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PERFORMANCE EVALUATION OF TRACTOR WITH ATTACHED IMPLEMENTS

Sandeep Sharma[1]
Associate Professor,
Mechanical Engineering Department,
Asra College of Engg. & Technology, Bhawanigarh (India)

Mohit Gaba[2],
Assistant Professor,
Mechanical Engineering Department,
Asra College of Engg. & Technology, Bhawanigarh ***(India)***

Tejinder Singh[3]
Research Scholar,
Mechanical Engineering Department,
Asra College of Engg. & Technology, Bhawanigarh (India)

Abstract-

Tractor is used as a main source of power in developing countries. In order to reduce the cost of production it is necessary to understand and predict tractor performance, which is a goal of our researcher. The performance of tractor mainly depending on the handling of the implement with respect to the tractor and drawbar pull. Objectives of this paper is to maximizing the fuel efficiency of the engine and drive train, minimizing the travel reduction, and finding different means by which we can improve efficiency and travel speed of given tractor-implement system. Simple experiments are conducted and an instrumentation system is mounted on a Sonalika DI-750 tractor to measure the various performance parameters of the tractor and attached implements. Tractive performance evaluation was made by comparing the relationships of travel reduction, working depth and fuel efficiency. Highest performance was obtained in a given field by optimum gear selection and ballasting.

Keywords- three point hitch, ballast, travel reduction, draft sensing, implements

INTRODUCTION

PERFORMANCE data from various tractors and implements are essential for farm machinery management and manufacturers alike. Proper selection of tractors and implements for a particular farm situation can be determined from these performance parameters. These data can also be used to evaluate various farm machinery systems to determine the relative merits of each system. As field machines contribute a major portion of the total cost of crop production systems, proper selection and matching of farm machinery is essential to reduce significantly the cost of ownership and operation of farm machinery. Also, efficient operation of tractors and implements is a main concern for farmers because of the rising cost of fuel and other operating costs. (Tillage and tillage implement performance)

The agriculture tractor development comes out from quality analysis of effort to maximize the efficiency of energy use in agricultural production. So it is necessary to evaluate tractor performance with different implements. Moreover, studying the relationship between different parameter is necessary for quality analysis. It is necessary to co-ordinate the components of mobile energetic devices so as to create conditions for their optimum work. One of these have significant influence on transmission and use of the agriculture tractor output is the exploitation equipment of tractor – the three point hitch (TPH). (Load characteristic of tractor three-point hitch for their simulation in laboratory condition)

Three point hitch evolved a lot in last seventy years. Three-point hitch is most popular way of attaching implements to tractor because the implement and tractor becomes a compact unit easily maneuvered in limited space. Transport from one field to another is made much easier when an implement is attached by ` 1`1` a a three-point hitch because the implement is carried on the tractor.

While using attached implement through three point hitch, the biggest change of draft force is characterized by amplitude and period exists of plowing. The amplitude of draft force is increasing with escalating of agriculture tractors operating speed. Draft force is maximum in plowing than other agricultural work(harrowing, smoothing, sowing etc.)

Fuel consumption is the single largest variable cost during field operation of tractors and also one of the most influential parameters controlling the salability of the vehicle, particularly in developing countries. It can be argued that tractor is one of the main contributors in total agricultural fuel consumption. For example, nearly 15 to 18% of 40 million tonnes of diesel fuel used per annum in India goes to agricultural sectors and approximately 35-45% of that, is used to run the prime movers like tractor, power-tiller, etc. (Singh and De, 1999). Therefore any means to reduce the fuel consumption of tractor will not only help the farming community but also will be helpful for those developing countries, whose economies mainly depend on agriculture. Rapid socio-economic changes in some developing countries like India, China, etc, are influencing the agricultural mechanization pattern of these countries and expected to do so in future also (Mondal and Basu, 2009). For example, Indian tractor industry is now the largest in the world in number of unit production with an average of more than 0.2 million unit production per year. Total tractor population in India is approximately 2.53 million at present against world tractor population of 27.63 million. India holds second position in world for total number of tractor in use after USA. Considering the Asia-pacific region, 68.6% of total 7.69 million tractors are placed in developing countries.

Travel reduction has traditionally been called "slip" or "% slip," but technically this is incorrect. Slip occurs between surfaces. Travel reduction is a reduction in distance traveled and/or speed that occurs because of:

- Flexing of the tractive device.
- Slip between the surfaces.
- Shear within the soil.

From a power efficiency standpoint, travel reduction is a power loss caused by a loss in travel speed or distance traveled. Slip (travel reduction) occurs any time a wheel or traction device

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Tejinder Singh is with the Punjab Technical University, Jalandar (Pb.) INDIA

develops pull (net traction) (Brixius and Wismer, 1978).

Zero travel reduction can be defined using any of four methods (ASAE Standards, 2001b):

1. A self-propelled (zero net traction) condition on a non-deforming surface (recommended for rolling circumference data, as in published tire data).
2. A self-propelled (zero net traction) condition on the test surface.
3. A towed (zero gross traction, i.e., zero torque) condition on a non-deforming surface.
4. A towed (zero gross traction) condition on the test surface.

There are arguments for using any of the above methods for a particular traction test. In any case, the zero condition used to define the rolling radius should always be stated. The most common zero condition is use of the self-propelled condition on the test surface (method 2). However, tire data are usually given for a non-deforming surface (method 1). The difference in measured rolling radii between a non-deforming (hard) surface and a test surface is small under normal agricultural soil conditions (dry and/or untilled soil) and thus makes little difference in the final results. In any case, errors of defining "zero slip" do not affect the final tractive efficiency results, as travel reduction does not enter directly into the equation. It only affects the results where the losses are assigned, that is, either to travel reduction or motion resistance. The authors' preference is to use a self-propelled condition (zero net traction) on a hard surface, and this method is used throughout this paper. This method provides a repeatable test condition, results that should agree closely to published tire data, and data that can be replicated at other locations and test conditions. It is also easy to imagine a case of very soft soil where the zero condition may result in an apparent 100% slip, i.e., the vehicle gets stuck, while being assigned zero travel reduction.

Ballasting is other phenomenon by which we can improve tractor’s performance. Ballast is weight added to the tractor for the purpose of improving the tractor's performance. Depending on the field conditions and the drawbar requirements of the operation, the tractor's unballasted weight may actually be heavier than the optimal weight. Agricultural tractor ballasting recommendations have evolved over the years, based primarily on field experience.

Developing ballasting criteria requires an understanding of the objective of proper ballasting. There is probably not universal agreement, and the criteria may change to meet special situations, such as where mobility and flotation may be the primary requirement. However, for most situations encountered by agricultural tractors, the objective is to optimize the time spent during field operations at near maximum power delivery efficiency in order to maximize the work completed and to minimize the fuel consumption. While a net traction ratio of 0.4 (for tires) has been shown to be optimum for best tractive efficiency, it is difficult to use as a ballasting criterion because the drawbar pull of a farmer's tractor is seldom known. The gross traction ratio for maximum tractive efficiency varies from about 0.46 to 0.52 over a range of soil conditions. Since tractors must operate over a range of travel speeds and since ballast weights are not likely to be changed as tractor operations change, a compromise is needed. Tractors tend to be ballasted for the most severe or heaviest load operations, and these levels are maintained for other operations. If tractor PDE is to be optimized over a range of operations, then the tractor must be lighter than required for full load operation in the worst condition.

From a tractor performance standpoint tire play an important rule. The general rule for tire selection should be "bigger is better." The second rule should be that larger diameter is preferred over larger width, again from a performance standpoint. In either case, tires should be operated at the correct pressure for the load being carried. Lower tire pressures are helpful from a compaction standpoint, as ground pressure is roughly equal to tire pressure. In addition, lower pressures help control power hop as they allow a wider range of tire pressure adjustments to be made. Larger tires can operate at lower pressures for the same weight. Correctly inflated radial-ply tires provide a 5% to 7% efficiency improvement over bias-ply tires.

literature review

Chaplin et al. [8] and Chancellor [7] mentioned about the classification of dynamometers. In the first group includes the dynamometers in which transducers were mounted on a frame in between tractor and implement whereas in second group dynamometer arms were modified to hold the transducer. Johnson and Voorhees [14] designed force dynamometer to measure draft, vertical force and torque simultaneously and individually in a vertical longitudinal plane caused by the implement. Hobbs and Hesse [13] developed an electronically controlled three-point hitching system consisting draft sensor, pressure sensor, speed sensor and position sensor. The system was able to automatically control the hydraulic system by adjusting position of the implement and draft level with respect to the tractor speed.

Reid et al. [23] developed a draft measurement system with a threepoint hitch dynamometer for category I or II tractors. They used three cantilever beams mounted vertically with a strain gage. But during the field tests they encountered two problems; one was bending of the steel frame and other was some lead wires from the gage were damaged and need to be replaced after use. Upadhyaya et al. [25] carried out the accuracy of mounted implement draft prediction using strain gages mounted directly on linkage system. They mentioned that for determining the draft and vertical forces it is essential to measure the amount of forces acting on the links and the orientation of these links.

Palmer [22] developed a three-point linkage dynamometer for tillage research. He designed a standard quick attachment coupler to fit all the tractors and implements with standard category. He used commercial load cells connected to analogue input device and two U-shape frames with six load cells in orthogonal manner. Godwin et al. [12] designed a dynamometer to measure the forces and moments acting on the implements. The dynamometer was able to measure the three orthogonal forces acting on the implement and three moments acting about the orthogonal axes.

Turner [24] used standard load cell to measure the draft force attached to the drawbar and considered side forces as negligible. He measured power delivery efficiency and found that there was increase in the drawbar power up to certain extent with increased wheel slip and further increase in wheel slip tends to decrease in the drawbar power.

Al-Jonabi et al. [3] conducted a research study of performance of the three-point linkage-implement depth transducer. They used extended octagonal ring transducer in each lower link without changing geometry of the linkage and load cell to replace the top link. They found that there was significant change in the draft force with respect to depth and horizontal forces were almost equals to that of resultant forces while vertical forces were in decreasing manner. Lee et al. [17] designed and evaluated the electro hydraulic tillage depth control system for rotary implements mounted on tractors. The different tests were carried out in a paddy field where the ditches were artificially made. Based on the results they claimed that there was linear relationship in between the tillage depth and angle of the lift arm within the certain range of angle.

Al-Jonabi et al. [4] performed research to study the effect of the forward speed and depth of plowing on the dynamic traction ratio in a sandy loam soil. A load cell was installed on top link while two extended octagonal ring transducers were installed on lower link to measure the draft forces. Also a rotary position transducer was used to measure the operating depth of the plow. They concluded that the dynamic traction ratio increased with increased forward speed of tractor and depth of plowing.

Al-Jalil and Mukahal [2] designed and evaluated the adjustable three point hitch dynamometer. The dynamometer was adjustable with the variable implement width and height and designed with three telescopic beams connected to the central T-shaped box. After experiments, they claimed that dynamometer was capable of measuring the implement forces in three dimensions.

Kheiralla et al. [16] designed and developed a three point auto hitch dynamometer for agricultural tractors for measuring the horizontal and vertical draft forces. They used U-shaped frame that mounted in between tractor links and implement for category I and II tractors. Khan et al. [4] designed and calibrated a bi-axial direct mounted strain gauged lower links system for measurement of tractor-implement forces for perpendicular forces up to 10 kN. They found that there was high degree of linearity between the bridge output voltage and the force applied with very small amount of hysteresis effect. Lotfi et al. [18] developed and evaluated a three point hitch dynamometer and a fifth wheel for mounted implement draft and tractor speed measurement. The three different load cells were used to measure draft forces installed on the frame and frame was attached to the three point hitch of the tractor. A fifth wheel was equipped with an encoder shaft and attached to the tractor to measure actual tractor speed

Alimardani et al. [8] designed and devel.oped a three-point hitch dynamometer to measure the draft forces of category 0 and I tractors. They fabricated the dynamometer in the reverse U-shape which allows use of PTO at the same time. This fabricated dynamometer was able to measure the resistance pull of soil engaged implement.

Bentaher et al. [6] developed the instrumentation system to study the tillage power optimization. They directly install strain gages on the three point hitching system and utilized three dimensional analysis of the tractor linkage mechanism. A dynamic calculus program was developed to consider the changes of the three-point hitch mechanism geometry during the field operations. A transformation matrix was derived to transfer the force of the transducers into orthogonal component of the tillage force.

Godwin et al. [11], Oskoui et al. [20], Owen [21], Al-Janobi [5], Kheiralla et al. [16] and Davis [10] all found the same trend of increase in the depth results in increase in the resultant forces of the three point hitch linkage. Further, the horizontal forces were almost equal to the resultant forces and vertical forces tend to decline.

Oskoui et al. [20], Kheiralla etal. [16], Davis [10] found that the resultant forces increased by increasing the forward speed. Lee et al. [17] reported about the problem encountered during the study and that was reduction in the tractor speed due to load increase to the engine when the actual tillage depth was increased.

Tractive "inefficiency" is caused by both velocity losses and pull losses. The loss in travel speed is commonly referred to as "slip," although it is more accurately referred as "travel reduction." Travel reduction is the result of the theoretical travel speed (Vt) not being entirely converted to forward progress (Va) due to losses within the soil, between the soil surface and the traction device, and within the traction device (hysteresis, and tire windup or belt slippage). Travel reduction losses are visible, that is, the operator can see it happening. The other component of tractive "inefficiency," which is less visible and often overlooked, is a loss of pull (net traction) when motion resistance reduces the amount of gross traction that is converted to useful output (net traction). This is part of what happens when a tractor is overballasted. Travel reduction is reduced, but motion resistance is increased. Motion resistance losses are especially relevant to belts, as internal losses within the belt drive mechanism, rollers, and bending of the belt are normally greater than those within a tire. On soft soils, the internal losses of belts are generally compensated for by lower external motion resistance than that of tires. [26]

$$\text{TE (ratio)} = \frac{output\ power}{input\ power} = \frac{NT \times Va}{Axle\ Power}$$

$$= \frac{NT}{GT}\frac{Va}{Vt} = \frac{NT/_{Wd}}{GT/_{Wd}}\frac{Va}{Vt} = \left(\frac{NRT}{GRT}\right)\left(\frac{Va}{Vt}\right)$$

Where,
TE= tractive efficiency
NT= net traction
Va= actual velocity
Vt= theoretical velocity
Wd= dynamic weight
NRT= net traction ratio
GRT= gross traction ratio

problem formulation

Problem Identification

The present tractor hydraulic system having problems like,
- Poor efficiency and time consuming
- Uncomfortable for operator
- complicated to diagnose and needs constant maintenance which results in the less economical and less beneficial farm activities to the farmers.

These research gaps offer a new platform for researches to find out the probable long term solutions with low cost technology.

Main objective of the study was:
To evaluate the performance of the present three-point hitching system and compute the fuel consumption and tractive performance of the tractor.
The specific objectives of this study were
1) To develop the instrumentation system to measure the draft forces on implement, depth of the implement and forward speed of tractor.
2) Conduct the experiments to measure the draft forces, depth of the implement, forward speed of tractor and fuel consumption.
3) Compute fuel consumption, specific fuel consumption and slip of tractor during the farm operation.
4) Compute the dynamic traction ratio and tractive efficiency of the tractor.

Material and Methodology

A Sonalika DI-750III tractor was instrumented so that drawbar pull, travel speed, engine rpm and transmission output torque could be measured in the field.

The test tractor was equipped with standard pneumatic radial tires. The size of front tires was 6.00-16 with ply rating 8 and the size of rear tires was 13.6-28 with ply rating 12. Both sets of tires were manufactured by Goodyear. Care was taken to maintain inflation pressures constant during the tests. The static weight distribution was 9.065 kN front and 11.805 kN rear, for a total vertical load of 20.87 kN unballasted and with ballast static weight distribution was 9.065 front and 18.669 rear, for a total vertical load of 27.734 kN.

The same ballast was used for the drawbar performance test.

Tractive performance was evaluated over a wide range of slip on the different soil surfaces.

After reviewing the strengths and weaknesses of the various types of three point linkage dynamometers, it was decided that to mount the strain gages directly on the three point hitching links. The strain gages were installed by forming Whetstone’s full bridge and half bridge. The combination of four strain gages connected by Whetstone’s full bridge or half bridge forms a one force transducer which is able to measure the forces acting on it.

Drawbar performance test is conducted both at laboratory conditions and at field, differently with ballast and without ballast. Performance variables under laboratory conditions are measured using a 50kN load cell.

Field tests comprising of mould board ploughing, disc ploughing and harrowing. All the tests are conducted at full accelerator settings, when the no load speed of the engine varied from 2315-2356 rpm.

The brief specification of the implements used during field test are given below in **table i**

Field tests were conducted in a heavy and light soil both. Initial soil moisture content and bulk density were respectively 8-15 % and 1.00-1.99 gm/cm3 for the 6-21 cm soil depth layer. Average working width of all implements was different. Average speed of operation was also measured for different operations. Fuel consumption is also measured for different operations precisely. Flags placed to mark the beginning and end of each test run.

In drawbar performance test under laboratory conditions, the test tractor was operated in the ballasted and unballasted mode. In each mode, the tractor operator used five different gears (L1, L2, L3, L4 and H1) and ran the engine at full throttle. But in field test only ballasted tractor is used in the recommended gear for the particular operation. The differential lock was kept engaged at all times to insure equal travel reduction at each drive wheel. Performance variable under laboratory conditions were measured using a 50 kN load cell.

Tire of tractor is marked in such a way which can be easily absorbed and used to measure the travel reduction. A zero travel reduction is assumed by driving a tractor in a self propelled condition on a non-deforming surface for a known distance. The rolling radius measured by the above method is used to calculate the theoretical displacement. The difference in measured rolling radius between a non-deforming (hard) surface and a test surface is small under normal agricultural soil conditions (dry and/or untilled soil) and thus makes little difference in the final results.

Travel reduction ratio=

$$1 - \frac{actual\ displacement}{theoretical\ displacement}$$

During test run, we already know the actual displacement and theoretical displacement is calculated by counting the number of revolutions and knowing the rolling radii of the tire. The differential lock was kept engaged at all times to insure equal travel reduction at each drive wheel.

A custom type transparent type fuel tank is used to measure the fuel consumption precisely. Tank is calibrated after every 100ml. After every test reading of the fuel tank is accurately noted to measure fuel consumption.

Working depth is measured by simple depth gauge randomly. Average of four random sample from a particular field is considered as the working depth of the implement for that field.

Results

Table ii show the summary of the field performance test with different attached implements. It also shows all the different parameters which influences performance.

The results of drawbar performance test consisting of maximum power and pull without or with ballast are tabulated in **Table iii**.

Figure i shows the relationship between drawbar pull (kN) and forward speed of tractor under ballasted conditions.

Figure ii show the relationship between drawbar pull (kN) and specific fuel consumption (g/kWh).

Figure iii shows the relationship between drawbar pull (kN) and wheel slip% (travel reduction).

Table i

S. No.	Item	M.B. ploughing	Disc ploughing	Disc harrow
1	Make	N.A.	TAFE	N.A.
2	Type	Mounted	Mounted	Trailed
3	No. of bottom/disc	3	3	16 (8 in each gang)
4	Type of mould board/ disc	General purpose	Plain, concave	Plain, concave
5	Size of bottom/disc(mm)	370	655	580
6	Spacing of bottom/disc	305	280	223
7	Lower hitch point span(mm)	790	740	--
8	Mast height(mm)	500	435	--
9	Over all dimension(mm):			
	- Length	1880	1820	1865
	- Width	1100	1060	2270
	- Height	1070	1170	490
10	Gross mass(kg)	315	250	565

Table ii

S. No.	Parameter / operation	Mould board ploughing	Disc ploughing	Disc harrowing
I.	Type of soil [27]	Heavy	Heavy	Heavy & light
II.	Average soil moisture (%)	8-15	11-15	8-10
III.	Bulk density of soil (g/cc)	1.79-1.99	1.79-1.96	1.00-1.87
IV.	Cone index (kg/cm^2)	5.78-9.36	5.10-8.34	3.49-8.51
V.	Average speed of operation (kmph)	3.80-4.56	4.62-4.94	7.05-8.17
VI.	Average travel reduction (%)	12.9-21.8	6.6-18.3	3.6-7.1
VII.	Average depth of cut (cm)	17-21	16-22	6-9
VIII.	Average working width (cm)	101-112	81-91	149-175
IX.	Area covered (ha/h)	0.350-0.452	0.326-0.380	0.856-1.208
X.	Fuel consumption: - (l/h) - (l/ha)	 5.2-6.96 11.79-19.74	 4.67-5.57 13.48-14.48	 4.56-5.67 3.78-6.04
XI.	Average draft of implement, kN (kgf)	7.86-8.63 (802-880)	7.33-8.24 (747-840)	4.35-5.66 (444-577)

Table iii

Gear	Travel speed, (km/h)	Drawbar power, kW	Drawbar pull, kN	Engine speed (rpm)	Travel reduction (%)	Fuel consumption		Specific energy, (kWh/l)	Maximum sustained pull, kN
						kg/kWh	l/h		
1	2	3	4	5	6	7	8	9	10
i)	**Maximum power test (tractor unballast)**								
L1	2.63	10.8	14.8	2237	14.8	0.418	5.52	1.96	16.7
L2	4.68	18.8	14.4	2163	14.4	0.335	7.67	2.45	14.9
L3	7.29	25.3	12.5	2109	12.5	0.301	9.27	2.73	13.8
L4	8.53	25.1	10.6	2105	10.6	0.302	9.25	2.71	11.8
H1	10.78	26.2	8.8	2103	8.8	0.293	9.33	2.81	9.8
ii)	**Maximum power test (tractor ballast)**								
L1	2.55	14.4	20.2	2199	14.8	0.37	6.5	2.21	22.3
L2	4.62	24.4	19	2083	11.3	0.313	9.31	2.62	20.7
L3	7.53	25.8	12.4	2099	5.7	0.292	9.22	2.8	13.4
L4	8.67	25.5	10.6	2101	5.1	0.297	9.27	2.75	11.8
H1	10.81	26.4	8.8	2085	4	0.288	9.28	2.84	9.5

Figure i

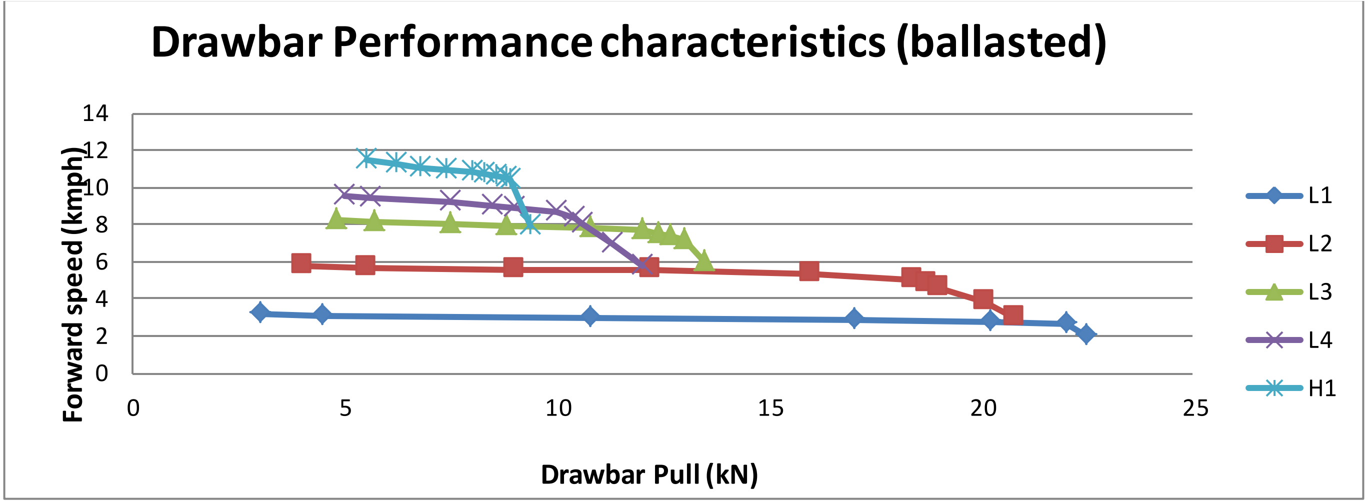


Figure ii

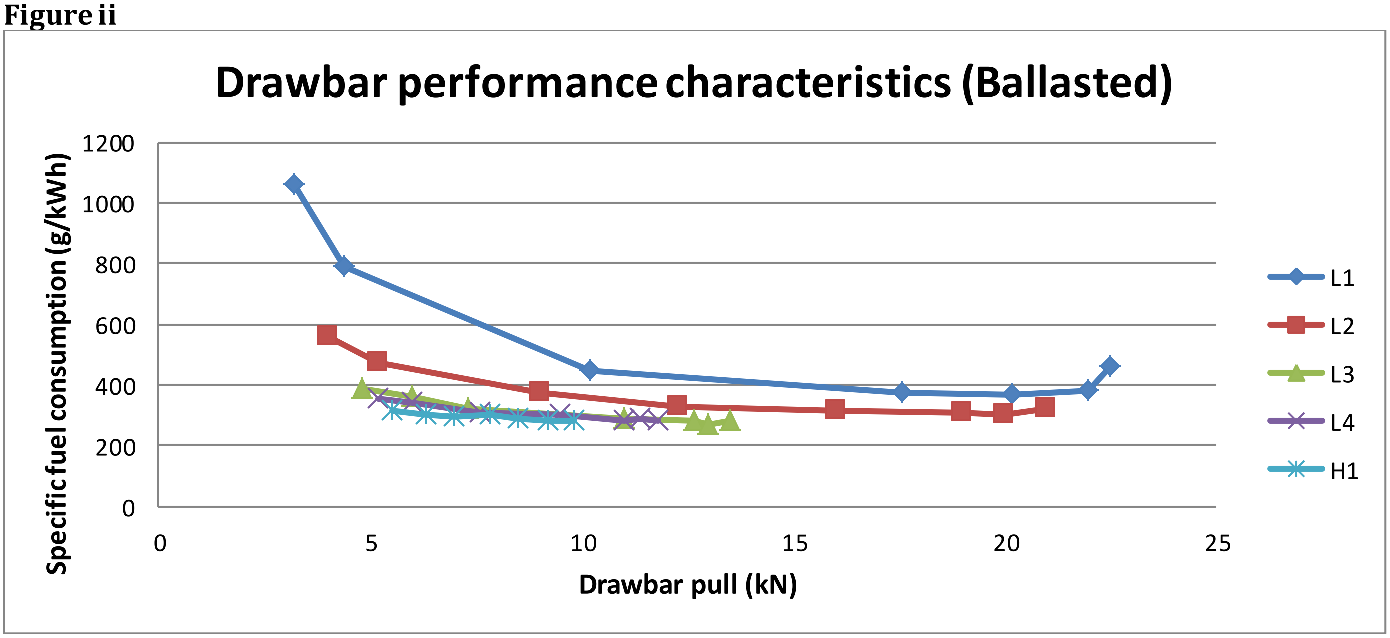
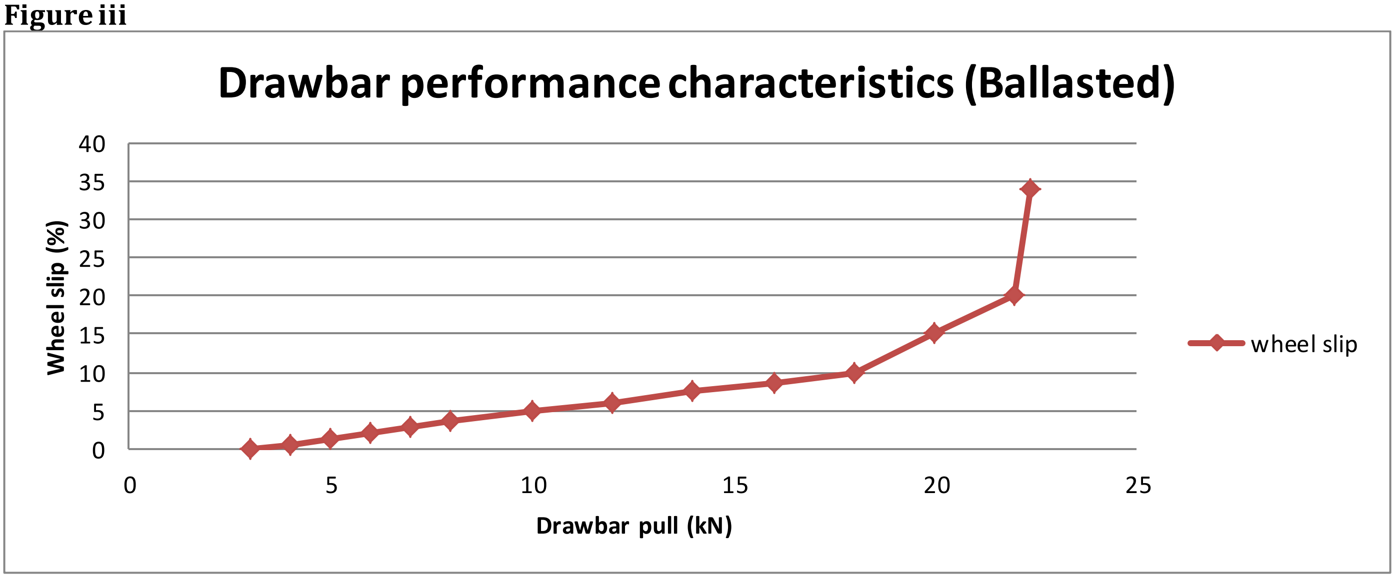


Figure iii



Conclusion

The prepared instrumentation system was able to measure all the draft forces acting on the three point hitch linkage, depth of the implement and slip of wheels. Mounting strain gages directly on the links provide accurate and sensitive draft force measurement. The draft forces were increased with increased working depth and working speed.. The vertical force components had very less effect on the weight addition to the tractor. The drawbar power and slip were found linear in nature up to the certain limit. Increased depth were responsible to increase the fuel consumption while at different working speeds, the fuel consumption was unstable. Specific fuel consumption was increased with increased drawbar power and higher. Tractive efficiency and drawbar pull both can be improved by using proper ballast. But over ballasting also increases fuel consumption.

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