Study of tractive efficiency as an effect of ballast and tire inflation pressure in sandy loam soil

Pravin Prakash Jadhav[1*], Ajay Kumar Sharma[2], Sachin Vilas Wandkar[1], Babasaheb Sukhdeo Gholap[1]

(1. *Farm Machinery Testing and Training Centre, Dr. A. S. College of Agricultural Engineering, MPKV, Rahuri (MS), India* 413 722;
2. *Department of Farm Machinery and Power Engineering, College of Technology and Engineering, MPUAT, Udaipur (RJ), India* 313 001)

Abstract: The experiments were conducted in sandy loam soil in stubble field. Tillage operations were performed using 55 hp tractor with two bottom mouldboard plough and disc plough for four combinations of rear and front ballast (i.e. no ballast, 90 daN front, 90 daN front and 200 daN rear, 200 daN rear) and four combinations of inflation pressure in front and rear tires (i.e. 90 kPa rear and 140 kPa front, 90 kPa rear and 200 kPa front, 130 kPa rear and 140 kPa front and 130 kPa rear and 200 kPa front tire) to study their effects on tractive efficiency of tractor for primary tillage operations. The test was conducted at recommended speed of operation 2.7 - 4 km h^{-1}. It was found from the results that combination of 200 daN rear ballast and inflation pressure of 130 kPa at rear, 200 kPa at front was found suitable for improving the performance of agricultural tractor with maximum tractive efficiency of 72.43% and 71.27% for mouldboard plough and disc plough respectively.

Keywords: tractor, ballast, inflation pressure, plough, tractive efficiency, sandy loam, primary tillage

Citation: Jadhav, P.P., A.K. Sharma, S.V. Wandkar, and B. S. Gholap. 2013. Study of tractive efficiency as an effect of ballast and tire inflation pressure in sandy loam soil. Agric Eng Int: CIGR Journal, 15(2): 60−67.

1 Introduction

India is predominately an agricultural country. Agriculture continues to remain a significant sector of the Indian economy. Mechanization of agriculture is an essential input to the modern agriculture which leads to reduced human drudgery and enhanced agricultural productivity. During the last 50 years the average farm power availability in India has increased from about 0.30 kW/ha in 1960-61 to about 1.73 kW/ha in 2009-10 (Singh et al., 2011).

Now a day's most of the agricultural operations are carried out using tractor to improve pull and propulsion. A tractor is also intended to provide transport option with trailer for movement of materials and for field operations to power and propel agricultural heavy draft machines. For field work, the tractor is often used for tasks requiring high drawbar forces at lesser speeds (Alcock, 1986). Thus, the tractor must interface with the implement for providing the operating parameters necessary to meet the performance objectives for field work functions.

Tillage machinery requires large amount of power for adequate operation, the operations are costly operations among all the agricultural operations (Dahab and Mohamed, 2002). It is well known that among many tractors, tractor ballast and inflation pressure individually and in combination affect the tractor performance in terms of tractive efficiency, drawbar force, slippage, field capacity etc.

Increasing the ballast on pneumatic tires, up to a certain weight, improves the tractor performance as judged by its speed, fuel consumption and wheel slip. Coefficient of traction increases with increase in normal load up to certain value of slip beyond which it decreases with increase in normal load (Sharma and Pandey, 1997).

Received Date: 2012-12-13 **Accepted Date:** 2013-04-02
***Corresponding Author: Pravin Prakash Jadhav,** Farm Machinery Testing and Training Centre, Mahatma Phule Krishi Vidyapeeth, Rahuri (MS), India 413 722, Email: pravin.jadhav111 @gmail.com.

A tractor with an over ballast burns more fuel than it should because of high torque requirement and also the premature drive train problems. An under ballast tractor experiences tire tread wear due to excessive wheel slip. The effective field capacity is reduced and the farmer spends more time and money in agricultural operations. Therefore the optimum ballasting is required to the minimum power lost during a tillage operation (Casady, 1997).

Inflation pressure determines tire stiffness, which has a significant influence on the ground contact area of the tire and pressure distribution over the contact surface. Adjusting tire inflation pressure has been used as a means of reducing soil compaction and improving the tractive performance and drawbar characteristics of agricultural tractors. Effects of inflation pressure on ground contact pressure, pressure beneath the tire, drawbar characteristics as well as tractive efficiency have been considered by many researchers (Raper et al., 1995; Jun et al., 2004). The reduced tire inflation pressure of appropriate tire types can improve the drawbar characteristics and consequently fuel consumption (Smerda and Cupera, 2010).

Despite of this, it has been observed that farmers more commonly use ballast for stability of the tractor rather than improving its performance especially for the heavy draft operations. Also inflation pressure is maintained in the tires keeping in mind the regular use of tractor and personal experience of the tractor operator. This leads to higher fuel consumption and lower field capacity and efficiency of tractor and implement finally resulting in the economic loss to the farmer. There is less information available for the correct tire inflation pressure and ballast combination for primary tillage operations in the region. Moreover, the tractor manufacturers do not mention the suitable ballast combination and suitable tire inflation pressure for different drawbar pull for better tractive efficiency, less fuel consumption and slip.

Keeping this in view, the study was planned to find suitable combinations of tractor ballast and inflation pressure especially for heavy draft operations which require more energy to improve tractor performance. The outcome of the study will help the users and manufacturers to maximize the tractor implement performance thereby increasing the profits from agriculture. The specific objective of this study is to study the effect of ballast and tire inflation pressure on tractive efficiency for primary tillage operations using mouldboard plough and disc plough in sandy loam soil.

2 Material and Methods

The experiments using factorial RBD were conducted at Instructional Farm at College of Technology and Engineering, MPUAT, Udaipur, Rajasthan, India. The experiments were carried out in stubble field left after harvesting of maize crop. The soil parameters such as moisture content, soil cone index and bulk density were measured at the various locations before the experiments (Table 1). These parameters were measured using digital cone penetrometer (Accuracy+ 0.5” (+ 1.25 cm), + 15 PSI (+ 103 kPa)), digital soil moisture meter and core cutter. Tillage operations were performed using 55 hp (JD 5310) tractor with two bottom mouldboard plough and disc plough (Table 2). The various combinations of rear and front ballast (i.e. no ballast, 90 daN at front, 90 daN at front and 200 daN at rear, 200 daN at rear) (1 daN = 10 N = 1 kg) and inflation pressures in front and rear tires (i.e. 90 kPa rear and 140 kPa front, 90 kPa rear and 200 kPa front, 130 kPa rear and 140 kPa front, and 130 kPa rear and 200 kPa front tires) were considered for the experiments. These inflation pressures were adjusted at every experiment without change of tires. These values were based on

Table 1 Properties of experimental soil

Soil type	Sandy loam soil
Bulk density / gm cc^{-1}	1.7
Soil moisture content / % (Dry basis)	15
Cone index / kPa	839.16
Previous crop	Maize

Table 2 Specifications of primary tillage implements used for experiments

Implement	Width/mm	Specifications
Mouldboard plough	700	General purpose type, one way plough, two bottoms in the frame each of width 350 mm
Disc plough	800	Two discs each of 630 mm diameter with tilt angle of21°, disc angle 44°

weight distribution of front and rear wheel for ballast and tractor manufacturer recommendations for inflation pressure. The tests were conducted at recommended speed of operation ranging between 2.7 to 4 km h^{-1} (Indian Standard: 9253, 2001).

2.1 Field Layout

A 150 × 80 m size field was selected for the experiments. Field was divided into two parts of 150 × 40 m size as shown in Figure 1.

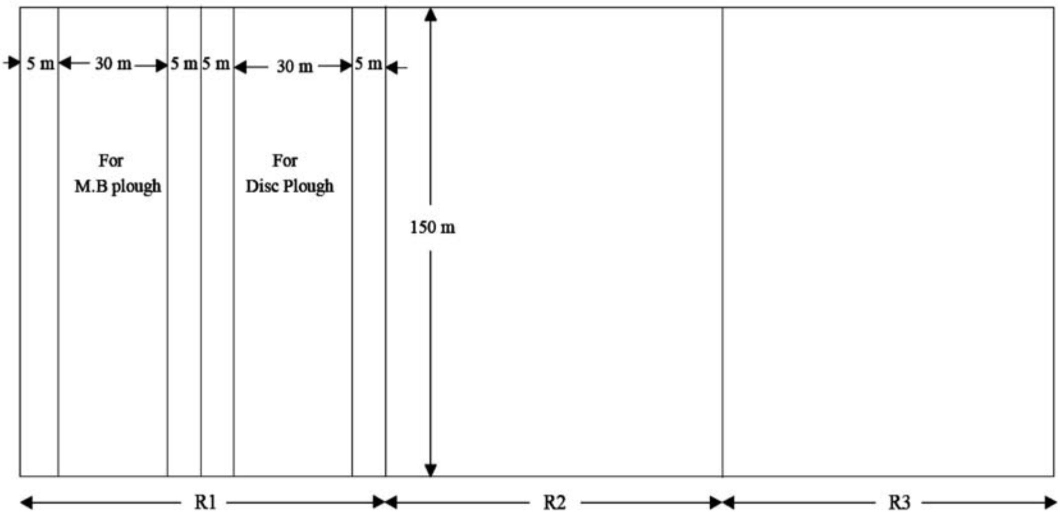

Figure 1 Field layout for experiments

2.2 Measurement of different parameters during experiment

Experiments were conducted to study the effect of different combinations of ballast and inflation pressure on tractive efficiency for two primary tillage implements. Procedure for measurement of different parameters during experiments is presented in the text below.

2.2.1 Tractive efficiency

It is defined as the ratio of output power to the input power for a traction device. It is the measure of efficiency with which the traction device transforms the torque acting on the axle into linear drawbar pull. It was calculated using Equation (1), Equation (2) and Equation (3) (Barger et. al., 1967).

$$TE = \frac{P \times Va}{T \times \omega} \quad (1)$$

where, TE = tractive efficiency, %; P = pull, N; T = wheel torque (input), N-m; ω = wheel rotation, rad s^{-1}; and Va = actual speed, m s^{-1}.

$$TE = \frac{P \times Va}{T \times V/r} = \frac{P}{F} \times (1-s) \quad (2)$$

where, F = gross thrust force acting on the wheel (P + R), N; Vt = theoretical velocity, m s^{-1}; r = radius of wheel, m; s = slip (decimal) and R = rolling resistance, N.

Thus,

$$TE = \frac{P}{P+R}(1-s) \quad (3)$$

2.2.2 Speed of travel

The speed of operation was measured in field by fixing two poles in the test plot 30 m apart. Time required to cover the 30 m distance was measured with the help of stopwatch and speed of operation in km h^{-1} was calculated from an average of 5 readings. The forward speed during the experiments usually ranged between 2.7 km h^{-1} to 4 km h^{-1}.

2.2.3 Measurement of rolling resistance

Rolling resistance of a tractor was measured by a dummy tractor towing the test tractor through load cell connected in between with digital load indicator. Rear tractor kept in neutral position while the front tractor pulled the rear one. The reading of load indicator was noted from digital indicator at fixed interval of time. An average of 5 readings was considered in computing the force required to pull a tractor.

2.2.4 Draft

To determine the draft of implement load cell with digital indicator was used. Load cell was placed in between two tractors as shown in Figure 2 and implement was hitched to the rear tractor. The gear of the rear tractor was kept in neutral position and implement hitched behind the tractor and desirable depth was given with hydraulic control lever. Front tractor pulled the rear tractor with implement as shown in Figure 3. The reading of load indicator was recorded from digital load indicator. The difference of calculated draft and rolling resistance was taken as draft of implement for further calculations.

Figure 2 Draft measurement setup

Figure 3 Measurement of draft of the implement during the field experiments

2.2.5 Slip calculation

Time required to cover 30 m distance on zero condition (smooth tar road) was measured and theoretical speed of operation was calculated from an average of 5 readings. The actual speed of operation was calculated as described above. The slip was calculated as:

$$s = \frac{Vt - Va}{Vt} \quad (4)$$

where, S = slip, (decimal); Va = Speed of tractor in a field, m s^{-1} and Vt = Speed of tractor on hard surface, m s^{-1}.

3 Results and Discussion

The various tests were conducted in stubble field condition after harvesting of maize crop to study the effect of ballast and tire inflation pressure on the tractive efficiency of the tractor for primary tillage operations. The performance of agricultural tractor was tested using the primary tillage implements (mouldboard plough and disc plough) at four different ballast conditions viz. no ballast, 90 daN at front, 90 daN at front and 200 daN at rear and 200 daN at rear axle and four different inflation pressure combinations viz. 90 kPa rear and 140 kPa front, 90 kPa rear and 200 kPa front, 130 kPa rear and 140 kPa front, and 130 kPa rear and 200 kPa front tires respectively with operating speed 2.8 km/h. Based on results, the analysis of variance was carried out using factorial RBD to find out the significant difference between various treatments.

3.1 Effect of ballast on tractive efficiency for mouldboard plough

The analysis of variance shows that the main and their interaction effects of plough, ballast and inflation pressure were highly significant on tractive efficiency (Table 3). The relationship between ballast and tractive efficiency for mouldboard plough at different inflation pressure combinations is shown in Figure 4. It is evident from the curves that the tractive efficiency increases gradually with increase in ballast. Table 4 shows that the average increase in tractive efficiency is 15.90% with increase in ballast from no ballast condition to 200 daN rear ballast condition for mouldboard plough at all inflation pressures. The results confirm the findings of Burt et al., (1980) that tractive efficiency is affected by dynamic load on tire.

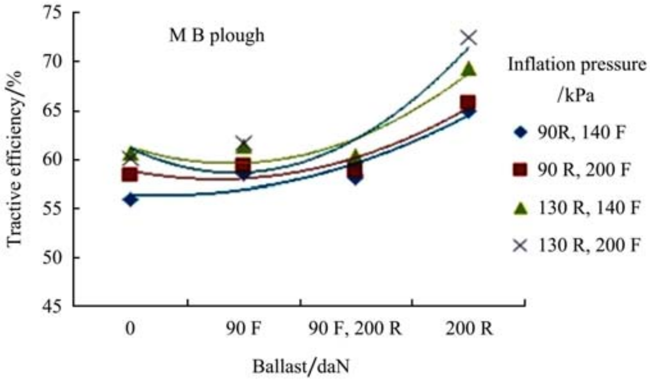

Figure 4 Relationship between ballast and tractive efficiency for mouldboard plough at different inflation pressure combinations

Table 3 Analysis of variance for plough, ballast and inflation pressure on tractive efficiency

S N	SOURCE	DF	SS	MS	F	SE	CD
1	Plough	1	454.527	454.527	827365.335**	0.003	0.013
2	Ballast	3	970.914	323.638	589111.250**	0.005	0.018
3	Inflation pressure	3	67.2039	22.4013	40776.6220**	0.005	0.018
4	Plough × Ballast	3	67.8535	22.6178	41170.7300**	0.007	0.025
5	Plough × Inflation pressure	3	62.5848	20.8616	37973.9370**	0.007	0.025
6	Ballast × Inflation pressure	9	47.6537	5.29485	9638.10200**	0.010	0.036
7	Plough × Ballast × Inflation pressure	9	17.2799	1.91998	3494.90500**	0.014	0.051
8	Error	62	0.03406	0.000549			

Note: ** Significant at 1% level, GM = 63.742 (63.742), CV = 0.037.

Table 4 Mean values showing the two variable interaction effects of plough and ballast on tractive efficiency (per cent)

Plough	Ballast / daN				Mean
	0	90 F	90 F + 200 R	200 R	
Mouldboard plough	58.792	60.229	59.102	68.140	61.566
Disc plough	62.955	64.768	65.825	70.122	65.918
Mean	60.873	62.498	62.463	69.131	63.742

Note: CV = 0.037, CD = 0.025.

The experimental data were analyzed using a nonlinear regression technique to obtain the best fit values of coefficient a_{1MPTE}, a_{2MPTE} and a_{3MPTE} in the generalized form of a second degree of polynomial as shown in Table 5.

$$TE = a_{1MPTE} + a_{2MPTE}B + a_{3MPTE}B^2 \quad (5)$$

where, TE = Tractive efficiency, %; B = Ballast, daN; a_{1MPTE}, a_{2MPTE} and a_{3MPTE} = regression coefficients.

The R^2 values reported in the Table 5 indicate that the experimental data fit the Equation (5) very well.

Table 5 Coefficients of an estimated multiple regression $TE = a_{1MPTE} + a_{2MPTE} B + a_{3MPTE}B^2$ to describe the response of ballast (daN) on tractive efficiency (per cent) for primary tillage (Mouldboard plough)

Plough	Inflation Pressure/kPa	a_{1MPTE}	a_{2MPTE}	a_{3MPTE}	R^2
Mouldboard plough	90 R, 140 F	58.19	-2.835	1.102	0.88
	90 R, 200 F	62.59	-5.212	1.470	0.87
	130 R, 140 F	66.96	-7.793	2.062	0.87
	130 R, 200 F	69.56	-11.38	2.962	0.82

3.2 Effect of ballast on tractive efficiency for disc plough

The relationship between ballast and tractive efficiency for disc plough at different inflation pressure combinations is shown in Figure 5. It is evident from the curves that the tractive efficiency increases gradually with increase in ballast. Tractive efficiency is more with adding ballast at rear for 130 kPa rear, 200 kPa front tire inflation pressure combination.

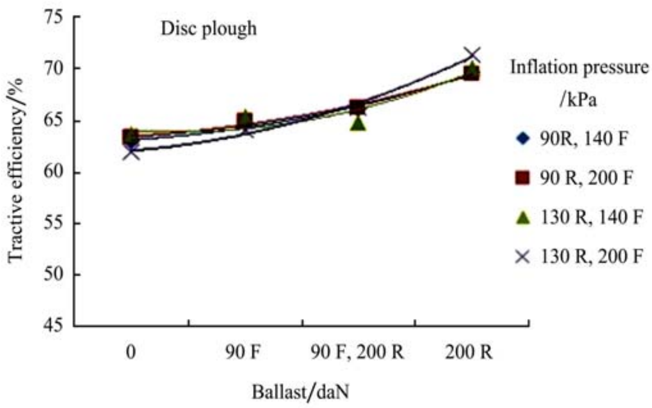

Figure 5 Relationship between ballast and tractive efficiency for disc plough at different inflation pressure combinations

The two variable interaction effect for disc plough (Table 4) shows that there was a significant difference in tractive efficiency at no ballast, 90 daN front, 90 daN front and 200 daN rear and 200 daN rear axle ballast conditions. Table 4 shows that the average increase in tractive efficiency is 11.38 per cent with increase in ballast from no ballast condition to 200 daN rear ballast condition for disc plough at all inflation pressures. The results confirm the findings of Burt et al. (1980).

The experimental data were analyzed using a nonlinear regression technique to obtain the best fit values of coefficient a_{1DPTE}, a_{2DPTE} and a_{3DPTE} in the generalized form of a second degree of polynomial as shown in Table 6.

$$TE = a_{1DPTE} + a_{2DPTE} B + a_{3DPTE} B^2 \quad (6)$$

where, TE = Tractive efficiency, %; B = Ballast, daN; a_{1DPTE}, a_{2DPTE} and a_{3DPTE} = regression coefficients.

The R^2 values reported in the Table 6 indicate that the experimental data fit the Equation (6) very well.

Table 6 Coefficients of an estimated multiple regression $TE = a_{1DPTE} + a_{2DPTE} B + a_{3DPTE} B^2$ to describe the response of ballast (daN) on tractive efficiency (per cent) for primary tillage (Disc plough)

Plough	Inflation Pressure/kPa	a_{1DPTE}	a_{2DPTE}	a_{3DPTE}	R^2
Disc plough	90 R, 140 F	62.86	-0.232	0.471	0.98
	90 R, 200 F	63.20	-0.203	0.437	0.98
	130 R, 140 F	65.58	-2.413	0.858	0.86
	130 R, 200 F	61.89	-0.564	0.719	0.99

3.3 Effect of inflation pressure on tractive efficiency for mouldboard plough

The analysis of variance shows that the main and their interaction effects of plough, ballast and inflation pressure were highly significant on tractive efficiency (Table 3).

The relationship between inflation pressure and tractive efficiency for mouldboard plough at different ballast conditions is shown in Figure 6. It is evident from the curves that the tractive efficiency increases gradually with increase in inflation pressure. This was more dominant at 200 daN rear ballast conditions.

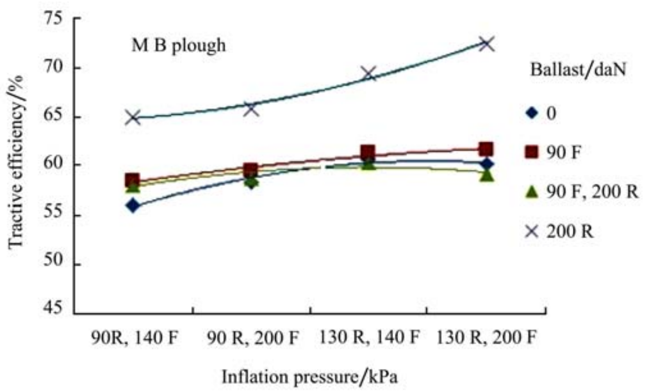

Figure 6 Relationship between inflation pressure and tractive efficiency for mouldboard plough at different ballast conditions

The two variable interaction effect for mouldboard plough (Table 7) shows that there was a significant difference in tractive efficiency when tire inflation pressure increased from at 90 kPa rear, 140 kPa front to 130 kPa rear, 200 kPa front tire inflation pressure combination. Table 7 shows that the average increase in tractive efficiency was 6.67 per cent for similar with increase in inflation pressure for mouldboard plough at all ballast conditions.

Table 7 Mean values showing the two variable interaction effect of plough and inflation pressure on tractive efficiency/%

Plough	Inflation Pressure / kPa				Mean
	90 R, 140 F	90 R, 200 F	130 R, 140 F	130 R, 200 F	
Mouldboard plough	59.378	60.594	62.955	63.336	61.566
Disc plough	65.820	65.978	65.993	65.880	65.917
Mean	62.599	63.286	64.474	64.608	63.742

Note: CV = 0.037, CD = 0.025.

It is clear from Table 8 that for mouldboard plough there was no significant difference in tractive efficiency at 130 kPa front and 140 kPa rear and 130 kPa rear, 200 kPa front tire inflation pressure at 90 daN ballast condition. The results confirm the findings of Burt et al. (1980). This may be similar to findings of Casady (1997) that addition of front ballast reduces weight at rear which caused decrease in tractive efficiency.

Table 8 Mean values showing the three variable interaction effect of plough, ballast and tire inflation pressure on tractive efficiency / %

Plough	Ballast /daN	Inflation pressure / kPa			
		90 R, 140 F	90 R, 200 F	130 R, 140 F	130 R, 200 F
Mouldboard plough	0	55.95	58.39	60.66	60.16
	90F	58.47	59.46	61.37	61.61
	90F, 200R	58.09	58.79	60.40	59.13
	200R	65.00	65.73	69.38	72.44
Disc plough	0	62.97	63.31	63.62	61.91
	90F	64.68	64.93	65.42	64.04
	90F, 200R	66.01	66.15	64.84	66.27
	200R	69.60	69.52	70.07	71.27

Note: CD = 0.051.

The experimental data were analyzed using a nonlinear regression technique to obtain the best fit values of coefficient a_{1MBTE}, a_{2MBTE} and a_{3MBTE} in the generalized form of a second degree of polynomial as shown in Table 9.

$$TE = a_{1MBTE} + a_{2MBTE} P + a_{3MBTE} P^2 \quad (7)$$

where, TE = Tractive efficiency, %; P = Inflation pressure, kPa; a_{1MBTE}, a_{2MBTE} and a_{3MBTE} = regression coefficients.

The R^2 values reported in the Table 9 indicate that the experimental data fit the Equation (7) very well.

Table 9 Coefficients of an estimated multiple regression $TE = a_{1MBTE} + a_{2MBTE} P + a_{3MBTE} P^2$ to describe the response of inflation pressure / kPa on tractive efficiency / % for primary tillage (Mouldboard plough)

Plough	Ballast / daN	a_{1MBTE}	A_{2MBTE}	A_{3MBTE}	R^2
Mouldboard plough	0	51.40	5.152	-0.732	0.97
	90 F	56.45	2.071	-0.187	0.95
	90 F + 200 R	55.44	2.938	-0.492	0.94
	200 R	64.56	-0.321	0.583	0.98

3.4 Effect of inflation pressure on tractive efficiency for Disc plough

The relationship between inflation pressure and tractive efficiency for disc plough at different ballast conditions is shown in Figure 7. It is evident from the curves that the tractive efficiency increases gradually with increase in inflation pressure. Tractive efficiency is more with adding ballast at rear.

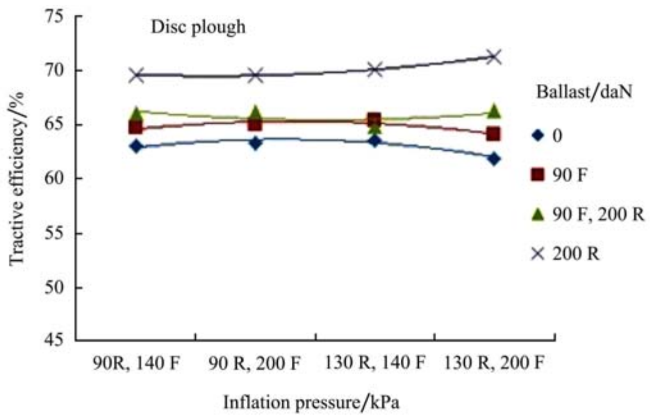

Figure 7 Relationship between inflation pressure and tractive efficiency for disc plough at different ballast conditions

The two variable interaction effect for disc plough (Table 7) shows that there was no significant difference in tractive efficiency at 90 kPa rear, 140 kPa front and 130 kPa rear, 200 kPa front tire inflation pressure combinations. Table 8 shows that the average increase in tractive efficiency is 0.09 per cent with increase in inflation pressure from 90 kPa rear, 140 kPa front to 130 kPa rear, 200 kPa front inflation pressure for disc plough at all ballast conditions. This may be due to fact that effective field capacity with inflation pressure resulting minimize in tractive efficiency (Wood and Mangione, 1994).

It is clear from Table 8 that for disc plough there was no significant difference in tractive efficiency at 90 kPa rear, 200 kPa front and 130 kPa rear, 140 kPa front tire inflation pressure for no ballast condition. Similarly no significant difference was observed at 90 kPa rear, 140 kPa front and 90 kPa rear, 200 kPa front inflation pressure for at 90 daN at front, 200 daN at rear ballast condition. There was no significant difference in tractive efficiency at 90 kPa rear, 200 kPa front and 130 kPa rear, 200 kPa front tire inflation pressure for at 90 daN at front, 200 daN at rear ballast condition. Similarly no significant difference was observed at 90 kPa rear, 140 kPa front and 90 kPa rear, 200 kPa front inflation pressure for at 200 daN rear ballast condition.

The experimental data were analyzed using a nonlinear regression technique to obtain the best fit values of coefficient a_{1DBTE}, a_{2DBTE} and a_{3DBTE} in the generalized form of a second degree of polynomial as shown in Table 10.

$$TE = a_{1DBTE} + a_{2DBTE} P + a_{3DBTE} P^2 \tag{8}$$

where, TE = Tractive efficiency, %; P = Inflation pressure, kPa; a_{1DBTE}, a_{2DBTE} and a_{3DBTE} = regression coefficients.

The R^2 values reported in the Table 10 indicate that the experimental data fit the Equation (8) very well.

Table 10 Coefficients of an estimated multiple regression $TE = a_{1DBTE} + a_{2DBTE} P + a_{3DBTE} P^2$ to describe the response of inflation pressure / kPa on tractive efficiency / % for primary tillage (Disc plough)

Plough	ballast/daN	a_{1DBTE}	a_{2DBTE}	a_{3DBTE}	R^2
Disc plough	0	61.10	2.275	-0.512	0.97
	90 F	63.08	1.894	-0.407	0.96
	90 F + 200 R	67.56	-1.665	0.322	0.98
	200 R	70.32	-1.044	0.320	0.99

4 Conclusions

From the experiments followings conclusions were drawn:

1) Rear ballast of 200 daN resulted in improving the performance of agricultural tractor by about 11.74% than no ballast, only front ballast and combination of front and rear ballast conditions for tractive efficiency for primary tillage operations.

2) Tire inflation pressure 130 kPa rear, 200 kPa front

tire resulted in improving the performance of agricultural tractor by about 2.63% than 90 kPa rear, 140 kPa front tire and 90 kPa rear, 200 kPa front and 130 kPa rear, 140 kPa front tire inflation pressure combinations for tractive efficiency for primary tillage operations.

3) The rear ballast of 200 daN and 130 kPa rear, 200 kPa front tire inflation pressure was found suitable for improving the performance of agricultural tractor by maximum tractive efficiency (72.43% and 71.27%) for mouldboard plough and disc plough respectively.

References

Alcock, R. 1986. Tractor Implement Systems. AVI Publishing co., INC. Wasport, Connecticut.

Barger, E.L., J.B. Liljedahl, and E.C. McKibben. 1967. Tractors and their Power Units. Wiley Eastern.

Burt, E.C., A.C. Bailey, and J.H. Taylor. 1980. Effect of dynamic load distribution on the tractive performance of tires operated in tandem. *Transaction of the ASAE*, 23(6): 1395-1400.

Casady, W. W., 1997. Tractor tire and ballast management. Agricultural publication G1235. Internet review.

Dahab, M.H., and M.D. Mohammed. 2002. Tractor tractive performance as affected by soil moisture content, tire inflation pressure and implement type. *Agricultural Mechanization in Asia, Africa and Latin America*, 33 (1): 29-34.

Indian Standard: 9253. 2001. Guideline for field performance and haulage test of agricultural wheeled tractor.

Jun H., T. R. Way, B. Lofgren, M. Landstrom, A.C. Bailey, E.C. Burt, and T.P. McDonald. 2004. Dynamic load and inflation pressure effects on contact pressures of a forestry forwarder tire. *Journal of Terramechanics*, 41(4): 209-222.

Raper, R.L., A.C. Bailey, E.C. Burt, T.R. Way, and P. Liberati. 1995. The effect of reduced inflation pressure on soil tire interface stresses and soil strength. *Journal of Terramechanics*, 32(1): 45-51.

Sharma, A.K., and K.P. Pandey. 1997. Effect of normal load on drawbar performance of traction tires. *Journal of Agricultural Engineering,* 34(1): 1-9.

Singh, S.P., R.S. Singh, and S. Singh. 2011. Sale trend of tractors and farm power availability in India. *Agricultural Engineering Today*, 35 (2): 25-35.

Smerda, T., and J. Cupera. 2010. Tire inflation pressure and its influence on drawbar characteristics and performance – energetic indicators of a tractor set. *Journal of Terramechanics*, 47(6): 395-400.

Wood, R. K., and D.A. Mangione. 1994. Tractive benefits of properly adjusted inflation pressures: farmer experiences. *Applied Engineering in Agriculture*, 10(1): 13-16.