

PERFORMANCE EVALUATION OF SELF PROPELLED SIX ROW TEFF SEEDLING TRANSPLANTER

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ABSTRACT

To study the performance of the developed teff transplanting machine, the parameters used were hill spacing (cm), number of seedlings per hill (No.), transplanting depth (cm), missing hills (%), defective hills (No.), buried hills (%), damaged hills (%), floating hills (%), transplanting efficiency (%), time requirement (min), fuel consumption (L), field capacity (ha h⁻¹), and field efficiency (%). The experiments were carried out using a randomized complete block design (RCBD) comparing machine transplanting and manual transplanting. Both transplanting methods were evaluated at three seeding rates of 60, 80, and 120 g per tray and three forward speeds of 0.6, 0.8, and 1.2 km h⁻¹. Each treatment was replicated three times. Data analysis was performed using ANOVA, and the comparison of means was determined using the Least Significant Difference (LSD) test at the 5% level of significance. The mean values of hill-to-hill spacing (13.82 and 12.96 cm), number of seedlings per hill (3.94 and 5.00 No.), and transplanting depth (3.79 and 4.04 cm) for the two treatments, respectively, showed no significant difference at the 5% probability level. However, the mean values of missing hills (9.69 and 12.72%), floating hills (1.78 and 4.61%), buried hills (1.39 and 3.36%), damaged hills (2.22 and 7.72%), defective hills (15.11 and 28.56%), and transplanting efficiency (84.89 and 71.44%) differed significantly at the 5% probability level. The actual field capacity, effective field capacity, and field efficiency of the machine and manual transplanting were 0.055 and 0.011 ha h⁻¹, 0.037 and 0.0099 ha h⁻¹, and 67.27% and 87.61%, respectively.

አህጽራት

የጤፍ ተከላ የጤፍ ምርትን ሊያሻሽሉ ከሚችሉ ስራዎች አንዱ ነው። አርሶ አደሮች የጤፍ ችግኝን የሚተከሉት የሰው ጉልበት በመጠቀም ሲሆን ብዙ የሰው ሃይል የሚፈጅ ለውጥ ሲኖር ነው። እንዲህ ላለው ከፍተኛ የተከላ ሥራ ምክንያቱ የሜካኒካል የጤፍ መትኪያ ባለመኖሩ ነው። የጤፍ ንቅለተከላ ማሸን አፈጻጸምን ለመገምገም የሚከተሉት መለኪያዎች ጥቅም ላይ የዋሉ ሲሆን እነሱም ሂል-ቱ-ሂል ስፔሲንግ (ሴ.ሜ)፣ የተተከሉ ችግኞች ብዛት (ቁ)፣ የመትከል ጥልቀት (ሴ.ሜ)፣ የሳይሉ ሂል (%)፣ የተንሳፈሩ ሂል (%)፣ የተቀበሩ ሂል (%)፣ የተበላሹ ሂል (%)፣ የመትከል ቅልጥፍና፣ ፊልድ ካፓሲቲ (ሂ ሰ) እና የካይፎ ፍጆታ (ሊት) ተለክተዋል። ሙከራው የተካሄደው በዘፈቀደ የተሟላ ብሎክ ዲዛይን (RCBD)። በአጅ መትከል እና የማሸን ትራንስፕላንት በሶስት የዘርያ መጠን 60 ግራም በአንድ ትሪ፣ 80 ግራም በአንድ ትሪ፣ እና 120 ግራም በአንድ ትሪ፣ የማሸን ፍጥነት፣ 0.6 ኪ.ሜ በሰአት፣ 0.8 ኪ.ሜ በሰአት፣ 1.2 ኪ.ሜ በሰአት። እያንዳንዱ ፓራሜትር ሦስት ጊዜ ተደግሟል። መረጃው ANOVAን በመጠቀም የተተነተነ ሲሆን የትርጉም ንፅፅሩም በ5% ትርጉም ደረጃ ትንሹ ጉልህ ልዩነት በመጠቀም ተወስኗል። ሂል ቱ ሂል ያለው ከፍተኛ አማካይ 13.82፣ 12.96 ሴ.ሜ፣ በአንድ ሂል ላይ ያሉ ችግኞች ቁጥር 3.94, 5.00 no.; የመትከሉ ጥልቀት 3.79፣ 4.04cm ከሁለቱ ትራት መንገድ በቅደም ተከተል፣ ውጤቱም አማካይ እሴቶቹ በ 5% የመቻል ደረጃ ላይ ከፍተኛ ልዩነት እንደሌላቸው አረጋግጧል። የተዘለሉ ሂል አማካኝ ዋጋዎች 9.69, 12.72%; የተንሳፈሩ ሂል, 1.78, 4.61%; የተቀበሩ ሂል 1.39, 3.36%; የተበላሹ ሂል, 2.22, 7.72%; ጉድለት ያለባቸው ሂል 15.11, 28.56%; የመትከል ውጤታማነት 84.89, 71.44% በ 5% የመቻል ደረጃ ላይ ከፍተኛ ልዩነት አላቸው። ትክክለኛው የመስክ አቅም, ውጤታማ የመስክ አቅም, የማሸን የመስክ ብቃት 0.055ha h⁻¹, 0.011 ha h⁻¹, 0.037 ha h⁻¹, 0.0099 ha h⁻¹, 67.27%፣ 87.61% በቅደም ተከተል ናቸው።

INTRODUCTION

Teff is a staple cereal crop that is predominantly grown under rainfed farming systems and is highly contingent on the pattern and adequacy of seasonal rainfall. Beyond its foundational role in food security, teff is attracting increasing global attention due to its gluten-free characteristics, which align with rising consumer demand for gluten-free products (Jemal M.K., 2018).

Nutritionally, teff grain tends to be relatively rich in calcium, iron, and lysine compared with many other cereals, contributing to its appeal as a nutrient-dense food source (Spaenij-D., 2005; Zhu F., 2018). This expanding international interest underscores teff's potential to serve both as a domestic staple in Ethiopia and as a valuable export commodity, which in turn highlights the demand for supportive policies that can foster growth at both local and global scales.

In spite of its importance, average teff yields remain modest, typically around 1.9 t ha⁻¹ (Kidu, 2025; Hailu Feyisa et al., 2023). This yield ceiling reflects several agronomic and logistical challenges faced by producers, including labor intensive cultivation practices and management constraints that influence plant establishment, weed and pest pressure, and resource use efficiency.

One key agronomic practice transplanting has the potential to raise biological yield, but it comes with notable labor requirements. Manual transplantation, which involves handling seedlings and performing line marking, can demand substantial labor input approximately 300 up to 350 man-hours per hectare. Such labor intensity can be a bottleneck, particularly during peak seasons, and may cause delays that ultimately reduce yields (Tamanna et al., 2018). In contrast, mechanical transplanters offer considerable cost and time savings: studies indicate that transplanting costs can be reduced by about 66% and time requirements by roughly 93% when using mechanical transplanters compared with manual methods (Sharma et al., 2002). Self-propelled transplanters further enhance timeliness and can deliver additional labor savings (Sharma et al., 2002). Nevertheless, despite these advantages, the adoption of transplanting technology in Ethiopia remains limited. This gap points to the need for affordable, small scale transplanting solutions that are accessible to smallholder farmers and compatible with local farming practices.

Another common practice in teff cultivation is broadcasting seed at relatively high rates (roughly 25 up to 50 kg ha⁻¹), which increases plant density and elevates the risk of lodging. High-density plantings can also intensify insect pressure and lead to intensified competition for nutrients and light, complicating weed management and pest control and often resulting in suboptimal yields. On the other side, agronomic interventions that improve seedling establishment and plant spacing such as transplanting seedlings can help mitigate lodging and improve crop performance. Evidence from various studies suggests that transplanting teff seedlings at intra-row spacings of about 10–15 cm can enhance yield relative to broadcasting, while also reducing lodging. For instance, earlier research by Tareke B. (2010), Zewdie G.T. (2010), and Teklu Y. (2005) reported yield gains associated with optimized transplanting practices. Lodging, a major constraint on teff production, can cause losses estimated up to about 30%, underscoring the potential value of improved establishment methods (Tareke B., 2013). Recent results indicate that transplanted teff often shows lower lodging indices compared with broadcasting, pelleting, or row planting, though the outcomes can vary depending on the specific method and environmental context (Kidu, 2025; Yadav et al., 2024). Additionally, transplanting may promote better root development and more efficient uptake of nutrients and water, potentially enhancing nitrogen-use efficiency and vegetative growth without increasing lodging (Thakur A.K. et al., 2023). However, these agronomic benefits must be weighed against the higher labor costs of transplanting, particularly in smallholder contexts, where labor-saving machinery and affordable equipment are essential for economic viability (Fekremariam, 2020).

The aim of this study is to determine the performance of a Self-Propelled Six-Row Teff Seedling Transplanter in comparison with manual transplanting. The assessment focuses on key performance indicators such as crop establishment, seedling uniformity, percentage damage, missing index, field capacity, field efficiency, and fuel consumptions.

MATERIALS AND METHODS

Experimental Site

This study was conducted at Melkasa Agricultural Research Center (MARC). Melkassa is located in the Central rift Valley of Ethiopia. The place is situated at an altitude of 1466 m above sea level and lies on the geographical coordinates of 8° 24' 0" N, 39° 20' 0" E Latitude and Longitude respectively. It receives 763 mm mean annual rainfall, of which 70% falls during the major cropping season: June to September. The dominant soil type in the area is sandy loam.

Description of Self-propelled Teff Seedling Transplanter

The machine is designed to address transplanting operation of teff seedling (TST). It is propelled by a 5 hp gasoline engine, utilizing belt and pulley from engine to main shaft, then chain and sprocket from main to secondary and third shaft as power transmission and speed reduction system.

The engine's rotational speed (rpm) is initially reduced four times before being transferred to the main shaft. From the main shaft, the rpm is further reduced four times to reach the secondary shaft. The power is then reduced another four times and transmitted to the wheel shaft and the third shaft.

The third shaft is integral to the transplanter's operation, as it incorporates key components such as the cranking arm, cranking finger, and connecting square pipe. As the shaft rotates, the cranking arm completes a full 360-degree rotation, while the connecting square pipe and cranking finger reciprocate in an up-and-down motion. This reciprocating action enables the cranking finger to pick up seedlings during its downward motion and place them into the soil, returning to its original position during the upward motion by following a precise trajectory.

The wheel shaft is equipped with a driven wheel, which propels the machine forward at a walking speed. Additionally, the seedling tray, front wheel, and tray side movement mechanism are linked onto the wheel of the transplanter, ensuring smooth operation and seedling placement. Teff seedlings, grown in a nursery, are placed on the seedling tray of the mechanical transplanter. As the machine moves across the puddled field, the grasping fork of the transplanting arm extracts a preset number of seedlings from the seedling mat. The transplanting arm is actuated by a cranking mechanism connected to the third shaft, which directs the seedlings into the puddled soil. After each transplanting cycle, the fork arm resets to its original position, ready for the next stroke. This design ensures efficient, precise, and consistent transplanting of teff seedlings, tailored to the needs of agricultural practices in puddled fields.

Experimental setup and Field evaluation

The purpose of this study was to assess the field performance of a self-propelled six-row Teff transplanter at the experimental farm of the Melkasa Research Center (MARC). It features fixed planting depth, number of seedlings per hill, hill spacing, and transplanting speed, as well as adjustable row spacing of 15 to 20 cm. Table 1 lists the machine's specific technical characteristics. Mat-type seedlings were raised in the metal trays. This was accomplished by evenly spreading the teff seeds of a high-yielding cultivar, Quncho (DZ-Cr-387), across the trays at three seeding rates of 60 g, 80 and 120 g tray⁻¹. The mat seedlings were ready for transplanting when they had four to three leaves and were thirty days old, with an average height of 14 cm. The trays were covered with fine soils. The field was prepared using standard tillage techniques, which include leveling with a tractor-drawn leveler, secondary tillage with a disc harrow twice, and initial plowing with disc plough once.

Table 1

Specification of the Developed Teff Seedling Transplanter

Types of machine	Self-Propelled Walking-Type Teff Transplanter
Engine	Air cooled, 4 cycle gasoline engines
Engine power (hP rpm ⁻¹)	5/2800 rpm
Overall dimensions (LxWxH)	2.20 m x 2.60 m x 1 m
Weight (Kg)	200 kg
Number of rows	6 rows
Rows Spacing(cm)	15-20(adjustable)
Hill Spacing(cm)	10-15
Wheel diameter(cm)	50
Wheel width(cm)	12
Transmission type	Pulley and belt; chain and sprocket
Planting finger	Finger arm
Metering unit	Four-link crank mechanism
Seedling type	Mat-type seedling
Mat seedling box	58x27x3
Field capacity, ha h ⁻¹	0.072-0.1

Before the tests started, all required adjustments, including hill spacing, number of plants per hill, and planting depth, were made based on the design of the prototype and agronomic considerations. The row and hill spacing for teff cultivation was considered 10 to 15 cm (Fekremariam M., 2020; Worku Kebede, 2022). To evaluate the performance of the teff transplanting machine, the parameters presented in Table 2 were followed, and data were recorded on hill spacing (cm), number of seedlings per hill (No.), transplanting depth (cm), missing hills (%), floating hills (%), buried hills (%), damaged hills (%), defective hills (No.), transplanting efficiency (%), time taken (min), field capacity (ha h^{-1}), field efficiency (%), and fuel consumption (L). The experiments were conducted using a randomized complete block design (RCBD) involving both machine and manual transplanting. Both transplanting methods were evaluated at three seeding rates of 60, 80, and 120 g tray^{-1} and at three forward speeds of 0.6, 0.8, and 1.2 km h^{-1} . Each treatment was replicated three times. Data analysis was performed using ANOVA, and mean comparisons were assessed using the Least Significant Difference (LSD) test at the 5% level of significance.

Table 2

Parameters to Study the Performance of the Machine			
No.	Variables	Levels	Rep.
Independent Variables			
1	Seed rate (60g, 80g, 120g) tray^{-1}	3	3
2	Age of seedling (30 days old)	1	3
4	Transplanted mechanism: Manual Vs Developed Teff transplanter	2	3
5	Forward speed, 0.6, 0.8, 1.2 km h^{-1}	3	3
Dependent Variables			
6	Hill spacing, cm		3
7	Number of seedlings hill^{-1} , No.		3
8	Transplanting depth, cm		3
9	Missing hills, %		3
10	Floating hills, %		3
11	Buried hills, %		3
12	Damaged hills, %		3
13	Defective hills, No.		3
14	Transplanting efficiency, %		3
15	Time requirement, min.		3
16	Field capacity, ha h^{-1}		3
17	Field efficiency, %		3
18	Fuel consumption, L.		3

Hill spacing: Ten random observations were taken, and the means were calculated to represent hill spacing. Hill-to-hill spacings were measured after transplanting by using metric scale.

Number of seedlings per hill: The number of teff seedlings per hill was calculated by taking ten random observations and calculating the means. By counting the number of teff seedlings selected by the planting finger and then placed in the field per hill following transplanting, the number of seedlings per hill was determined.

Transplanting depth: Immediately upon transplanting, the teff seedlings were uprooted in order to determine the depths of teff transplantation. In order to uproot them, the teff seedlings were kept near the surface of the puddled soil. Five random observations were made to determine the transplanting depth, and the distance between that point and the tip of the roots was measured using a scale.

Missing hills: It is the hills where no teff seedlings are transplanted due to failure of fingers to pluck seedlings from tray. The numbers of missing hills were counted along with total number of hills in a 10 m area after operation.

The percentage of the missing hills was calculated using the following formula.

$$\text{Missinghills, \%} = \frac{\text{Number of Missinghills}}{\text{Total number of hills}} \times 100 \quad (1)$$

Floating hills: It is the hills where all the seedlings in a hill were either floating on the ground or just placed on the surface of the mud due to weak anchoring. After operation floating hills were counted with total number of hills in a 10 m length area. The percentage of floating hills was calculated using the following formula.

$$\text{Floatinghills, \%} = \frac{\text{Number of Floatinghills}}{\text{Total number of hills}} \times 100 \quad (2)$$

Buried hills: Hills which are completely buried under soil after transplanting are called buried hill. Buried hills were counted with total number of hills in a 20 m area after operation. The percentage of the buried hills was calculated using the following formula.

$$\text{Buried hills, \%} = \frac{\text{Number of Buried hills}}{\text{Total number of hills}} \times 100 \quad (3)$$

Damaged hills: These can be divided into two categories. Damage is caused by cutting or bending of the seedlings or by internal damage to the growing point of the seedling due to crushing by the planting fork. This definition includes only damage that can be detected by observation and counted.

$$\text{Damaged hills, \%} = \frac{\text{Number of damaged hills}}{\text{Total number of hills}} \times 100 \quad (4)$$

Defective hills: Total defective hills are the sum of missing hills, floating hills, buried hills and damaged hills.

Transplanting efficiency: Transplanting efficiency is the percentage of seedlings placed correctly. It is calculated by subtracting total defective hills from 100%.

Time requirement is an important parameter for the operation. The time at the start and completion of transplanting was recorded to determine the effective transplanting time. In addition, the time required for turning at the field edges, refilling the transplanter trays with seedlings, and repairing breakdowns was recorded. These additional times were considered as time losses for the transplanting operation.

Effective field capacity is the actual rate of area coverage by a machine. Effective field capacity was determined using the following relationship:

$$\text{Effective field capacity, } \text{ha h}^{-1} = \frac{\text{Total area covered (ha)}}{\text{Total time taken (hr)}} \quad (5)$$

The total time taken in above relationship includes time losses in turning, loading of mat nursery and machine adjustment required during operation.

Field efficiency is the ratio between the productivity of a machine under field conditions and the theoretical maximum productivity and it can be calculated using the following equation (Mehta et al., 2005):

$$\text{Field efficiency, \%} = \frac{\text{Effective field capacity (ha h}^{-1}\text{)}}{\text{Theoretical field capacity (ha h}^{-1}\text{)}} \times 100 \quad (6)$$

The theoretical field capacity was determined using the following relationship:

$$\text{Theoretical field capacity, (ha h}^{-1}\text{)} = \frac{W \times S}{10} \quad (7)$$

where, W is width of operation (m), S is speed of operation (km h^{-1})

Fuel consumption: Before starting the field operation, the fuel tank of the machine was filled. The duration of the field operation was recorded. After completion, the fuel tank was refilled, and the quantity of fuel added was noted. Fuel consumption was calculated using the method described by Mehta et al. (2005). The field operation and fuel refilling were recorded for this purpose.

$$\text{Fuel consumption (L h}^{-1}\text{)} = \frac{Ft}{T} \quad (8)$$

Where:

F = Fuel consumption rate, (L h^{-1});

Ft = Fuel used during operation, (L);

T = Total time needed for operation, (h).

RESULTS

Tables 3 through 5 and Figures 1 through 9 depict the recorded performance of the developed teff seedling transplanter compared with manual transplanting.

Table 3

Effect of treatments on selected dependent parameters

Treat ment		HTHS*	NSph*	DepthT*	Mhills*	Fhills*	Bhills*	Dhills*	Defhills*	Tefficiency*	TTime*
		[cm]	[no']	[cm]	[%]	[%]	[%]	[%]	[%]	[%]	[min]
Manu- al	Mean	13.82a	3.94a**	3.79a	9.61a	1.78a	1.39a	2.22a	15.11a	84.89a	6.39
	N	18	18	18	18	18	18	18	18	18	18
	S. D	2.536	1.697	.673	3.032	1.060	1.092	.808	3.411	3.411	1.38
	Min	10	2	3	6	0	0	1	10	80	4.00
	Max	18	7	5	15	4	3	4	20	90	8.80
Ma- chine	Mean	12.96a	5.00b	4.04a	12.72b	4.61b	3.56b	7.72b	28.56b	71.44b	1.31
	N	18	18	18	18	18	18	18	18	18	18
	S. D	2.402	1.237	.543	3.594	1.614	1.042	1.406	6.119	6.119	.236
	Min	9	3	3	7	3	2	6	19	61	1.00
	Max	16	8	5	19	7	6	11	39	81	1.80

*HTHS (hill-to-hill spacing), NSph (Number of seedlings per hill), DepthT (Transplanting depth), Mhills (Missing hills), Fhills (Floating hills), Bhills (buried hills), Dhills (damaged hills), Defhills (defective hills), Tefficiency (Transplanting efficiency), TTime (Time taken). ** The means followed by the letter do not have a significant difference, at the 5 percent level of probability.

Table 4

Effect of seed rate on selected dependent parameters

Seed rate, (g)		HTHS*	NSph*	DepthT*	Mhills*	Fhills*	Bhills*	Dhills*	Defhills*	Tefficiency*	TTime*
		[cm]	[no.]	[cm]	[%]	[%]	[%]	[%]	[%]	[%]	[min]
60	Mean	14.02a*	3.08a	4.02a	9.75a	3.75a	2.08a	4.92a	20.58a	79.42a	3.25a
	N	12	12	12	12	12	12	12	12	12	12
	S. D	1.657	.900	.459	2.417	1.815	1.311	2.678	7.051	7.051	2.15
	Min	11	2	3	6	1	0	2	12	67	1.20
	Max	16	4	5	14	7	4	9	33	88	7.00
80	Mean	12.53a	4.50b	3.66a	8.67b	2.58a	2.17a	4.58a	18.00b	82.00b	3.97a
	N	12	12	12	12	12	12	12	12	12	12
	S. D	1.596	1.314	.604	2.146	1.505	1.467	2.575	6.564	6.564	2.65
	Min	10	3	3	6	0	0	1	10	74	1.20
	Max	16	7	5	12	5	4	8	26	90	7.30
120	Mean	13.63a	5.83c	4.07a	15.08c	3.25a	3.17a	5.42a	26.92c	73.08c	4.33a
	N	12	12	12	12	12	12	12	12	12	12
	S. D	3.588	1.030	.723	2.429	2.454	1.642	3.825	9.219	9.219	3.45
	Min	9	5	3	10	0	0	1	14	61	1.00
	Max	18	8	5	19	7	6	11	39	86	8.80

*HTHS (hill-to-hill spacing), NSph (Number of seedling per hill), DepthT (Transplanting depth), Mhills (Missing hills), Fhills (Floating hills), Bhills (buried hills), Dhills (damaged hills), Defhills (defective hills), Tefficiency (Transplanting efficiency), TTime (Time taken). ** The means followed by the letter do not have a significant difference, at the 5 percent level of probability.

Table 5

Effect of forward speed on selected dependent parameters

Speed, (km h ⁻¹)		HTHS*	NSph*	DepthT*	Mhills*	Fhills*	Bhills*	Dhills*	Defhills*	Tefficiency*	TTime*
		[cm]	[no.]	[cm]	[%]	[%]	[%]	[%]	[%]	[%]	[min]
0.6	Mean	14.02a**	3.08a	4.02a	9.75a	3.75a	2.08a	4.92a	20.58a	79.42a	3.25a
	N	12	12	12	12	12	12	12	12	12	12
	S. D	1.657	.900	.459	2.417	1.815	1.311	2.678	7.051	7.051	2.15
	Min	11	2	3	6	1	0	2	12	67	1.20
	Max	16	4	5	14	7	4	9	33	88	7.00
0.8	Mean	12.53a	4.50b	3.66a	8.67b	2.58a	2.17a	4.58a	18.00b	82.00b	3.96a

Speed, (km h ⁻¹)	HTHS*	NSph*	DepthT*	Mhills*	Fhills*	Bhills*	Dhills*	Defhills*	Tefficiency*	TTime*	
	[cm]	[no.]	[cm]	[%]	[%]	[%]	[%]	[%]	[%]	[min]	
N	12	12	12	12	12	12	12	12	12	12	
S. D	1.596	1.314	.604	2.146	1.505	1.467	2.575	6.564	6.564	2.65	
Min	10	3	3	6	0	0	1	10	74	1.20	
Max	16	7	5	12	5	4	8	26	90	7.30	
1.2	Mean	13.63a	5.83c	4.07a	15.08c	3.25a	3.17a	5.42a	26.92c	73.08c	4.33a
N	12	12	12	12	12	12	12	12	12	12	
S. D	3.588	1.030	.723	2.429	2.454	1.642	3.825	9.219	9.219	3.44	
Min	9	5	3	10	0	0	1	14	61	1.00	
Max	18	8	5	19	7	6	11	39	86	8.80	

*HTHS (hill-to-hill spacing), NSph (Number of seedling per hill), DepthT (Transplanting depth), Mhills (Missing hills), Fhills (Floating hills), Bhills (buried hills), Dhills (damaged hills), Defhills (defective hills), Tefficiency (Transplanting efficiency), TTime (Time taken). ** The means followed by the letter do not have a significant difference, at the 5 percent level of probability.

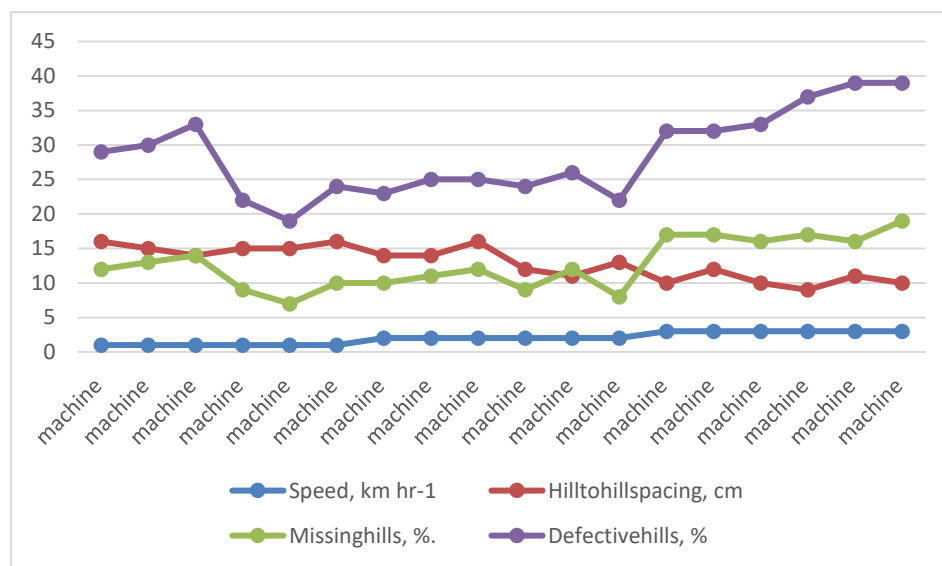


Fig. 1 - Effect of forward speed on hill-to-hill spacing, missing hills (%), and defective hills of the teff transplanter

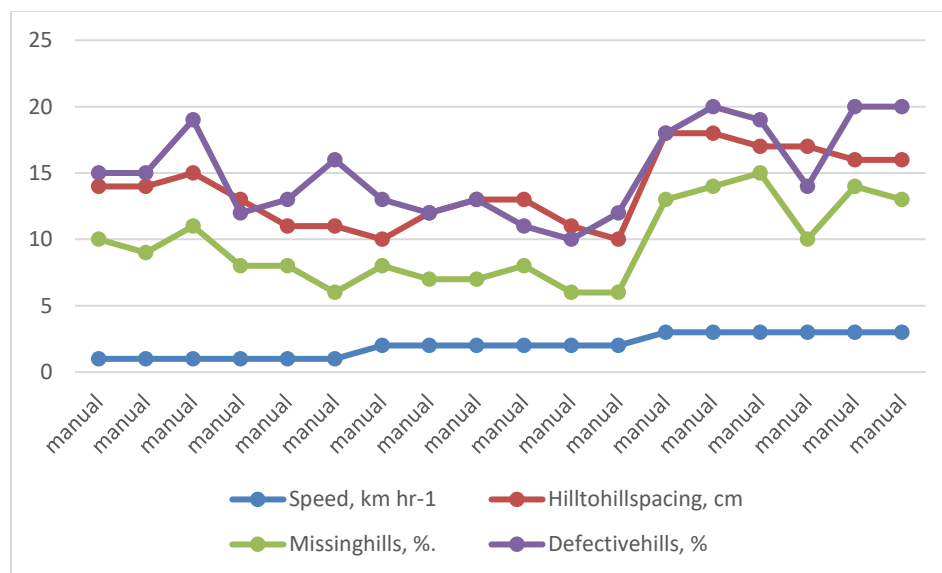


Fig. 2 Effect of forward speed on hill-to-hill spacing, missing hills (%), and defective hills under manual transplanting

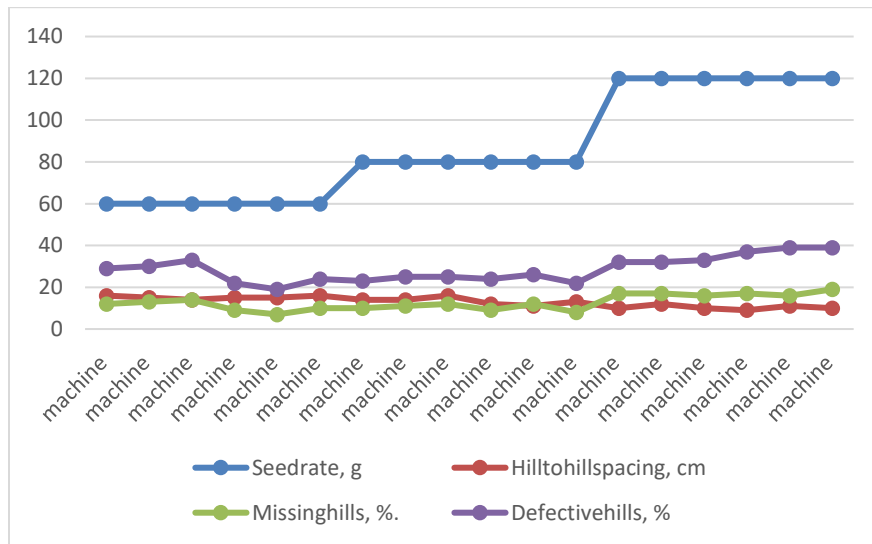


Fig. 3 - Effect of seed rate on hill-to-hill spacing, missing hills (%), and defective hills of the teff transplanter

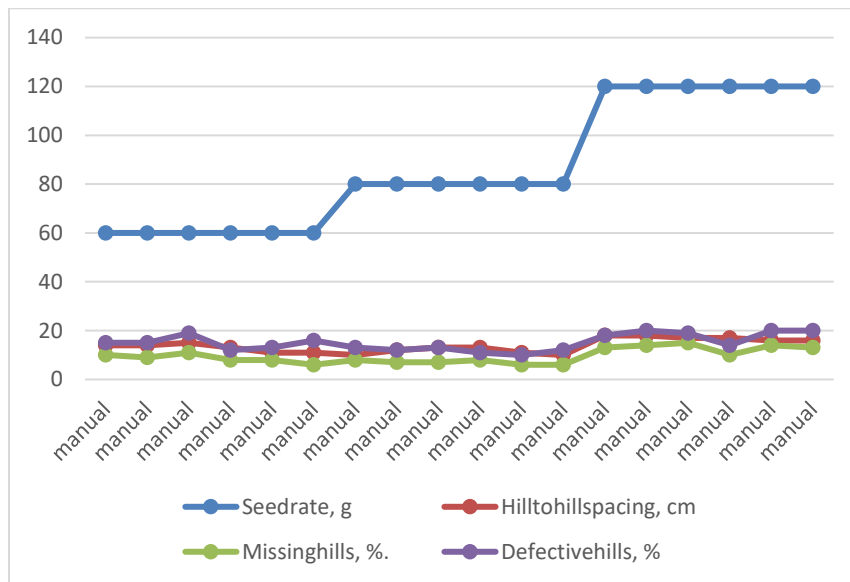


Fig. 4 - Effect of seed rate on hill-to-hill spacing, missing hills (%), and defective hills under manual transplanting

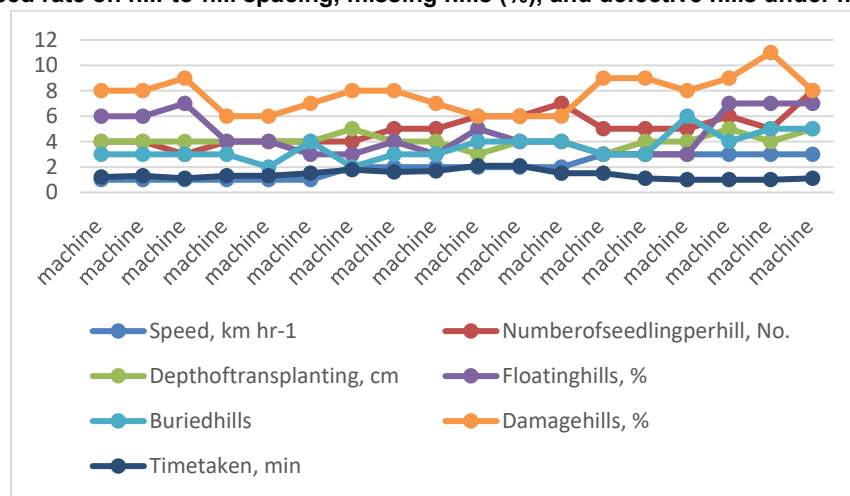


Fig. 5 - Effect of forward speed on number of seedlings per hill (No.), floating hills (%), buried hills (%), damaged hills (%), and time taken (min) of the teff transplanter

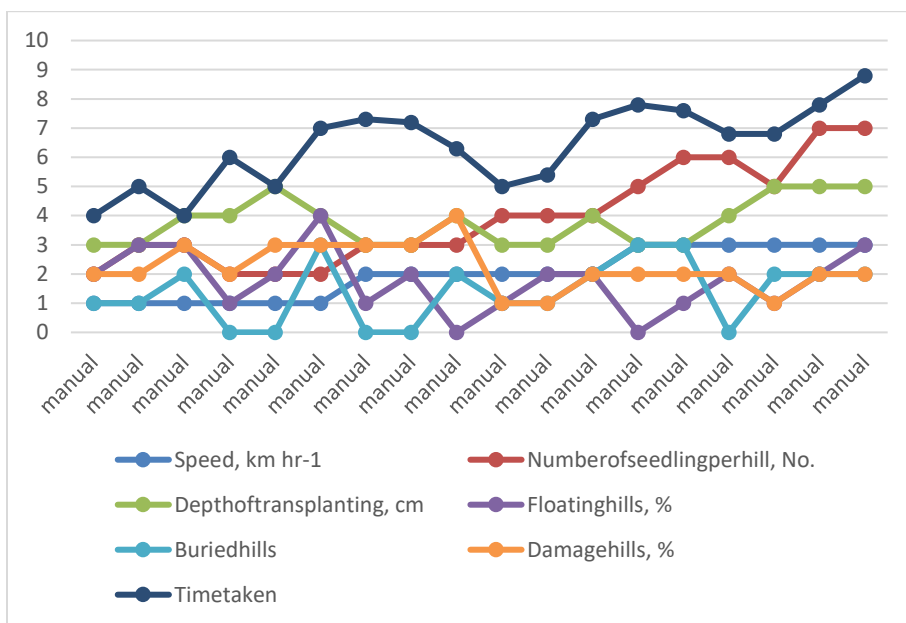


Fig. 6 - Effect of forward speed on number of seedlings per hill (No.), floating hills (%), buried hills (%), damaged hills (%), and time taken (min) under manual transplanting

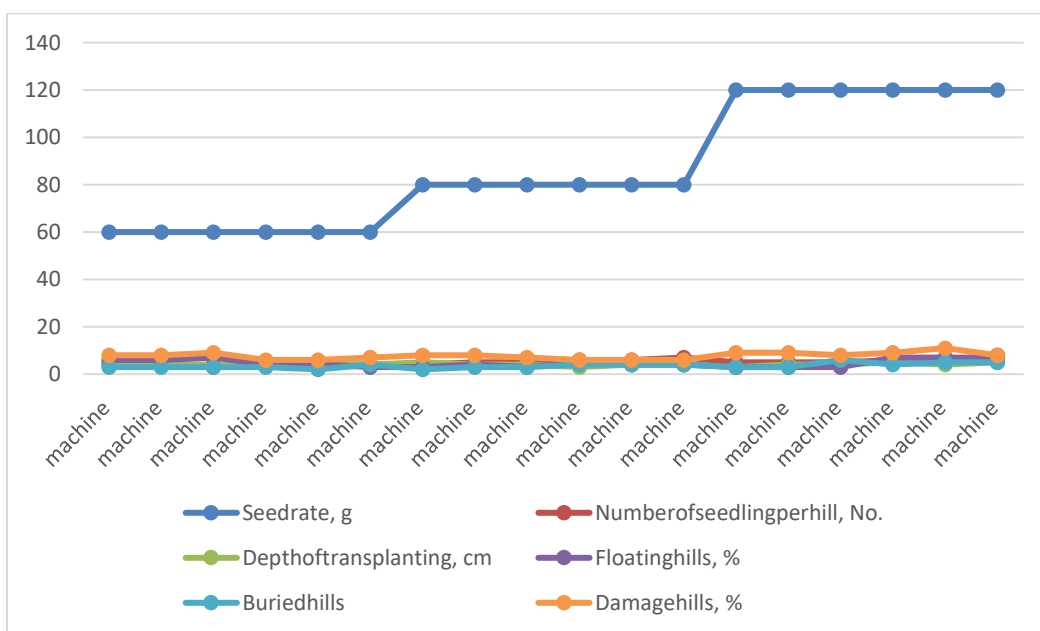


Fig. 7 - Effect of seed rate on number of seedlings per hill (No.), floating hills (%), buried hills (%), damaged hills (%), and transplanting depth of the teff transplanter

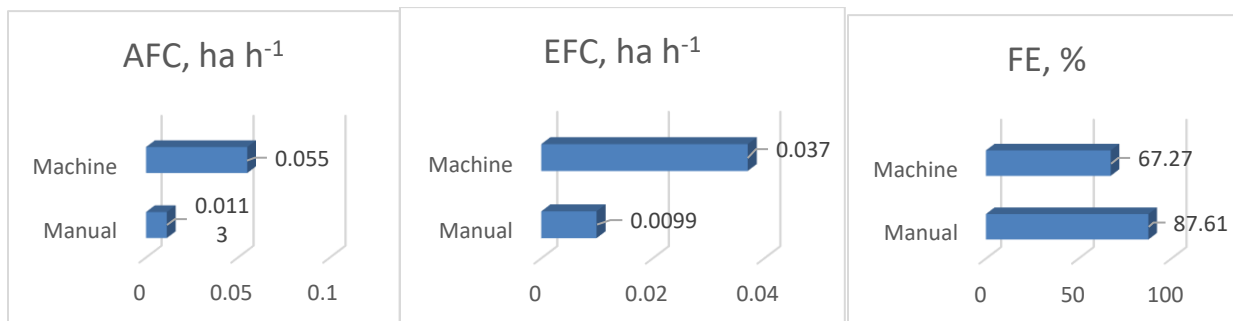


Fig. 8 - Actual field capacity (AFC, ha h⁻¹), effective field capacity (EFC, ha h⁻¹), and field efficiency (FE, %)

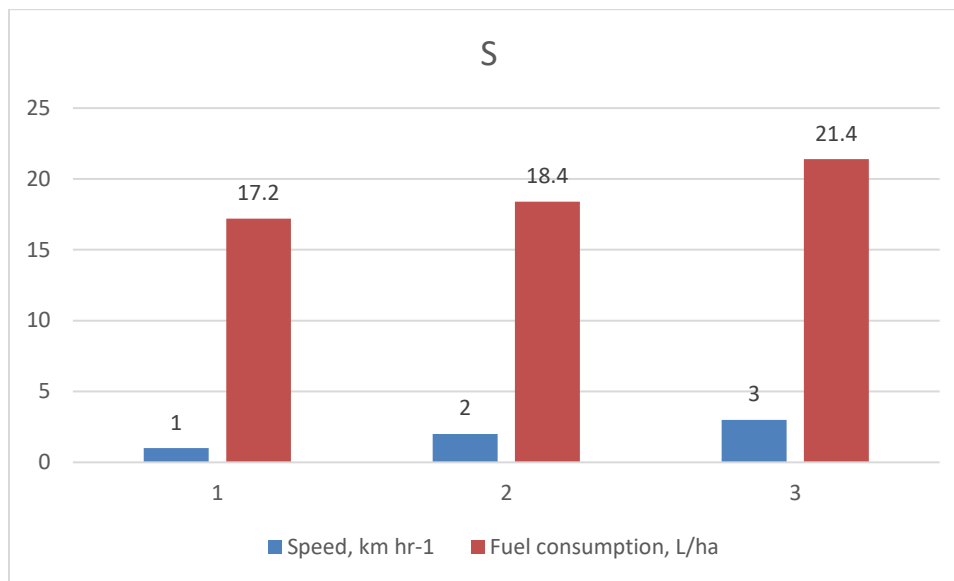


Fig. 9 - Machine forward speed (km h⁻¹) versus fuel consumption (L ha⁻¹)



Fig. 10 - Photographs taken during evaluation: (A) transplanted teff, (B) teff seedlings, and (C) machine testing

As shown in Table 3, the mean values of hill-to-hill spacing (13.82 and 12.96 cm), number of seedlings per hill (3.94 and 5.00), and transplanting depth (3.79 and 4.04 cm) for the two treatments, respectively, did not differ significantly at the 5% probability level. However, the mean values of missing hills (9.69 and 12.72%), floating hills (1.78 and 4.61%), buried hills (1.39 and 3.36%), damaged hills (2.22 and 7.72%), defective hills (15.11 and 28.56%), and transplanting efficiency (84.89 and 71.44%) differed significantly at the 5% level of probability (*Chaitanya et al., 2018*). The hill-to-hill spacing for both treatments was within the recommended range of 10-15 cm (*Fekremariam M., 2020*).

Table 4 presents the effect of seed rate on the selected dependent parameters. The mean values of hill-to-hill spacing (14.02, 12.53, and 13.63 cm), transplanting depth (4.02, 3.66, and 4.07 cm), floating hills (3.75, 2.58, and 3.25%), buried hills (2.08, 2.17, and 3.17%), and damaged hills (4.92, 4.58, and 5.42%) at seed rates of 60, 80, and 120 g, respectively, did not differ significantly at the 5% probability level. However, the mean values of missing hills (9.75, 8.67, and 15.08%), number of seedlings per hill (3.08, 4.50, and 5.83 No.), defective hills (20.58, 18.00, and 26.92%), and transplanting efficiency (79.42, 82.00, and 73.08%) at seed rates of 60, 80, and 120 g, respectively, showed significant differences at the 5% level of probability. The hill-to-hill spacing for both treatments was within the recommended range for teff transplanting (10–15 cm) (*Wubante N. and Menzir M., 2017; Fekremariam M., 2020*), with values of 13.82 and 12.98 cm for manual and machine transplanting, respectively. Figures 1 through 4 show the effect of forward speed and seed rate on hill-to-hill spacing, missing hills (%), and defective hills. The number of seedlings per hill was 3.94 and 5.00 for manual and machine transplanting, respectively. Both treatments resulted in a higher number of seedlings per hill than the recommended 2-3 seedlings per hill. This was attributed to the thin nature of teff seedlings, which created difficulty in picking 2-3 seedlings per stroke by the finger arm of the machine and by hand.

The transplanting depth was observed to be 3.79 and 4.04 cm for manual and machine transplanting, respectively, which showed that both methods placed the seedlings at the recommended depth (i.e., 4 cm). The ideal planting depth is crucial during transplanting operations, as it significantly affects floating hills (Dewangan *et al.*, 2005).

As depicted in Table 3, missing hills of 9.61 and 12.72% were observed for manual transplanting and the developed teff transplanter, respectively. This shows that the developed teff transplanter resulted in a higher percentage of missing hills than the manual method. Floating hills of 1.78 and 4.61% were observed for the manual method and the developed transplanter, respectively, indicating a higher percentage of floating hills with the developed transplanter. For buried hills, values of 1.39 and 3.56% were observed, showing that the developed machine produced more buried hills than the manual method. This was attributed to poor seedbed preparation, land unevenness, and the depth control mechanism of the developed machine. Damaged hills of 2.22 and 7.72% were observed for manual and machine transplanting, respectively, indicating higher seedling damage with the developed teff transplanter. This was due to improper synchronization between the tray-side movement and the finger arm reciprocating motion of the machine. Defective hills of 15.11 and 28.56% were observed for manual transplanting and the developed machine, respectively. The higher defective hills observed with the developed teff transplanter were due to the cumulative effects of missing hills, floating hills, buried hills, and damaged hills, as well as the thin nature of teff seedlings.

Therefore, the newly developed teff transplanter achieved a transplanting efficiency of 71.44%, which was lower than that of the manual method (84.89%) (Table 3). However, the developed transplanter exhibited a higher field capacity than the manual method, with values of 0.037 and 0.0099 ha h⁻¹, respectively. The transplanting efficiency of the transplanter was within the acceptable range for transplanters (Tamanna *et al.*, 2018).

Figures 1 through 6 show the effects of forward speed and seed rate on transplanting performance parameters, including hill-to-hill spacing, missing hills (%), buried hills (%), damaged hills (%), and defective hills. The results indicate that, with increasing seed rate, missing hills, buried hills, damaged hills, and defective hills increased, while hill-to-hill spacing, floating hills, and transplanting efficiency decreased. Similarly, with increasing forward speed, the number of seedlings per hill, missing hills, buried hills, and defective hills increased, whereas hill-to-hill spacing and transplanting efficiency decreased.

As depicted in Fig. 8, the actual field capacity, effective field capacity, and field efficiency of the machine and manual transplanting were 0.055 and 0.011 ha h⁻¹, 0.037 and 0.0099 ha h⁻¹, and 67.27% and 87.61%, respectively. The field efficiency of the transplanter was within the acceptable range for transplanters (Tamanna *et al.*, 2018).

CONCLUSIONS

Overall, the field performance of the transplanter was satisfactory. Transplanting teff seedlings results in higher yield; however, the transplanting technique is a very expensive process in teff production. Therefore, the developed machine alleviates the limitations of manual transplanting methods and has the potential to improve teff production while reducing cost, time, and labor requirements.

By maintaining appropriate transplanting depth and forward speed, the percentages of missing, floating, damaged, and buried hills can be reduced. In addition, the percentages of defective and damaged hills can be reduced by properly adjusting the plant-to-plant distance.

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