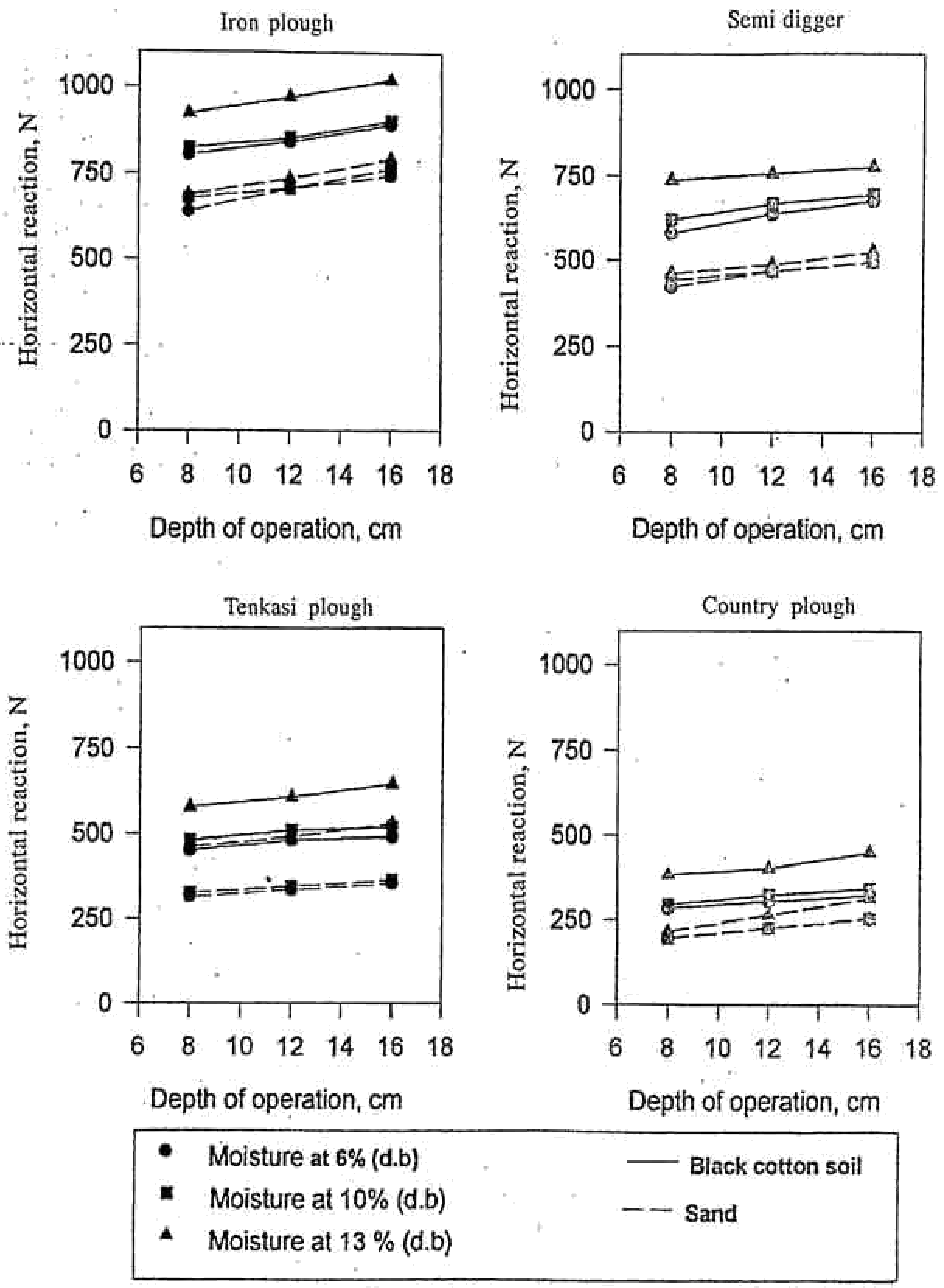



Fig.2. Influence of depth on horizontal reactions

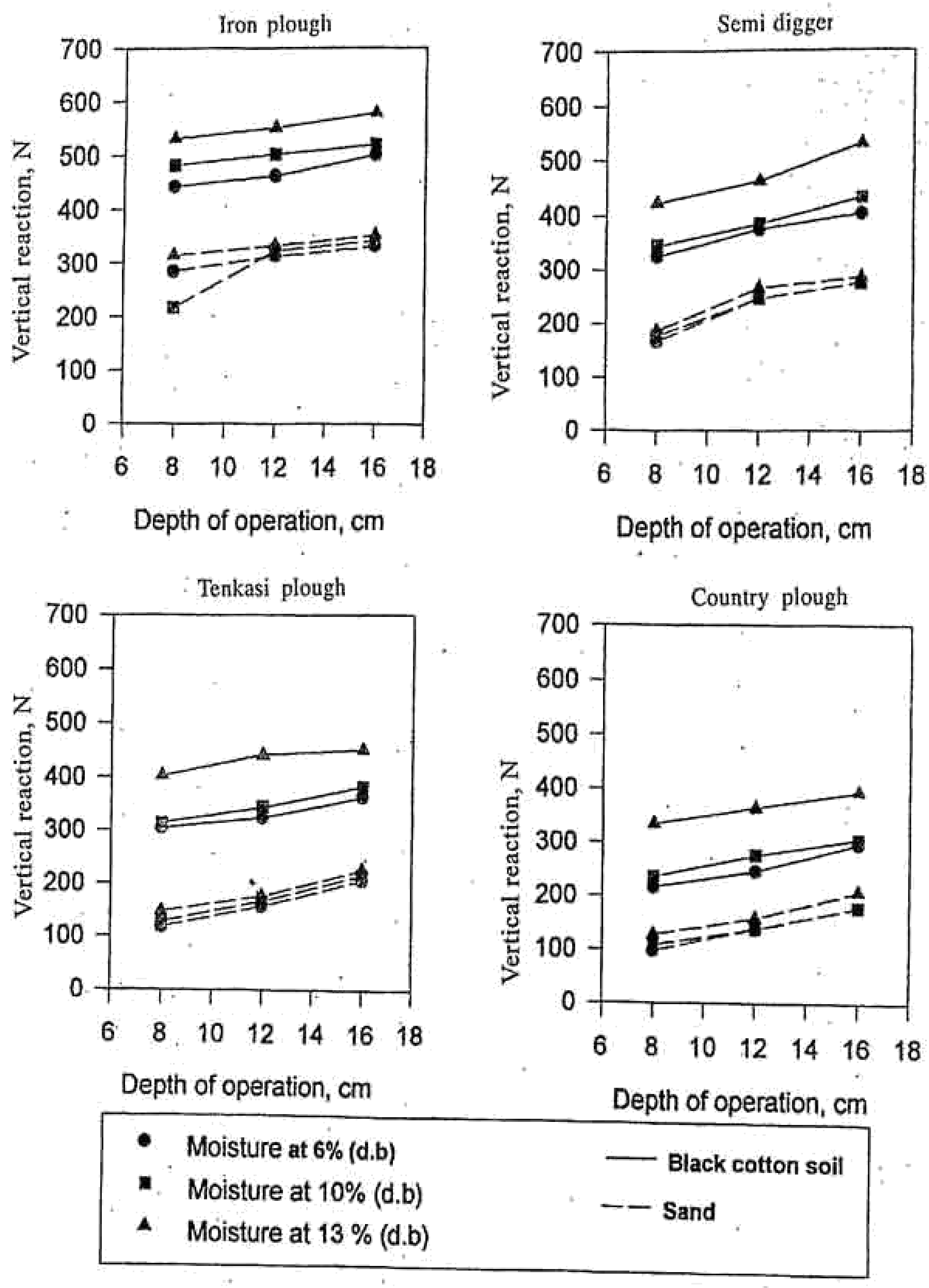



Fig.3. Influence of depth on vertical soil reactions

any lateral soil reaction. The semi digger having a twist only at the extreme end, indicated a considerably lesser lateral reaction compared to the iron plough.

*d. Effect of depth of operation on the couple*

As anticipated, the couples were present only for the iron plough and the semi digger, since of their unsymmetrical construction. In both the cases, the direction of the couple was clock-wise as viewed from the front end of the ploughs. As for the iron plough, it was at a maximum value of 6100 Nm at the operating depth of 12 cm, but was only about 4500 - 5000 Nm at all other depths. However, in the case of semi digger, the couple increased non-linearly from about 4000 Nm at 8 cm depth to 5000 Nm at 16 cm.

*e. Effect of soil moisture on the reactions*

The general observation in all the cases of soil reactions pertaining to the black soil is that they increased with an increase in moisture content. There was particularly an increase in horizontal reactions when moisture increased over 10 per cent. This is more due to the entry of the soil-tool interaction from the frictional phase into the adhesive mode. Generally moisture had insignificant effect on the soil reactions in sand.

## Conclusions

Among the country plough, iron plough, Tenkasi plough and semi digger tested, the horizontal reactions were found to increase with an increase in depth of operation. The unit drafts of the ploughs were respectively 3.5 to 4.8, 5.3 to 6.6, 4.0 to 6.1 and 2.65 to 4.25 N $cm^{-2}$. The vertical soil reactions indicated suctional force. The couples were present for iron plough and semi digger in clockwise direction. The soil reactions of the ploughs increased with increase in moisture content.

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