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Field Performance Evaluation of Tractor Drawn Tillage Implement Used in Hilly Regions of Arunachal Pradesh

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ABSTRACT

Selecting a most energy efficient tillage system often require the field performance data of various tillage implements under varying local conditions. Unfortunately the performance and energy input data for many of these tillage implements are very rear and not readily available in the hill regions of Arunachal Pradesh. Such information will probably guide the farmers of these regions in selection of suitable tillage implements. Keeping the importance of such information in mind, the present study was conducted to determine the field performance of tractor drawn tillage implements namely 2-bottom mouldboard plough, 2-bottom disk plough and spring loaded 7-tine cultivator. The percentages of width actually utilized (average effective width) were measured to be 86.67 % (52 cm), 84.7 % (59.3 cm) and 61.21 % (101 cm) for mouldboard plough, disk plough and tine cultivator respectively. Among the implements the spring loaded tine cultivator recorded the minimum draft per unit width (3.34 kNm^{-1}) and power (3.29 kW) followed by disk plough (9.01 kNm^{-1}) & (5.03 kW) and mouldboard plough (11.69 kNm^{-1}) & (7.2 kW). The spring tine cultivator also recorded the highest average field capacity (0.22 ha/h) and lowest fuel consumption of 18.13 L/ ha (4.01L/h). The average effective field capacity and fuel consumption of mouldboard plough and disk plough were respectively 0.168 ha/h & 26.87L/ha (4.48 L/h) and (0.16 ha/h) & 24.79 L/ha (3.95 L/h). However, the maximum field efficiency was observed in disk plough (83.75 %), followed by mouldboard plough (78.75 %) and spring tine cultivator (64.1%). The minimum delay time (time lost) per hectare was obtained with used of disk plough (1.16 h/ha), followed by mouldboard plough (1.28 h/ha) and spring tine cultivator (1.63 h/ha).

1. Introduction

Timeliness in agricultural operations right from the seed bed preparation to threshing and harvesting crops are essential for land labour productivity. Farm equipment acts as a device to ensure that other input give the desired results. Thus, it may be said that farm equipment and the techniques associated with its use broadly constitute the field of agricultural mechanization (Oduma et al. 2015). Energy is another important key in agricultural operations. Updhyaya et al. (1984) asserts that energy plays key role in various land tillage, seeding/planting and harvesting of agricultural productivities.

Tillage is the base operation in agricultural systems and its energy represents a considerable portion of the energy utilized in crop production (Larson and Clyma 1995). Sale et al. (2013) highlighted that agriculture is very sensitive to timely operations and weather conditions, and huge amount of money is spent on investment, therefore there is the need to evaluate the capacitive performance of agricultural machines for proper machinery selection, optimization and farm scheduling. Machines can be evaluated over a short period in productive work- equivalent to speed trials or they can be monitored over-time taking into account associated delays (Yohannah and Ifem 2003).

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Draft and power requirements are important parameters for measuring and evaluating performance of tillage implements and therefore are considered to be essential when attempting to correctly match a tillage implement to a tractor (Grisso et al. 1996; Al-Janobi and Al-Suhaibani 1998). Efficient machinery management requires accurate performance data on the capabilities of individual machines in order to meet a given work schedule and to form balanced mechanization systems by matching the performance of separate items of equipment (Whitney 1988). Selecting a most energy efficient tillage system often require the field performance data of various tillage implements under varying local conditions. Unfortunately the performance and energy input data for many of these tillage implements are very rear in the hill regions of Arunachal Pradesh. Such information will probably guide the hill and valley farmers in selection of suitable tillage implements. The present study is carried out to evaluate the field performance of tractor drawn tillage implements namely, 2 bottom mouldboard plough, 2 bottom disk plough and spring loaded 7 tine cultivator.

2. Materials and Methods

The experiment was conducted at Research and Experimental field, Department of Agricultural Engineering of North Eastern Regional Institute of Science and Technology (NERIST), Nirjuli, Arunachal Pradesh (India). The soil at the experimental site was sandy loam; topography was flat and was covered with grassy weeds. Prior to the field experiment, soil samples were collected randomly from ten spots and three soil depth 5 cm, 15 cm and 25 cm using soil samplers. Initial weights of all the samples were taken on digital balance and dried it at 105^{o} C for 24 hours. The volume of the soil sampler were measured, the dried samples collected from the oven and final weights were recoded. Moisture content on dry weight basis and bulk density was computed for each sample and average moisture content (db) and bulk density Table 1(a) shows the soil type, soil composition, moisture content and bulk density values for the experiment. Cone index indicates soil hardness and is expressed as force per square centimetre required for a cone to penetrate into soil were computed. Cone penetration resistance was measured by a digital cone penetrometer having 30^{o} cone angle and a base diameter of 12.83 mm (0.51 in.). According to ASAE standards, the device was driven into the soil at a constant speed of 0.02 m/s and the readings were recorded at various depths. Cone index was measured at 10 different spots over 0 - 25 cm depth range. Table 1 (b) shows the results of soil cone index of the experimental field.

Table 1(a). shows the soil type, average moisture content (db), and bulk density determined for the field used for the experiment.

Type of soil	Sandy loam	
Soil Composition	(%)	
Sand	72.50	
Silt	5.50	
Moisture content (db), Soil bulk density and Cone index		
Depth(cm)	Average soil moisture content (%)	Average soil bulk density (g/cc)
7.00	8.50%	1.30
13.00	13.40%	1.40
19.00	16.50%	1.40
25.00	18.20%	1.60

Table 1(b). shows the average soil cone index over 0 - 25 cm depth range taken at 10 different spots.

Depth (cm)	Cone index (kg/cm^2)
2.00	0.00
7.00	8.20
13.00	11.20
19.00	17.50
25.00	22.15

2. Tillage Implements and Tractors

Three tillage implements namely mouldboard plough, disk plough and a cultivator were used in the experiment. The implements were tractor mounted tillage implements most commonly used for tillage operation such as ploughing, seed bed preparation etc. in hill valleys of Arunachal Pradesh. For the field trial, the depth of cut was set at 20 cm for all the implements. The disc angle and tilt angle of the disc plough was set at 40^{o} and 15^{o}, respectively. General descriptions of the selected implements are given in the following section. Two tractors were used in this experiment, one as test tractor John Deer 5038 D (4wd, 38 Hp) and the other one as auxiliary tractor HMT 3522 (35 Hp). Figure (1) shows the tillage implements, auxiliary and test tractors and Table (2) shows the specification of the tillage implements.

3. Description of the implements

2 Bottom mouldboard plough

The mouldboard plough is primary tillage equipment and it is a general purpose having two bottoms each of 30 cm width of cut. It cuts trash and buries it completely.

2 Bottom disk plough

The plough consists of common main frame, disc beam assemblies, rockshaft category-1, a heavy spring loaded furrow wheel and a gauge wheel. The disc angle ranges from 40^o-45^o to obtain the desired width of cut and the tilt angle ranges from 15-25^o for penetration. Disc plough is used for primary tillage operation especially useful in hard and dry, trashy, stony or stumpy land conditions and in soil where scoring is a major problem.

Spring loaded 7 tine cultivators

Cultivator consists of a rectangular frame, tines (spring loaded) having reversible shovels and 3-point hitch system. Primarily used for intercultural operation after the crop has come up a few centimetres above the ground, opening the land, preparing the seed bed and also used for intercultural operation by adjusting the tines as per row spacing.

Other equipments

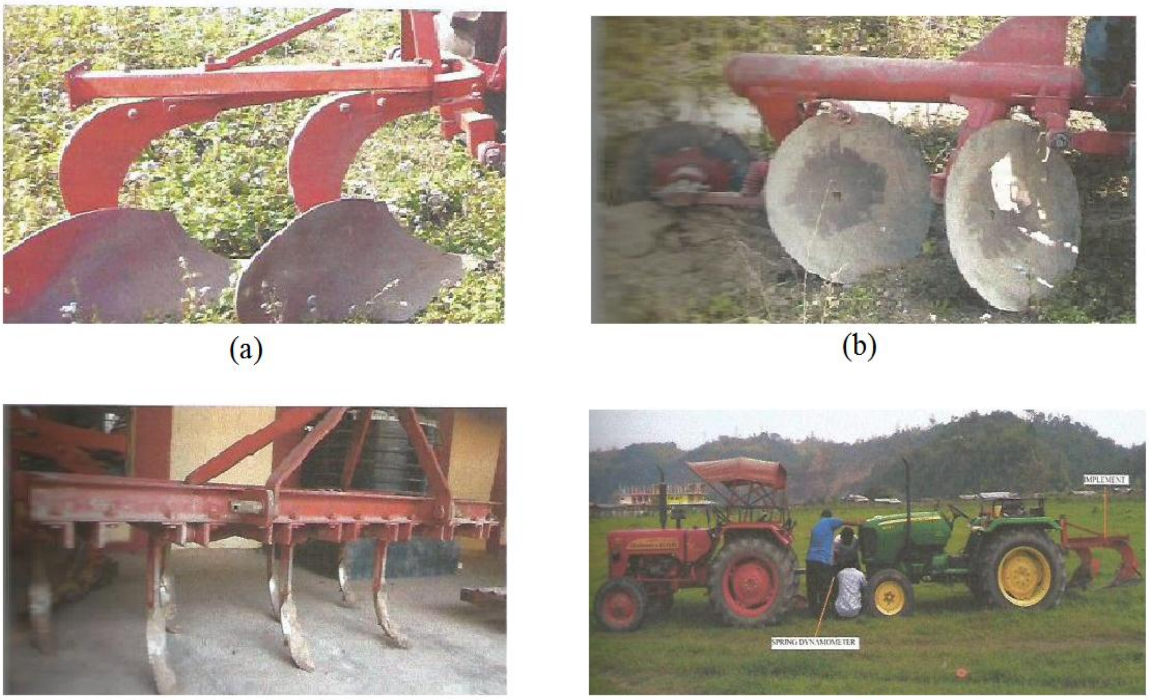
Other equipments used in the field experiment includes a spring dynamometer (1000kg), measuring tape, ranging rods, stop watches, steel/iron chain used for pulling the test tractor by the auxiliary tractor for implement draft measurement and a graduated glass cylindrical container for measuring fuel consumption.

Experimental Design and Treatment Applications

The experimental design was a complete randomized block design. Treatments were three different types of tractor drawn tillage implements - a mouldboard plough, disk plough and spring tine cultivator. Four replications of each treatment were taken in the field, resulting in a total of 12 plots. The size of each plot was 40 m x 3 m (120 m^2). The field layout is shown in Figure (2)

Field test performance parameter

The parameters measured for determining the performance of the tractor drawn tillage implements in the experiment includes operating speed, effective operating width, depth of operation, implement draft, productive time, delay time, area covered in unit time and fuel consumption. These parameters were used for determining the performance indicators like actual/effective field capacity, field efficiency, theoretical field capacity, specific fuel consumption and power requirement of the tillage implements.



(c) (d)

Figure 1 (a) 2 Bottom Mouldboard Plough (b) 2 Bottom Disk Plough
(c) Spring Loaded 7 Tine Cultivator (d) Auxiliary Tractor (HMT) and Test Tractor (John Deer)

Table 2. Specifications of selected tillage implements used for experiment.

Particulars	Mouldboard plough	Disk plough	Spring loaded 7 tine
No. of bottom(s)/ tines	2	2	7 tines
Operating width	30 x 2 cm	35 x 2 cm	165 cm
Depth of cut	Upto 40 cm	Upto 30 cm	12.7 - 22.5 cm
Weight	244 kg	236 kg	180 kg
Power requirement	30 - 40 Hp	25 - 60 Hp	25 - 60 Hp

Measurement of draft

- Attached a tillage implement on the three point hitch linkage system of the test tractor (John Deer 5038) such that the implement was kept in the operating position.
- Attached a direct reading spring dynamometer in front of the test tractor and its gear was kept in neutral position.
- An auxiliary tractor (HMT) was link with the test tractor through the spring dynamometer.
- The auxiliary tractor pulled the test tractor at constant speed with the latter in neutral gear but with the implement in the operating position (RNAM test code),
- Draft was recorded for a measured distance of 40 m plot length.
- On the same plot, the implement was lifted up (implement in idle position) form the ground and draft of the test tractor only was recorded.
- The draft of the implement is given by the difference of between the two readings.

Hence the draft of the implement is determined as follows:

$$D_P = D_{PT} - D_T \qquad (1)$$

Where, $\mathbf{D_P}$ is the draft of the implement (kg)

$\mathbf{D_{PT}}$ is the draft of test tractor with implement in operating position (kg)

$\mathbf{D_T}$ is the draft of test tractor (unloaded) (kg)

This procedure was carried out for all the tillage implements and four replications were made for each implement.

Measurement of effective field capacity, theoretical field capacity and field efficiency

For determining the actual field capacities of the tillage implement, the test tractor with implement was operated in the field plot at a constant speed. During the operation, the time taken to cover the plot length, time required for actual tilling operation, time spent in turnings at the head lands, and any delay time encountered during the operation such as minor machine adjustment, cleaning clogged equipment *etc*. were all recorded using stop watches in each plot for each implement. The width of cut was also measured at various points along the straight rows in all the plots using steel rule and average value determined.

Measurement of total field time

Total time (total field time) is the time spent in the field while covering a given area and it includes the productive time (effective time), and any delay time such as time spent in turning at the head lands, time spent in minor machine adjustment, time spent in cleaning clogged equipment etc. during the operation. Thus total time is calculated as follows:

$$T_T = T_P + T_D \qquad (2)$$

Where, $\mathbf{T_T}$ is the total field time (in s)

$\mathbf{T_P}$ is the productive (effective) time (in s)

$\mathbf{T_D}$ is the delay time which includes turning time, minor adjustment, cleaning clogged equipment during operation (in s)

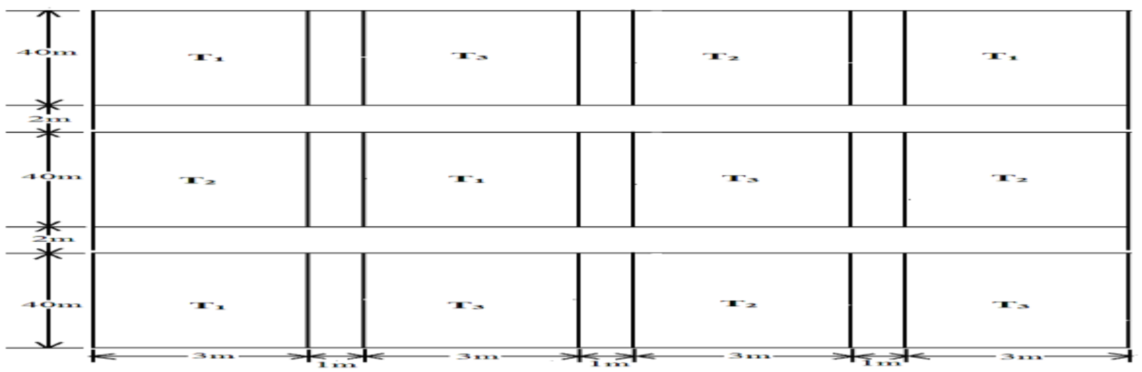


Figure 2. Field layout of the experimental area. Treatments: $\mathbf{T_1}$: Mouldboard plough, $\mathbf{T_2}$: Disk plough $\mathbf{T_3}$: Spring tine cultivator

Measurement of operating speed

For measurement of operating speed of test tractor implement combination, time taken to cover the entire plot length (i.e. 40 m) was considered. The operating speed is calculated as plot length divided by the time required traveling the plot length. Then the speed is determined by taking average of such six readings.

$$V = \frac{L}{t} \quad (3)$$

Where, **V** = Speed in meter per second (m/s)

L = Plot length (40 m) in meter (m)

t = Time taken to cover the plot length (i.e. 40 m) in second (s).

Measurement of power requirement

Having measured the operating speed of test tractor implement combination in the test plot, the power required for the operation is calculated as follows:

$$P = \frac{(D_P * V)}{75} \quad (4)$$

Where, **P** = Power in Hp

D_P = Draft in kg

V = Average operating speed (m/s)

Effective (actual) field capacity is determined as follows:

$$EFC = \frac{A * 0.36}{(T_P + T_D)} \quad (5)$$

Where, EFC is effective (actual) field capacity (ha/h)

A is the area of test plot in m^2 = 120 m^2

T_P is the productive (effective) time (s)

T_D is the delay time which includes turning time, minor adjustment, cleaning clogged equipment during operation (s)

Theoretical field capacity is determined as follows:

$$TFC = W_E * V * 0.36 \quad (6)$$

Where, **TFC** is the theoretical field capacity (ha/h)

W_E is the average effective operating width measured in the field (m)

V is the average operating speed (m/s)

Field efficiency

It is the ratio of effective field capacity to theoretical field capacity, in %. Field efficiency includes the effect of time lost in the field such as time spent in turning *etc*. and failure to utilize the full width of the machine and for overlap of implements width.

$$FE = \frac{EFC * 100}{TFC} \quad (7)$$

Where, **FE** is field efficiency (%) and **EFC** and **TFC** are effective and theoretical field capacity respectively in ha/h.

Measurement of fuel consumption

The test tractor started working the plot with its full tank capacity. A graduated glass cylinder of 1 liter capacity was used to top up the fuel tank immediately after the completion of each plot. The total quantity of fuel needed to refill and top up the tank and the time taken to complete the plot area were recorded. The fuel consumption is determined as follows:

$$FC_A = \frac{Q_L * 10000}{A} \quad (8)$$

Where, **FC_A** is the fuel consumption in liter per hectare (L/ha)

Q_L is the reading of glass cylinder in liter (L)

A is the area of field plot in meter square (m^2)

$$FC_H = \frac{Q_L * 3600}{T_T} \quad (9)$$

Where, **FC_H** is the fuel consumption in liter per hour (L/h)

Q_L is the reading of glass cylinder in liter (L)

T_T is the time taken to complete the plot (area 120 m^2) in second (s)

4. Results and Discussion

The field performance of selected tillage implements which are most commonly used in hill regions of Arunachal Pradesh, namely mould board plough, disk plough and spring tine cultivator are evaluated in the field where the soil was sandy loam type. In the field trails, the performance parameters of tillage implement such as operating speed, effective operating width, depth of operation, implement draft, productive time, delay time, area covered in unit time and fuel consumption were measured. Using the data obtained from the field trials, performance indicators such as field capacity, field efficiency, theoretical field capacity, power requirement and fuel consumptions, were determined and evaluated for each type of implement under similar field conditions. Prior to the trial, the soil moisture content (db), bulk density, soil cone index were measured and presented in Table 1 (a) and 1 (b).

Speed of operation and effective width of cut

In the field trial, the depth of cut for all the tillage implements was set at 20 cm using the hydraulic depth control lever of the test tractor. The average operating speed of the test tractor with mouldboard plough, disc plough and spring tine cultivator were measured as 1.15 m/s (4.14 km/h), 0.92 m/s (3.31 km/h) and 0.96 m/s (3.45 km/h) respectively. Among the implements, mouldboard plough recorded the highest percentage of width actually utilized (average effective width of cut) in the tillage operation followed by disk plough and tine cultivator.

Table 3. Performance evaluations of mouldboard plow.

Sl. No.	Particulars	Plot 1	Plot 2	Plot 3	Plot 4	Average
1.	Plot size, m^2	120	120	120	120	120
2.	Average width, m	0.53	0.48	0.53	0.54	0.52
3.	Average speed, m/s (km/h)	1.17(4.21)	1.17(4.21)	1.11(4.0)	1.13(4.07)	1.15(4.14)
4.	Draft, kgf (kN)	628.60(6.17)	618.47(6.07)	593.95(5.83)	637.10(6.25)	619.53(6.08)
5.	Draft per unit width of cut, kNm^{-1}	11.64	12.64	10.99	11.57	11.71
6.	Power, kW	7.36	7.24	6.59	7.19	7.1
7.	Total field time, s (h)	250.00(0.07)	270.0(0.07)	254.0(0.071)	260.0(0.072)	258.5(0.072)
8.	Productive time, s (h)	195.0(0.054)	215.0(0.6)	205.0(0.057)	198.0(0.6)	203.25(0.056)
9.	Delay time, s (h)	55.0(0.0153)	55.0(0.0153)	49.0(0.014)	62.0(0.017)	55.25(0.015)
10.	Effective field capacity, ha/h	0.173	0.16	0.17	0.17	0.168
11.	Theoretical field capacity, ha/h	0.22	0.20	0.21	0.22	0.213
12	Field efficiency, %	78.0	80.0	81.0	76.0	78.75
13.	Fuel consumption, L/ha	23.33	30.83	25.00	28.33	26.87
14	Fuel consumption, L/h	4.03	4.93	4.25	4.71	4.48

Table 4. Performance evaluation of disk plough

Sl. No.	Particulars	Plot 1	Plot 2	Plot 3	Plot 4	Average
1.	Plot size, m^2	120	120	120	120	120
2.	Average width, m	0.57	0.58	0.63	0.59	0.593
3.	Average speed, m/s (km/h)	0.96(3.46)	0.902(3.25)	0.91(3.28)	0.925(3.33)	0.924(3.33)
4.	Draft, kg	550.0(5.4)	535.0(5.25)	546.0(5.36)	550.0(5.4)	544.75(5.34)
5.	Draft per unit width of cut, kNm^{-1}	9.46	9.05	8.50	9.14	9.01
6.	Power kW	5.23	4.82	7.97	5.09	5.03
7.	Total field time, s (h)	262.0(0.73)	275.0(0.08)	275.0(0.08)	270.0(0.075)	270.5(0.075)
8.	Productive time, s (h)	221.0(0.06)	230.0(0.064)	210.0(0.06)	220.0(0.061)	220.25(0.061)
9.	Delay time, s (h)	41.0(0.011)	45.0(0.013)	65.0(0.02)	50.0(0.014)	50.25(0.015)
10.	Effective field capacity, ha/h	0.16	0.16	0.16	0.16	0.16
11.	Theoretical field capacity, ha/h	0.20	0.22	0.18	0.20	0.2
12.	Field efficiency, %	84.0	84.0	86.0	81.0	83.75
13.	Fuel consumption, L/ha	20.83	27.50	27.50	23.33	24.79
14.	Fuel consumption, L/h	3.44	4.32	4.32	3.73	3.95

The percentages of width actually utilized (average effective width) were measured to be 86.67 % (52 cm), 84.7 % (59.3 cm) and 61.21 % (101 cm) for mouldboard plough, disk plough and tine cultivator respectively (Table 3, 4 & 5).

Draft and power require

The average draft required for the mouldboard plough, disk plough and spring tine cultivator were measured as 619.53 kgf (6.08 k N), 544.75 kgf (5.34 k N) and 343.56 kgf (3.37 k N) respectively (Table 3, 4, 5). The highest draft per unit width of operation was recorded for mouldboard plough (11.69 kNm^{-1}), followed by disk plough (9.01 kNm^{-1}) and spring tine cultivator (3.34 kNm^{-1}).

The average power needed to operate the mouldboard plough was found to be 9.6 hp (7.2 kW), followed by disk plough 6.7 hp (5.03 kW) and spring tine cultivator 4.39 hp (3.29 kW). The higher draft and higher power required for mouldboard may be attributed to its heavy weight 244 kg (Table 2) and higher average working speed of 1.15 m/s (Table 3) as compared to the disk and spring tine cultivator. The minimum draft of 3.37 kN and power 4.39 hp (Table 5) for the spring loaded tine cultivator may be attributed to its is lighter weight 180 kg (Table 2) and less volume of soil handling per unit time during operation.

Field time, productive time, delay time and fuel consumption

Among the implements tested, the spring tine cultivator recorded the lowest fuel consumption of 18.13 L/ha (4.01 L/h), followed by disk plough 24.79 L/ha (3.95 L/h) and mouldboard plough 26.87 L/ha (4.48 L/h) (Table 3, 4 & 5). Ploughing with mouldboard plough requires much tractive effort, it handles a large volume of soil per unit time and self weight of mouldboard plough is heavy and these may be the reasons for highest fuel consumption. Total field time is the sum of productive time (effective time) and delay time that may encountered during operation. From the experiment it is found that the maximum field time was recorded for disk plough followed by mouldboard plough and spring loaded tine cultivator.

Field efficiency and effective field capacity

The spring loaded tine cultivator shows the highest average field capacity of 0.22 ha/h and lowest field efficiency of 64.1% (Table 5). Disk plough recorded the maximum field efficiency of 83.75 % followed by mouldboard plough 78.75 %. Average effective field capacity of mouldboard plough and disk plough were 0.168 ha/h and 0.16 ha/h respectively (Table 3 &4). The field time per hectare for disk plough was 6.26 h and delay time 1.16 h (Table 6). The field time and delay time per hectare for mouldboard plough and spring loaded tine cultivator were 5.98 h & 1.28 h and 4.51 h & 1.63 h (Table 6) respectively. The maximum delay time per hectare was obtained when ploughing with spring loaded tine cultivator (1.63 h) followed by mouldboard plough (1.28 h) and disk plough (1.16 h). Higher delay time in case of spring tine cultivator may be attributed to its higher operating width which increases time spent in turning at headlands and it was also observed that the operator had to get down to clear the tines from clogging with thrash and weeds. With wider equipment, turns at headlands are longer with raised implements not in use and headland areas are often larger.

Conclusion

The field trails for performance evaluation of the tractor drawn tillage implements namely two bottom mouldboard (60 cm), two bottom disk plough (70 cm) and 7 tines spring loaded cultivator (165 cm) were carried out in the Research and Experimental Field, Agricultural Engineering Dept. NERIST Nirjuli (Arunachal Pradesh). The spring tine cultivator recorded the highest effective field capacity, lowest fuel consumption and power requirement while the mouldboard plough recorded the highest draft force and fuel consumption whereas the disk plough have the highest field efficiency and lowest delay time.

Table 5. Performance evaluation of spring tine cultivator

Sl. No.	Particulars	Plot 1	Plot 2	Plot 3	Plot 4	Average
1.	Plot size, m^2	120	120	120	120	120
2.	Average width, m	1.028	1.011	0.988	1.010	1.01
3.	Average speed, m/s	0.97	0.94	0.98	0.94	0.96
4.	Draft, kN	3.4	3.35	3.4	3.35	3.37
5.	Draft per unit width of cut, kNm^{-1}	3.30	3.31	3.44	3.31	3.34
6.	Power, kW	3.37	3.20	3.39	3.21	3.29
7.	Total field time, s (h)	183.8(0.051)	203.5(0.057)	186.5(0.052)	205.0(0.057)	194.7(0.054)
8.	Productive time, s (h)	120.0(0.033)	126.5(0.035)	124.3(0.034)	126.3(0.035)	124.3(0.034)
9.	Delay time, s (h)	63.75(0.017)	77.0(0.021)	63.0(0.018)	78.75(0.022)	70.63(0.096)
10.	Effective field capacity, ha/h	0.24	0.21	0.23	0.21	0.22
11.	Theoretical field capacity, ha/h	0.36	0.34	0.35	0.34	0.35
12	Field efficiency, %	65.7	62.3	66.7	61.7	64.1
13.	Fuel consumption, L/ha	15.83	19.17	16.67	20.83	18.13
14.	Fuel consumption, L/h	3.72	4.07	3.86	4.39	4.01

Table 6. Field time, productive time and delay time

Sl. No.	Tillage Implement	Average Field time per hectare, h	Average Productive time per hectare, h	Average Delay time per hectare, h
1	2 Bottom Mouldboard Plough	5.98	4.7048	1.28
2	2 Bottom Disk Plough	6.26	5.098	1.16
3	Spring Loaded 7 Tine Cultivator	4.51	2.88	1.63

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