Global Advanced Research Journal of Agricultural Science (ISSN: 2315-5094) Vol. 4(6) pp. 259-269, June, 2015.
Available online http://garj.org/garjas

Full Length Research Paper

Analyses of 3-dimensional draught and soil deformation forces caused by mouldboard plough in clay loam soil

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Accepted 10 June, 2015

Draught force and soil deformation forces distribution in three dimensions are important aspects that can help in developing better understanding of tillage process and also help the engineers to improve the efficiency of tillage implements. Lab experiments were carried out to analyze draught forces (horizontal force (Fx), vertical force (Fy) and side force (Fz) and soil deformation forces (horizontal deformation force (Dx), vertical deformation force (Dy) and side deformation force (Dz)) caused by mould board plough under different speeds, depth and moisture contents. Draught forces represented increasing trend with increasing speed and depth as highest horizontal force of 5.113 kN was observed at 15 cm depth and 2 m/s speed. The same force was decreased to 2.572 kN at same speed and depth when moisture content was increased from 27 % to 33 % representing negative impact of moisture content. Maximum soil deformation force of 95.25 N was observed in horizontal direction (Dx) at 2 m/s speed and depth of 15 cm (d3) under 27% moisture content. Similar variation trend were observed for draught and deformation forces under similar set of treatments. It was concluded that 33 % moisture content and 1 m/s speed can reduce the input energy. Soft sensing technology was also observed as a fast and effective way to study various soil forces under different field conditions.

Keyword: draught force in three directions, deformation force in three direction, moisture content, paddy soil, sensor's (JP-1, LD 80)

INTRODUCTION

Draught force analyses are important aspects of tillage and mostly studied in one dimension along the movement of tillage that hardly represent total draught force required by the implement. That issue can be resolved by measuring draught forces in three dimensions, horizontal, vertical and side (Desbiolles *et al*., 1997; Grisso & Perumpral, 1985). On the other hand, little work is done in the past to analyses the deformations force on soil caused by tillage tool that can't develop clear understanding of the mechanics of soil under the influence of agricultural tillage tools due to soil spatial and temporal (Kai *et al*., 2007). Estimating the tillage forces by using analytical or

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numerical models assuming soil engineering properties are stable, does not reflect the real nature of soil.

Therefore, a new approach is needed to quantify the variability of tillage forces due to variability of tillage system parameters that are associated with probability of soil deformation (Abdul *et al*., 1999; Mckyes *et al*., 1984; White *et al*., 2003) measured disturbed soil mass by tillage tools at different soil conditions and operating speeds reported. Soil deformed area was calculated by means of passive earth pressure theory with the shape of the soil deformed lodge were determined by soil weight and strength. They used the same expression proposed by (McKyes & Ali, 1977). However many studies have been only to measure soil failure pattern draught force with numerical methods (Khwantri *et al*., 2012; Jafari *et al*., 2006).

There are few references showing that little or no work done on deformation of soil force and its interaction with different tillage tools (Zhai, 2011).Presently there is no such theory that can predict the soil deformation forces in three dimensions. Considering the importance of soil deforming force in different soil-tillage tool processes that are of vital importance in agricultural field, it is surprising that deformation forces in soil cutting have been ignored (Aluko, 2000; Makanga *et al*., 2010).

Keeping in view all these important aspect, information technology is one of the solutions that can acquire, manipulate and represent interaction between soil and agricultural tools with precision. Sensor technology equipped with virtual instruments developed in Lab View software along with other necessary equipment is the example of such solution which is applied in the present study to study evaluate draught forces in 3D named as (draught force (Fx), vertical force (Fy) and side force (Fz)) along with soil deformation forces as (horizontal deformation force (Dx), vertical deformation force (Dy) and side deformation force (Dz)).

MATERIAL AND METHODS

The study was conducted in a laboratory using soil bin located in the Soil Mechanic Laboratory in the Department of Agricultural Mechanization Engineering, College of Engineering, Nanjing Agriculture University, China. Moulboard plough1LE – 435was used in the soil bin for the experiments. Soil bin was 6 m long, 2.5 m wide and 0.78 m deep. A 7.5 kW electronic motor was used as prime mover for the frame shown in (figure 1 (a) and figure 1(b)).

Soil preparation

Soil was taken from PukouYongning in South of Nanjing from paddy field. The soil used in experiment is silt clay using (Black et al., 1965) method to textural analyses. The experimental soil was sun dried for 15 to 25 days and then grinded with electrical hammer. After that it was sieved and filled in the soil bin shown in (figure 2). In the first step, soil was leveled by a wooden leveler and then a calculated amount of water was sprayed on the basis of existing moisture content using (Tagar et al., 2014) method. The operating parameter of tillage tool and soil, texture, physical and mechanical properties are shown in Table 1.

Draught Measurement

Three dimensional LD- 80 extended octagonal ring transducers which were produced by Yuyao Heng Tai automation equipment Co., Ltd., was used to measure draught forces in 3-D. Four holes in central portion of casing were made for attachment with mouldbroad plough. Sensor cables were taken out from the casing at different points in such a way that they were not interrupting other cables and special arrangements were made to save the cable from bending and breaking at outlet points. This designed system was named as three dimensional extended octagonal ring transducer as shown in figure 3 following Tagar et al., (2014), Chandio (2013) Saunders (2002) methods.

The other issue was to place the senor with plough which was solved by designing an attachment bar shown in (figure 4). With the help of this attachment bar, depth of tillage operation was also controlled.

Attachment bar and transducer were attached to mouldbroad plough with the help of high grade bolds that not only hold the system firmly and eliminate vibration but also to withstand high load developed while tillage process.

Measurement of the soil deformation forces in 3-D.

In this study the observation of soil deformation forces was measured by JP-1 force sensors, which is produced by Yuyao Heng Tai automation equipment Co., Ltd. Nine sensors were employed to measure three dimension soil deformation forces at three different points in the direction of movement of mouldbroad plough as shown in (figure 5).

During run of tillage tool soil deformation forces were recorded by computer. Soil deforming measurement system including force sensors and three dimensional draught sensors are shown in (Figure 6(a) and Figure 6(b)).

Resultant Draught Forces

Resultant draught force was calculated using algebraic sum of all three components of the forces as:

$$\mathbf{F = Fx_i + Fy_j + Fz_k} \quad 1$$

And the magnitude was calculated using the following equation.

$$F = (Fx^2 + Fy^2 + Fz^2)^{1/2} \quad 2$$

F = Total resultant draught force
Fx = Horizontal draught force
Fy = Vertical draught force

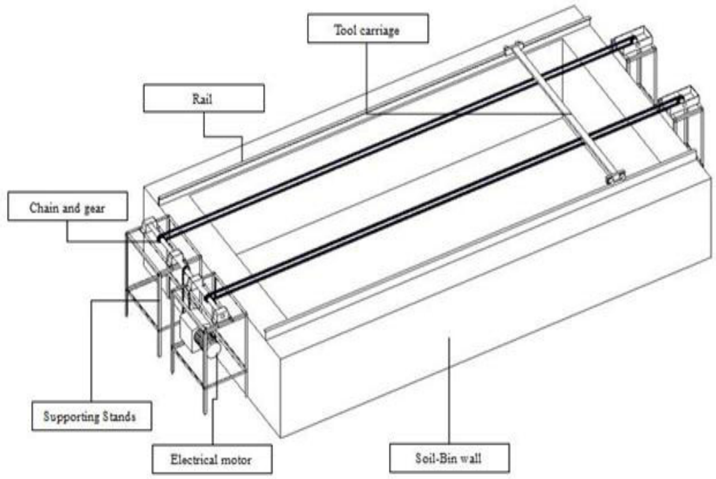

Figure 1 (a) Schematic view of soil-bin in two dimensions

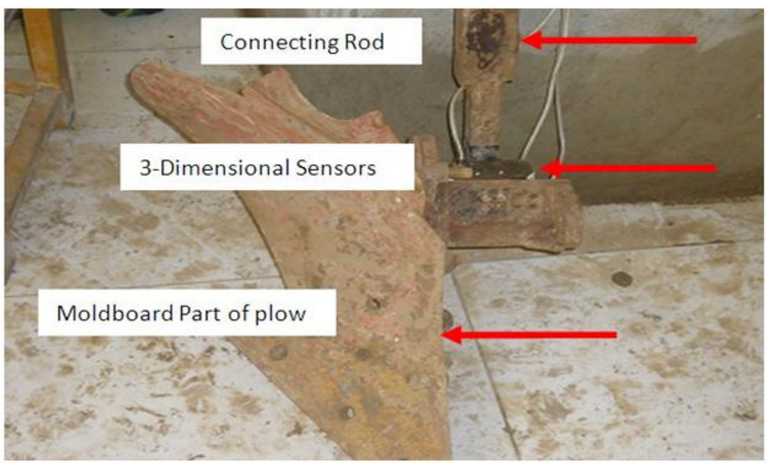

Figure 1 (b) three dimensional sensors with mouldboard plough and connecting rod.

Table 1 Tillage tool and soil parameters of soil bin soil

Parameters	Values of Parameters
Share Width of plough (cm)	36
Height of plough (cm)	26.5
Operating depths (cm)	5, 10, 15 (d1, d2 and d3)
Speed of mouldboard plough ($m.s^{-1}$)	1, 1.5 and 2 (S1, S2, and S3)
Soil Texture	Silt clay soil (Sand 11%, Silt 47% and clay 42%)
Plough angle (^{0})	90
Moisture content of paddy soil (%)	27, 30 and 33
Bulk Density ($g.cm^{-3}$)	1.54, 1.56 and 1.59
Soil internal frictional angle(^{0})	5.5, 5 and 4
Soil cohesion (kpa)	3, 1.9 and 1

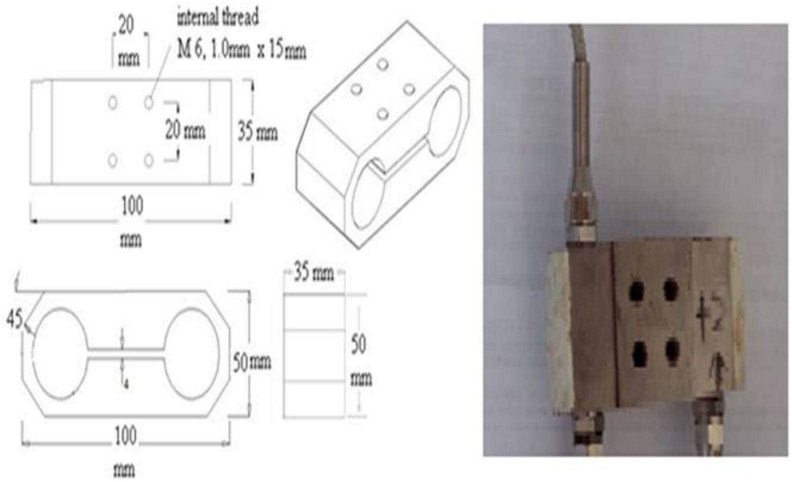

Figure 3. Thematic diagram and LD-80 Octagonal transducer

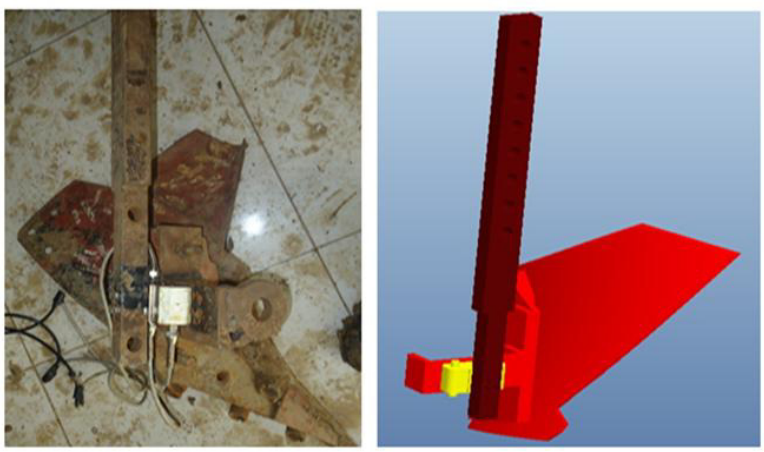

Figure 4 LD-80 Octagonal transducer attached with mouldboard plough

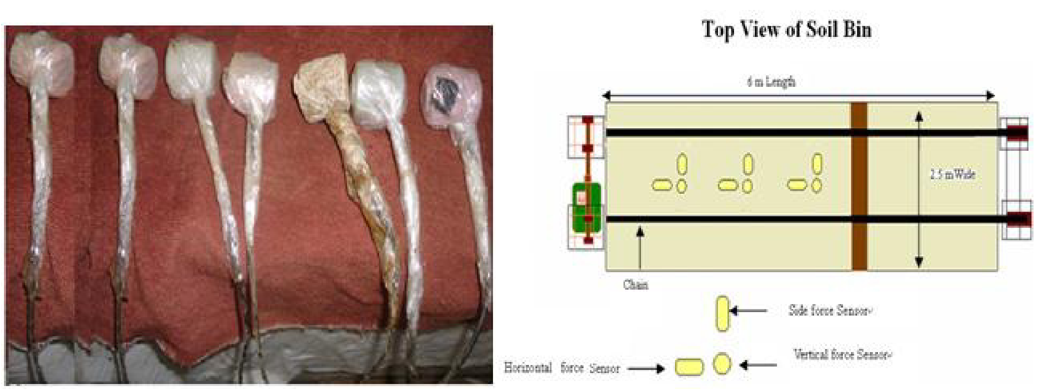

Figure 5 Series of soil deformations sensors (JP-1 force sensors) and thematic diagram of measuring soil deformation force

Figure 6 (a) Soil deformation sensor buried in soil

Figure 6 (b) Interaction of deformation sensor with plough

Fz = Side draught force

Data Acquisition System

LabView software was used to acquire the signal data from the sensors. These sensors were calibrated prior to the experiments, as described by Mari et al. (2014) and Tagar et al. (2014). Amplification was done before inputting data to LabView to reduce noise and improving signal quality. Data acquisition card were used to transfer signals from sensor to LabView in required format. A program was written in LabView according to the calibration of sensors to convert signals from sensor into force date. The output was monitored on software display as well as recorded into an excel sheet.

Statistically analyses

This study was designed as 3x3x3 factorial CRD (soil moisture3x operating speed x depth of tool). All data were analyzed through SPSS (ver. 16, SPSS, Inc., Chicago, IL, USA. Significance for differences between the treatments means were examined by analyses of variance (ANOVA), with a probability of 5%.

RESULTS AND DISCUSSIONS

Soil Deformation force in three directions (Dx, Dy and Dz)

Figure 7 (a) shows the variations in soil deformation force were observed with different treatments. Results showed that maximum soil deformation in horizontal direction (Dx) of 95.25 N was observed at 2 m/s speed and depth of 15 cm under 27 % moisture content. The overall trend of soil deformation forces on Dx was similar as reported Sharifat and Kushwaha (2000). On the other hand soil deformation force significantly ($p<0.05$) reduced to 35.33 N when moisture content was increased to 33 % showing the negative impact of moisture content on soil deformation forces. Minimum impact of moisture was observed when soil moisture was increased from 30% to 33% at 5 cm depth and 1 m/s speed where Dx reduced by 27.32 % resulting minimum value of 12.02 N among all treatments. Only 15 % increase in soil deformation force Dx was observed at 15 cm depth under 27 % moisture content. This was the least impact increasing speed found under

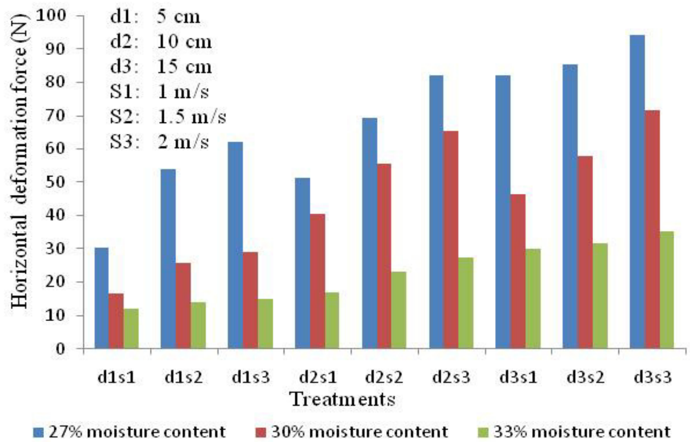

Figure 7 (a) Horizontal deformation forces under different moisture content and treatments

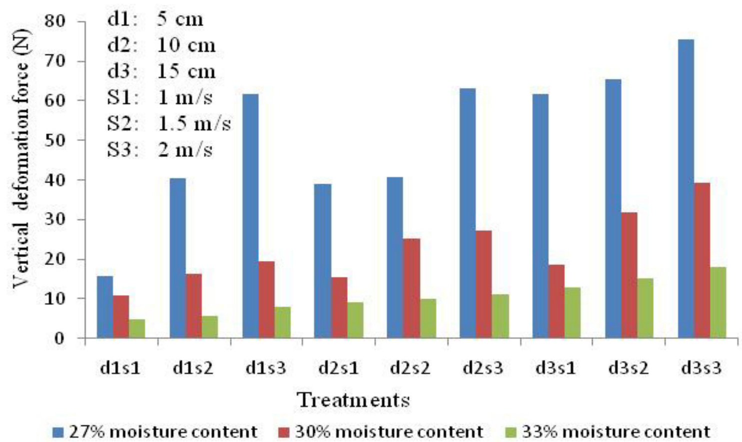

Figure 7 (b) Vertical deformation forces under different moisture content and treatments

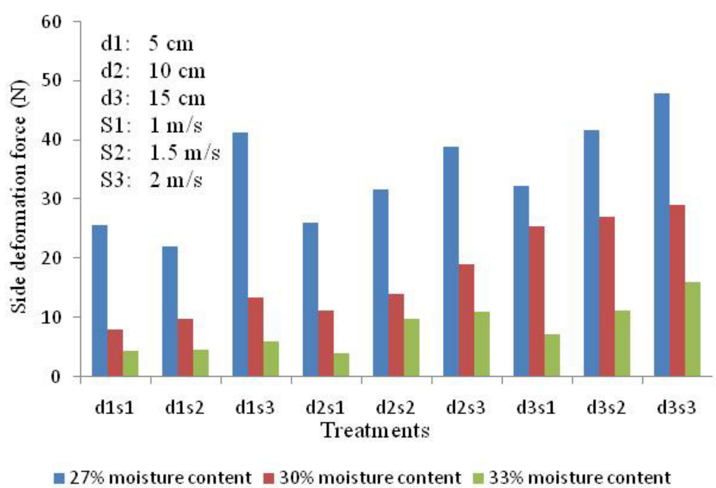

Figure 7 (c) Side deformation forces under different moisture content and treatments

Table 2 Means comparison of the soil deformation in different depths and moisture contents

depths	Deformation of soil N(Dx) 27% M.C	30% M.C	33% M.C	Deformation of soil N(Dy) 27% M.C	30% M.C	33% M.C	Deformation of soil N(Dz) 27% M.C	30% M.C	33% M.C
5	49.136	23.793	13.834	34.193	15.489	6.362	29.718	10.318	4.969
10	67.496	53.818	22.746	47.355	22.7857	10.301	32.489	14.779	8.078
15	95.604	58.543	32.365	72.947	30.046	15.268	44.919	27.579	11.545

Table 3 Means comparison of the soil deformation in different depths and speeds

Depth	Deformation of soil N(Dx)			Deformation of soil N(Dy)			Deformation of soil N(Dz)		
cm	1 m/s	1 m/s	1.5 m/s	2 m/s	1 m/s	1.5 m/s	1 m/s	1.5 m/s	2m/s
5	19.6	31.601	35.559	10.05	20.883	24.715	8.12	12.212	20.213
10	36.433	49.494	58.068	21.334	25.603	33.502	13.886	18.267	23.189
15	53.946	61.234	71.334	32.276	40.941	45.013	22.001	29.052	32.901

Table 4 Means comparison of the soil deformation in different speeds and moisture contents

Speed	Deformation of soil N(Dx)			Deformation of soil N(Dy)			Deformation of soil N(Dz)		
	27% M.C	30% M.C	33% M.C	27% M.C	30% M.C	27% M.C	30% M.C	33% M.C	27% M.C
1 m/s	55.8	34.327	19.877	40.161	14.879	9.012	28.12	15.201	5.194
1.5 m/s	72.891	46.391	23.048	52.485	24.598	10.345	34.092	16.935	8.483
2 m/s	83.513	55.438	26.011	61.843	28.803	12.585	44.945	20.521	10.916

during study. On the other end maximum speed impact on soil deformation forces was observed at 5 cm depth under 27 % moisture content with 103.68 % increment. Maximum depth effect on soil deformation was observed at 1m/s speed and 30 % moisture content as 181.2 % increment in Dx and minimum at 27 % moisture content and 2 m/s with 52.01 % increase similar trend was observe by (Urbán, márton *et al*. 2012; Karmakar *et al*. 2005).

The result of the vertical deformation forces (Dy) showed that positive impact of speed and depth was observed on vertical direction (Dy) when minimum value of 5.03 N observed at d1s1with 33% moisture content and maximum value of 75.75 N was observed at15 cm depth and 2 m/s speed with 27 % moisture content shown in figure 7 (b). Lowest values of forces were observed at 33 % moisture content whereas 30 % moisture content curve remain in between the 27 and 33% moisture as shown in figure 7 (b).

Figure 7(c) showed side deformation forces (Dz) represented which similar trends as horizontal and vertical forces in term of speed, depth and moisture content being maximum 178.49 % at 10 cm depth (D2)under 33% moisture content conditions whereas it was minimum at 15 cm depth (D3) under 30 % moisture content conditions. Side deformation force was increased by 218.27 % due to depth at 30% moisture content with forward speed of 1 m/s (S1) and 16.36 % increment was observed at 27 % moisture content with forward speed of 2 m/s (S3) results are agreement with Zhu *et al*., 2012; White *et al*., 2003).

From the tables 2 to 4., according to the Duncan's multiple range test results showed that, the values of soil deformation in Dx, Dy and Dz deformations was different in different operating experimental parameters in soil bin. Our all it was observed that increasing depth has more impact on the soil deformation forces as compare to increase in speed or moisture content.

Total draught forces of mouldboard plough in three dimensions (Fx, Fy and Fz)

Results showed that maximum draught forces (Fx) 6.15kN was observed at 2 m/s speed (S3) and depth of 15 cm (D3) under 27 % moisture content which was reduced by 3.84 kN when moisture content was increased to 33 % resulting in negative impact of moisture content shown in figure 8 (a). Minimum impact of moisture was observed when it was increased from 27% to 30% at 10cm depth (D2) and 1 m/s

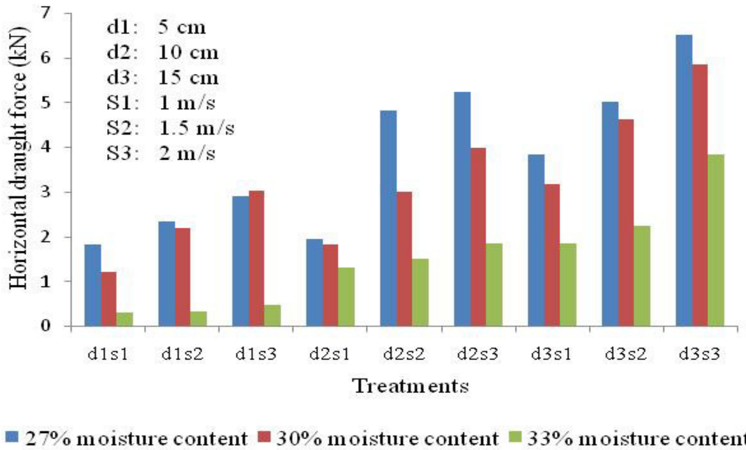

Figure 8 (a) Horizontal draught forces under different moisture content and treatments

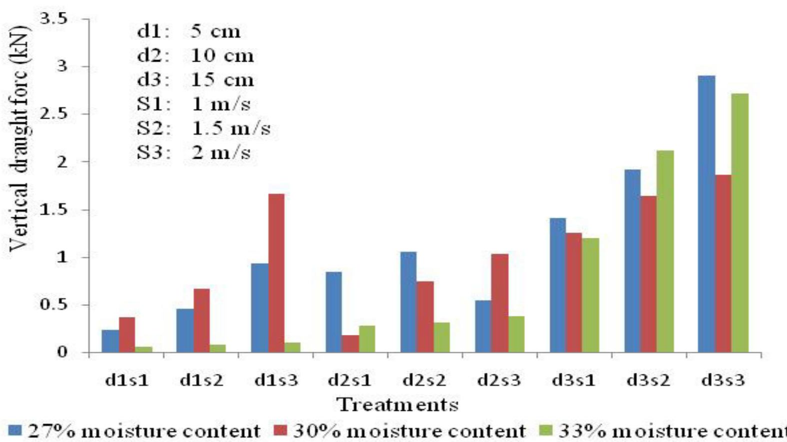

Figure 8 (b) Vertical draught forces under different moisture content and treatments

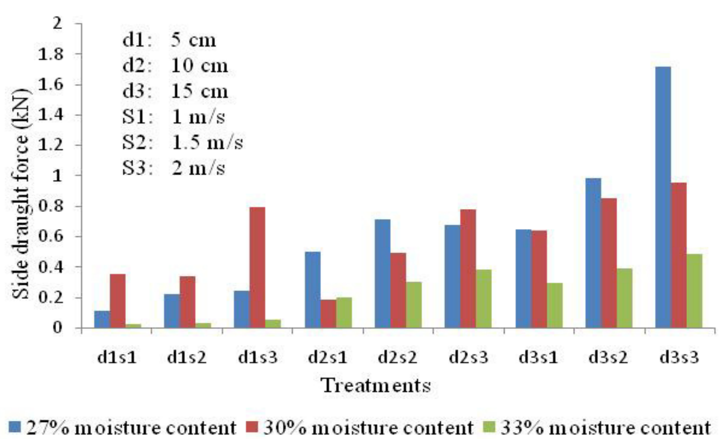

Figure 8 (c) Side draught forces under different moisture contents and treatments

Table 5. Means comparison of the draught force on mouldboard plough depth and moisture contents (Fx, Fy and Fz).

Depths Cm	Draught force kN (Fx)			Vertical force kN (Fy)			Side force kN (Fz)		
	27% M.C	30% M.C	33% M.C	27% M.C	30% M.C	33% M.C	27% M.C	30% M.C	33% M.C
5	2.392	2.179	0.376	0.545	0.894	0.091	0.197	0.497	0.04
10	4.422	2.975	1.588	0.837	0.661	0.342	0.629	0.496	0.291
15	5.113	4.588	2.572	2.071	1.592	2.299	1.135	0.826	0.395

Table 6. Means comparison of the draught force on mouldboard plough moisture content and speeds (Fx, Fy and Fz)

Moisture content (%)	Draught force kN (Fx)			Vertical force kN (Fy)			Side force kN (Fz)		
	1 m/s	1.5 m/s	2 m/s	1 m/s	1.5 m/s	2 m/s	1 m/s	1.5 m/s	2 m/s
27	2.981	4.036	4.91	0.835	1.147	1.47	0.433	0.637	0.891
30	2.083	3.299	4.359	0.602	1.023	1.521	0.396	0.574	0.849
33	1.171	1.384	1.981	0.759	0.863	1.11	0.173	0.24	0.312

Table 7 Means comparison of the draught force on mouldboard plough depth and speeds (Fx, Fy and Fz).

Depths cm	Draught force kN (Fx)			Vertical force kN (Fy)			Side force kN (Fz)		
	1 m/s	1.5 m/s	2 m/s	1 m/s	1.5 m/s	2 m/s	1 m/s	1.5 m/s	2 m/s
5	1.121	1.628	2.198	0.222	0.404	0.904	0.166	0.203	0.364
10	2.141	3.113	3.731	0.452	0.724	0.664	0.3	0.5	0.616
15	2.973	3.978	5.32	0.533	1.523	1.906	0.535	0.748	1.072

speed (S1) where Fx reduced 6.06 % whereas this reduction was 84.93 % when moisture content was increased from 30 to 33% at d1s2. Lowest Fx value of 0.3 kN was observed at 5 cm and 1 m/s on 33 % moisture content. Positive impact of moisture was positive only at d1s3 when moisture was increased from 27 to 30% moisture content with 4.07% the draught force significantly(<0.05) increase in Fx. Speed observed positive impact on Fx with 148.76% increase at 5 cm depth (D1) under 27 % moisture content conditions where as minimal increase was found 10 cm depth with 33 % moisture. Fx increased with depth up to 734.78 % at 2 m/s speed under 33 % moisture and minimum increase was observed at depth (5 cm) 109.69 % at 1 m/s speed and 27 % moisture the result was agreement with (Plouffe *et al.*, 1999; Iraj Ranjbar *et al.* 2013; Taniguchi et al., 1999).

The results of vertical direction forces (Fy) showed that positive impact of speed and depth was observed on vertical direction where minimum value of 0.06 kN observed at 5 cm depth and 1 m/s speed with 33% moisture content and maximum value of 2.898kN was observed at 15 cm depth and 2 m/s speed with 27 % moisture content. Lowest values of forces were observed at 33 % moisture content whereas 30 % moisture content curve fluctuate in between 27 % and 33 moisture as shown in figure 8 (b).

Figure shows 8 (c) side draught forces of plough (Fz) represented similar trends as vertical direction (Fy) in term of speed, depth and moisture content. Maximum effect of speed was observed to be 333.33 % at 10 cm depth under 30% moisture content conditions whereas it was least at 10 cm depth under 27 % moisture content conditions. Deformation force was increased 1350 % due to depth at 33 % moisture content with forward speed of 1 m/s and 20.25 % increment was observed at 30 % moisture content with forward speed of 2 m/s the result was agreement with (Naderloo *et al.*, 2009; Olatunji *et al.*, 2009; Makanga *et al.*, 1997; Suministrado *et al.*, 1990).

Mean comparisons of 3-dimensins draught forces due to depth, speed and moisture content were represented in Table 5, 6 and 7.According Duncan's multiple range test draught forces in three dimensions (Fx, Fy and Fz) was significantly affected ($p<0.05$) by factors i.e. moisture content, speed and depth; at all levels. Interactional effect between speed and moisture content, depth and moisture content, speed and depth were also significant. Table 5 presents the interaction effect of moisture content. Draught force decrease with increased of moisture content (Fx (2.392 to 0.37 KN), Fy (0.54 to 0.09) and Fz) and while the draught force increase with increasing operating speed of plough (Fx (2.392 to 0.37 KN), Fy (0.54 to 0.09) and Fz (0.19 to 0.04)).

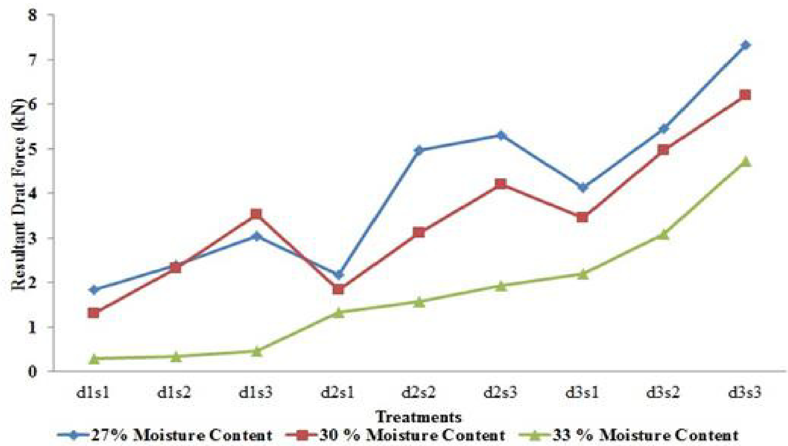

Figure 9 Resultant draught forces under different moisture content

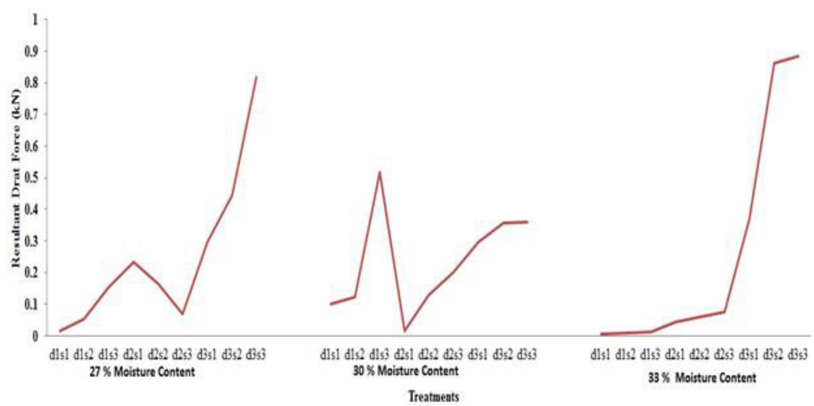

Figure 10 Difference between Draught force (Fx) Resultant draught forces (F)

Meanwhile, interactional effects of depth x Moisture content, moisture content x speed and depth x speed and moisture content x depth x speed ($p<0.05$) draught force, vertical force and side force shown in 5 to 7. However, we have to notice that moisture content and depth has more impact effect on the draught force then vertical force and side force subsequently speed. The comparison of moisture content, depth and speed in paddy soil has very little work is published (Zhai, 2011; Chandio, 2013).

Resultant Draught Forces (F)

It was the actual draught force required by implement. Magnitude was calculated and represented in figure 9. It was observed that resultant draught force (F) increased with depth as well as speed whereas it was decreased with increase in soil moisture content. At 5 cm depth and 2 m/s speed the F was slightly higher and non significant (>0.05) of F was found at 30 % moisture as compare to at 27 % due to side force reaction which had much higher value at 30 % moisture.

Draught force (Fx) which normally considered as total draught force were smaller than resultant or actual draught force (F) and this difference was represented in (figure 10) where with increasing speed and depth the difference magnitude was increasing and it decreased with increasing moisture content except at 33 % moisture content and 15 cm depth where it increased significantly (<0.05) with speed as compare to depth and soil moisture content.

CONCLUSION

Deformations of soil force have direct relationship with speed and depth with dominant effect of depth and inverse relation with moisture content. Draught forces also exhibit similar trend with speed and depth. Draught force at 33 % moisture was less as compare to 27 % moisture content whereas 30 % moisture content curves fluctuate between other two moisture content curves. Resultant draught force also increased with speed and depth whereas it decreased with moisture content. The difference between draught force (Fx) and resultant draught force was more at higher speed and depth as well as higher moisture. Resultant draught force was higher than horizontal force so it should be given importance as compare to horizontal draught force.

ACKNOWLEDGMENTS

Authors are grateful to National Natural Science Foundation of China for their financial support Via-grant number 51275250.

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