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Performance Evaluation of Power Tiller for Rice Cultivation in South Gondar Zone, Amhara Region, Ethiopia

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***Abstract*—**Tillage operation is the most power-intensive activity in agriculture. Ethiopian agriculture is primarily based on animal power, which is a drudgery, time-wasting, and energy-consuming work. In this research paper, a two-wheel hand tractor (single axle power tiller) and local animal power (using pair of oxen) have been used as treatment. The lay pout of the treatments had a 10-meter width by 40-meter length replicated three times. The experiment was conducted in three rice potential districts namely Fogera, Libokemkem, and Dera for three consecutive years. During the experiment, the most fundamental tillage parameters such as the width of cut, operation depth, speed of operation, fuel consumption (for power tiller), and yield data were recorded. From the three locations, most parameters had better performance at the Libokemkem site. The width, speed of operation, field capacity, and field efficiency were significantly ($P<0.05$) different for the two treatments with values of (29.951, 26.142) cm, (3.633, 2.214) km/hr, (0.108, 0.057) ha.hr^{-1}and (74.822, 69.682)%, respectively for power tiller and animal power. The fuel consumption was the least at Dera district with 9.411 L/ha consumption. The grain yield was 4.92 and 4.61 tone/ha for power tiller and draught animal respectively. The study indicated that using a power tiller for rice production was economically viable.

Keywords—animal power, field capacity, field efficiency, performance evaluation, power tiller, rice cultivation

I. Introduction

Ethiopia hast vast land and huge water resources in east Africa which is not yet exploited for crop production. The climate and topography makeup of the country are range from desert to cold, and from deepest, “Dalol”, to mountainous plateaus, “Ras Dashin”. Ethiopia’s climate is suitable to grow various types of crops. Land preparation is done by draft animal power in Ethiopian agriculture. It is the most intensive, power consuming and time taking activity. Farm power sources can be categorized into three major groups, such as human, animal, mechanical, and a combination of them [1]. Animal power is dominantly used by Ethiopian farmers for tillage activities, for threshing, and for rural transportation of produces. Agricultural mechanization is the most important tool for maximizing agricultural production. It increases the timeliness, consistency in field operations, efficiency and energy saving [2].

Rice is now becoming one component of the country’s agriculture [3] [4]. Rice cultivation is a recently appearing phenomenon in Ethiopia. The introduction of rice in Ethiopia had probably been started when the wild rice (*O. longistaminata*) was seen in the waterlogged areas of Fogera, (Amhara region) and Gambella Plains in the early 1970s [5] [6]. The Ethiopian rice potential area is estimated to be over 30 million hectares as the ministry of agriculture had reported in 2010 [7]. The trend of rice, in Ethiopia, shows an increment both in area and production of the crop since its introduction [5] [7]. The size of area being used for rice cultivation is low as compared to the country’s potential. In contrast, the importing rate of rice is significantly increasing. Exploiting the largest potential of rice can contribute to income generation, food and nutritional security and poverty alleviation for Ethiopia. From this perspective, the peoples of the land called this crop as a “millennium crop” [3]. The majority of rice farmers in Ethiopia are smallholders, and are producing it mostly for household consumption and sell the small surplus production to processors or paddy collectors [8] [9];.

Before the introduction of rice, farmers of the Fogera plain were mainly engaged in animal raring and production of few crop varieties. Due to the waterlogged nature of the area during the main rainy season, it was not suitable for the production of crops. But now a days, farmers and other peoples have mainly engaged in rice production and rice processing activities, and have improved their lives [3].

Rice planting methods (broadcasting, row planting, and transplanting) are also among the major factors limiting rice production. Rice row planting is reported to have a better yielding advantage over broadcast planting. Generating the appropriate spacing, based on crop and varietal differences in terms of tillering capacity and plant morphology is important [10] [11]. Such agronomic practices are tangibly addressed with the application of agricultural mechanization technologies. In the absent of proper land preparation using desirable mechanization implement, the production cannot be maximized and addressable.

Rice mechanization research team of Fogera, aims to develop new technologies for farmers that have key roles in meeting and contributing of food security [12]. Some rudimentary research was conducted in Ethiopia to improve small-scale mechanization implement such as animal-drawn plows, harvesters, threshers and storage technologies on major cereal and pulse crops (teff, maize, wheat, and haricot bean). Experience in Japan showed that timely field operations, increased rice acreages, yield and production are possible through the use of mechanization technologies (levelers, direct seeders, puddlers, and trans-planters) [13].

Land preparation in Ethiopia, is sequential cropping owing to the receipt of rainfall through two seasons per year in substantial parts of the country [14]. Farm operations to achieve timeliness of operations, efficient use of inputs, improvements in quality of produce and comfort of farmers, and reduction in loss of produce and drudgery, is highly desirable to sustain optimum levels of agricultural produce.

Despite the high promising value of rice to ensure food security, the cultivation method is very poor, traditional and inconvenient. The rapid coverage of rice production is limited by the back-warded tillage practices. So, rice mechanization is becoming the most focusing area in the rice sector. Farmers waste their energy, time, and money just sticking to the traditional practice. The Agricultural Engineering Research Directorate of Ethiopian Institute of Agricultural Research (EIAR) is therefore searching for an alternative and modern mechanization system to minimize their tiredness. The research directorate aims to shift the Ethiopian agriculture from draft power into mechanization. In this study, the performance and practicability of power tiller was evaluated in comparison with local draft animal power and the data had analyzed.

Objectives

- To evaluate the field performance of power tiller for rice production
- To evaluate the yield performance and economic advantages of power tiller and animal power for tillage
- To introduce and disseminate mechanization technology (power tiller) to the farmers

II. METHODOLOGY

A 10m X 40m plot of land with three replications from three districts was selected for a 15hp two-wheel tractor and the same area of the plot for conventional (pair of oxen) tillage. Eighty kilograms of X-Jigina rice variety was used for a total of 7200 m^2 plot and border area at a rate of 100 kg/ha. A total of 108 kg of Urea and 36 kg of DAP were applied at three stages with 150kg/ha and 50 kg/ha recommendations, respectively.

For the evaluation of the power tiller, the plot area was divided into two equal strips for 2 treatments with 3 blocks established on a plot size of (L×W) 40m×10m. The treatments were power tiller (PT) and conventional animal power (AP), which were arranged in a randomized complete block design (RCBD). AP practice was characterized by 3 repeated plowing with traditional oxen drew plow, 'Maresha'. The last plowing was done on the date of planting. For the field performance test and yield evaluation of the power tiller, an appropriate size of the land was selected from farmers' fields in Fogera, Dera, and Libo-Kemkem districts.

Soil parameters such as bulk density and moisture (inserting digital soil meter directly at different points of the plowing plot) were taken. The furrow width and operation depth (using steel scale meter), operation speed (dividing the total distance by the total working time), field capacity, and field efficiency were taken and determined. The field efficiency of the treatments from each test plots were collected and calculated using the mathematical equation given below.

$$FE = \frac{100 * Aw}{V * W\Delta T}$$

Where: FE = field efficiency (%); Aw = worked area during the test (m^2); ΔT = recorded period of time (s); W= nominal working width (m) and V = average speed (ms^{-1}). The field capacity of the power tiller was estimated by dividing the total working area to the total working time. Fuel consumption was also determined by measuring and subtracting the fuel level before and after the actual experimental work integrating with the tilled land and time. The yield and yield components such as population density (number of plants/meter), tiller number (number of branches per plant), plant height (in cm), panicle length (in cm), biomass and grain yield (in kg) were considered. Finally, the collected data had analyzed using Statistix 10 software and only the significant parameters discussed.

III. RESULTS AND DISCUSSION

Table 1 presents the data showing the tillage performance of the two treatments on some tillage parameters. The mean value of furrow width formed by the power tiller was found to be 29.951 cm. Whereas, the value for animal power was 26.142. The furrow width created by the power tiller disk plow is greater than that of the animal-driven traditional plow, "Maresha". The result is significantly different at P<0.05. The operation speed of the power tiller was significantly different (P<0.05) from the speed of animal power. The speed of the oxen was 2.214 km/hr, while that of the two-wheel tractor was 3.633 km/hr. The figure showed that the tillage practice using a power tiller was timely and speedy. The speed of draught oxen ranged from 0.86 to 0.96 for different body conditions [15].

The mean fuel consumption for the walking tractor was estimated to be 9.707 L/ha. The animal power does not require fuel during plowing rather they consume a continuous feed throughout their life span. The power tiller had significantly (P<0.05) higher field capacity compared with the animal power with values of 0.108 and 0.057, respectively. The experiment showed that using engine-driven tillage implement resulted in higher field capacities than the animal-driven local "Maresha". The field capacity and other tillage parameters of walking tractor determined by soil conditions [16]. Efforts to develop strip-tillage drills showed that two-wheeled tractors used conventional bent rotary blades that was designed for full disturbance of soil tillage resulted in poor furrow backfill and smeared furrows [17].

Table1: Effects of tillage types on tillage parameters

Treatments	Furrow width (cm)	Operation Speed (km/hr)	Fuel consumption (L/ha)	Field Capacity (ha.hr^{-1})	Field Efficiency (%)
PT	29.951^{a} ±2.212	3.633^{a}±0 .490	9.707^{a}±0 .754	0.108^{a}±0 .013	74.823^{a}±6.9 35
AP	26.142^{b} ±2.006	2.214^{b}±0 .2093	0.000^{b}±0 .000	0.057^{b}±0 .006	69.682^{b}±6. 499
α	0.05	0.05	0.05	0.05	0.05
CV	8.02	13.16	5.710	14.2	9.3
LSD	1.245	0.213	0.153	0.004	0.024

Note: PT: Power Tiller; AP: Animal Power

As shown in Table 2, the tillage frequency affected the speed of tillage operation significantly (P<0.05). The fastest speed operation was recorded for the third tillage, which was 3.069 km/hr. The first and the third tillage did not show a significant difference with each other, whereas, both showed significant difference from the second tillage operation. This might be due to the compaction of soil during the first tillage as a result of the highest moisture content.

The depth is significantly different at α=0.05 for tillage frequency. The first tillage operation was the shallowest in-depth (17.978 cm), the second showed the medium depth (18.950 cm) and the third resulted in the highest operation depth (22.956 cm). This might be due to the loosening and fines of the soil by the first and second tillage operations. The effect of tillage frequency had no effect for tillage one and three on actual field capacity, but tillage two had a significant effect with tillage one and three. This might be as a result of soil compaction by the first operation; the field capacity of the second operation had decreased. The soil structure matters the depth of tillage and yield of rice [18].

Table 2: Effects of tillage frequency on tillage parameters

Tillage frequency	Operation Speed (km/hr)	Operation Depth	Field Capacity (ha.hr^{-1})
1	2.994^{a}±0.818	17.978^{c}±1.240	0.084±0.030
2	2.707^{b}±0.692	18.950^{b}1.287	0.076^{b}±0.024
3	3.069^{a}±0.899	22.956^{a}1.009	0.088^{a}±0.029
α	0.05	0.05	0.05
CV	13.160	5.490	9.3
LSD	0.261	0.742	0.015

The location effect of the tillage types on the actual field capacity is shown in Table 3. Libokemkem and Dera weredas are not significantly different while the two districts are significantly different with Fogera district. For the overall mean value of the actual field capacity for the two treatments the least value was recorded at Fogera location, while the maximum value considering only location was shown in Libokemkem. This might be the soil's nature and the moisture content during tillage.

Table 3: Effect of Location on Fuel consumption and actual field operation

Location	Field Capacity (ha.hr^{-1})
Libokemkem	0.086^{a}±0.027
Fogera	0.078^{b}±0.029
Dera	0.084^{a}±0.028
α	0.05
CV	9.3
LSD	0.015

The fuel consumption of the power tiller was significantly different for the Libokemkem site, while its value was not significant for Fogera and Dera districts. The highest fuel consumption (10.05 L/ha) was observed at the Libokemkem-Bura location, whereas the lowest fuel consumption was recorded for Dera and Fogera with values of 9.411 and 9.661 L/ha respectively. This might be due to the highest clay soil proportion and moisture content at the Libokemkem-Bura site, because the more strong soil to till would consume more fuel.

The interaction of location and treatment had a significant effect on field capacity for the two treatments. The actual field capacity was not significant for power tiller across locations, but was significant comparing with the animal power. The highest field capacity of power tiller recorded in Libokemkem district, and the minimum field capacity belonged for the animal power at Fogera district.

Table 4: Interaction effect of location and tillage power source on fuel consumption and field capacity

Location	Treatment	Fuel consumption	Field Capacity (ha.hr^{-1})
Libokemkem	PT	10.050^{a}±0.825	0.111^{a}±0.010
Fogera	PT	9.661^{b}±0.599	0.104^{a}± 0.016
Dera	PT	9.411^{b}±0.758	0.110^{a}±0.011
Libokemkem	AP	0.000^{c}±0.000	0.061^{b}±0.003
Fogera	AP	0.000^{c}±0.000	0.051^{c}±0.006
Dera	AP	0.000^{c}±0.000	0.058^{bc}±0.006
α		0.05	0.05
CV		5.71	9.3
LSD		0.265	0.27

PT: Power Tiller; AP: Animal Power, values are mean ±SD

Table 5 presents the interaction effect of experiment location and tillage frequency on field capacity. The interaction of location and tillage frequency had a significant effect on the field capacity. The third tillage operation, for the three locations, was not significant for field capacity. The minimum value was recorded at the second tillage frequency of Fogera and Dera locations with values of 0.07 and 0.073ha.hr^{-1}, respectively. The highest value (0.09) under this experiment was recorded for the third tillage frequency and Dera location.

Table 5: Interaction effect of location and tillage frequency on fuel consumption and field capacity

Location	Tillage Frequency	Field Capacity (ha.hr^{-1})
Libokemkem	1	0.088^{a}±0.031
Libokemkem	2	0.083^{ab}±0.026
Libokemkem	3	0.087^{a}±0.028
Fogera	1	0.075^{bc}±0.031
Fogera	2	0.070^{c}±0.023
Fogera	3	0.089^{a}±0.036
Dera	1	0.088^{a}±0.031
Dera	2	0.073^{c}±0.026
Dera	3	0.090^{a}±0.029
α		0.05
CV		9.3
LSD		0.009

The interaction of tillage frequency and tillage power source were also significant ($P<0.05$) as shown in Table 6 below. The third tillage frequency showed the minimum fuel consumption rate, with a value of 8.908 L/ha, whereas, the highest values were observed for the first and second tillage frequencies. The fuel consumption for the first and the second tillage frequencies are not statistically different. The fuel consumption of walking tractor was 0.43L/hr at a depth and width of cut of 8.94 cm and 27.46 cm respectively [17].

Table 6: Interaction Effect of Tillage frequency and Treatment on Fuel consumption

Treatment	Tillage frequency	Fuel consumption (L/ha)
PT	1	9.994^{a}±0.350
PT	2	10.220^{a}±0.644
PT	3	8.908^{b}±0.452
AP	1	0.000^{c}±0.000
AP	2	0.000^{c}±0.000
AP	3	0.000^{c}±0.000
α		0.05
CV		5.71
LSD		0.2653

The interaction of three factors showed significance difference on fuel consumption for power tiller. The maximum fuel consumption across location and tillage frequencies were found to be 10.833 L/ha at the second tillage operation of Libokemkem site. The minimum fuel consumption (8.550 L/ha) was found at Dera location for the third tillage operation.

Table 7: interaction of location, tillage frequency and Treatment on Fuel consumption

Location	Tillage Frequency	Treatment	Fuel Consumption
Libokemkem	1	PT	10.167^{bc}±0.153
Fogera	1	PT	9.717^{cd}±0.284
Dera	1	PT	10.100^{bc}±0.458
Libokemkem	2	PT	10.833^{a}±0.635
Fogera	2	PT	10.243^{b}±0.140
Dera	2	PT	9.583^{de}±0.246
Libokemkem	3	PT	9.150^{ef}±0.377
Fogera	3	PT	9.023^{f}±0.464
Dera	3	PT	8.550^{g}±0.397
α			0.05
CV			5.71
LSD			0.4595

Table 8 presents the data showing the effects of location on yield and yield components of rice. The rice plant population ranged between 11.5 and 24.667 per meter. The highest population had observed in the Libokemkem location and the minimum at Fogera. The number of tillers had ranged from 6.667 to 10.333 per plant for randomly selected plants. The panicle length ranged from 14.5 to 16.833 cm. The fresh and dry biomass of the rice obtained at Libokemkem was significantly different from Fogera and Dera locations. Both weights of biomass were maximum at Libokemkem district. The values were not significant for Dera and Fogera districts. In the same way, the grain yield in Libokemkem wereda was higher whereas for the rest two districts the value was not significant. Tillage practice using a power tiller (walking tractor) was preferred and advanced for comparative agronomic evaluation with animal power (AP). The grain yield was found to be 2.386 and 2.184 (ton/ha) for PT and AP, respectively [2].

Table 8: Yield data across location

Location	Fresh BM (ton/ha)	Dry BM (ton/ha)	Grain weight (ton/ha)
Libo kemkem	15.67^{a}±0.225	11.33^{a}±0.209	5.12^{a}±0.027
Fogera	12.72^{b}±0.313	8.75^{b}±0.069	4.60^{b}±0.021
Dera	11.67^{b}±0.103	9.00^{b}±0.109	4.57^{b}±0.026
α	0.05	0.05	0.05
CV	16.97	13.89	4.56
LSD	0.291	0.173	0.028

Table 9 shows the effect of tillage power source on tiller number and grain yield. The power source had a significant difference (P<0.05) on the number of tiller and grain yield. Both parameters had higher results for power tiller compared to the animal-drawn local 'Maresha' implement.

Table 9: Effects of tillage power sources on the number of tiller formation and grain yield

Treatments	Number of tillers (number/plant)	Grain yield (ton/ha)
PT	9.222^{a}±2.333	4.92^{a}±0.031
AP	7.000^{b}±2.449	4.61^{b}±0.033
α	0.05	0.05
CV	14.53	4.56
LSD	1.238	0.023

Economic Analysis

Evaluating the performance of power tiller is very crucial for comparative economic analysis of power tiller and animal power for tillage. A pair of oxen having 300-400 kg of body weight requires 30-40 kg of grass and about 30 liters of water per day. (Source: farmers' interview)

Walking tractors work for about 6 days (with 10 working hours daily) in one cropping season for a farmer having 2 hectares of land. This shows for an average field capacity of 10 $hr.ha^{-1}$ about 60 Liters of fuel is required with 10 L/ha consumption rate, which means 60L*25ETB=1500 ETB. For service and maintenance about 1500 ETB is required, for one cropping season (6 months) the farmer costs 3000 ETB for tillage if he drives by himself the walking tractor. However, using a pair of oxen (30-40 kg forage)*30days*6months=5400-7200 kg of forage is required. This can be expressed locally in terms of man carrying bundles (on average 50 kg) of 108-144 carrying bundles, each costing about 200 ETB and total price 21,600-28,800 ETB. And for water intake, a 60L*30days*6months=10,800 liter of water is required. If we multiply it by 30 cents/Liter (cheap price) (0.3*10,800), the result becomes 3240 ETB. This indicates that over 30,000 ETB is required even forgetting the costs of keeping and cleaning their house.

In terms of time, the walking tractor can cover one hectare of land within 9.259 hours (field capacity 0.108 $ha.hr^{-1}$), whereas using draught animals it took 17.544 hours which was 8 hours delayed than the power tiller. This also can be further interpreted in terms of money. The samples taken from the power tiller tilled plot obtained 4.92 tons of rice while the samples taken from animal power tilled was 4.61 tons per hectare, which was 0.31 tones less than that of the power tiller tilled plot.

Generally, once the walking tractor purchased, the cost of operation is much less than the cost of using animal power by over 10 folds.

IV. CONCLUSIONS

The field performance of the long-handled walking tractor that was imported from Thailand had evaluated in comparison with the local tillage operation by the animal (pair of oxen). The soil where the experiment was conducted was the most difficult soil. Due to the soil nature, both treatments performed unsatisfactory result. However, comparing the two treatments, the power tiller having 15hp had better performance. The result showed that using a power tiller for rice production was effective in terms of operation cost, time consumption, and yield increment. The power tiller had better field capacity and field efficiency compared to the control. The fuel consumption of power tiller showed a reduction when the tillage frequency was increased from one to three. However, the field capacity and field efficiency had minor differences along location. This might be due to the similarities of soil property. However, to achieve these advantages the farmers have to get enough training about the operation and have to choose tolerable soil moisture content. Finally, the authors recommended that the power tillers having more than 15hp can perform well at a tolerable condition even if the soil is hard.

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