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Development and performance evaluation of a machine for planting of turfgrass

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ABSTRACT

Landscape plays a vital role in maintaining ecological balance and minimizing the consequences of global warming and due to increased demand for turfgrass and a shortage of servicing machinery for various stages of mechanization required for construction of landscaping, particularly cultivating machines, as well as the manual planting of turfgrass is exhaustive, time-consuming and costly. So, the current study aims to develop and manufacture a turfgrass planting machine, testing its performance, and investigate its operating costs. In the present study, seashore paspalum (*Paspalum vaginatum Sw.*) was used. The developed turfgrass planting machine was tested in sandy soil by studying the following variables: forward speed, applied load, and size of turfgrass sprigs. Results showed that the planting depth increased by decreasing the forward speeds (from 4.40 to 1.15 km/h) and increasing the load (from 100 to 200 kg). Additionally, increasing the size of the sprigs reduced planting depth because larger sprigs have more resistance to planting process. For small, medium, and large turfgrass sprigs, the highest planting efficiencies were 99.00, 96.84, and 77.24% with actual performance rates of 0.171, 0.165, and 0.154 fed/h, fuel consumption rates of 1.90, 2.02, and 2.24 L/fed, and field efficiencies of 62.36, 60.63, and 56.30% respectively. Whereas the operational costs of the developed machine were 44.98, 45.09, and 45.26 LE/h, while the turfgrass planting costs were 263.43, 272.85, and 293.58 LE/fed, respectively at forward speed of 1.15 km/h and applied load of 200 kg.

1. Introduction

Green spaces are considered vital components of modern urban environments due to their positive impact on the quality of life and individual health. They contribute to improving the local climate, reducing pollution levels, and promoting environmental sustainability. With the rapid urban expansion Egypt has witnessed in recent years, particularly with the development of new cities, the need for more green spaces has increased to keep pace with this expansion and meet the growing demand for public parks and green areas in residential neighborhoods, sports fields, golf courses, and tourist resorts, etc. (Hegazy et al., 2017). Also, Lee et al. (2015) mentioned that green spaces have many environmental benefits, including reducing the impact of heat and overcoming greenhouse gas emissions. Whereas, Morris (2003) said that scientific research has shown that hospital patients recover faster when they see beautiful landscapes and thus the grass contributes to improving physical, mental and healthy life. Moreover, Haq (2011) reported that the green spaces play a prominent role in increasing the value of property, because of its aesthetic shape, as well as providing leisure and relaxation facilities in particular to city dwellers and tourists.

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Fouad et al. (2017); Desoky (2005); Keleg (2018) highlighted the increasing efforts by the Egyptian government and non-governmental entities expanding green spaces in tourist areas, resorts, hotels, and both public and private facilities, which necessitates the expansion of turfgrass production to increase green spaces and address their shortage, especially in major cities like Cairo, aiming to improve the quality of life and reduce pollution rates. Furthermore, the turfgrass sector is estimated to be worth billions of dollars and has a significant economic impact. Most grasses belong to the Poaceae Gramineae family of plants. (*Paspalum vaginatum*) is a warm-season turf that can be employed in many places due to its ability to grow quickly and cover the ground in beautiful form and color (Sharaf El-Din et al., 2017).

De (2017) explained that grass is classified according to climatic requirements into two categories of cool season grasses and is suited to temperatures between 15 and 25°C. Warm season grasses are suitable for temperatures ranging from 25 to 35°C. Alzaghat et al. (1990) reported that the warm season grasses are spreading in Egypt. where less water is needed for irrigation. They are also durable and re-active with temperature, it can also be propagated vegetatively or by seeds and bears excessive shear close to the soil. Elmanee and Ahmed (2000) showed that the vegetation of the green flat consists of white ground parts that grow and expand beneath the soil surface, namely roots and rhizomes (ground market), and of green parts that grow above the soil surface such as the existing and running market, side branches and green leaves as shown in Fig. 1.

Trenholm (2001) stated that turfgrass can be grown and established in two main ways, by seed or vegetative propagation. Sowing is usually the easiest and most economical way to grow turfgrass. However, the creation of seeds requires a long period of time to form a complete turfgrass surface, and some types of turfgrass do not produce seeds, especially warm season grasses, most of which can be created by vegetative propagation by sodding, springing, stolonizing, planting. Also, he mentioned that sodding is the most expensive method of creating a lawn by vegetative propagation, but it produces so-called instant grass and is recommended in cases where immediate cover is required for aesthetics or to prevent soil erosion. Sods are grown and install them together tightly without leaving breaks or filling those joints with sand, making sure that the slides are in contact with the soil well so that they do not dry out during construction, and the soil must be wet for the first seven days after planting. Munshaw (2016) said that must cultivate the sods as soon as they are obtained, as they are perishable after 36 hours of harvesting, and after the planting process, the grass slices are compacted to ensure contact with the soil, as the air pockets between the soil and the grass obstruct the access of the small roots to the water in the soil and thus, they dry up and die. Alzaght et al. (1990) explained that the turfgrass stolons are obtained by cutting sod into small parts that do not contain adjacent soil, using special machines to uproot these legs, then scattered and buried in the soil with soil pressure around them, and these legs can produce roots easily when they come into contact with the soil in the presence of appropriate moisture.

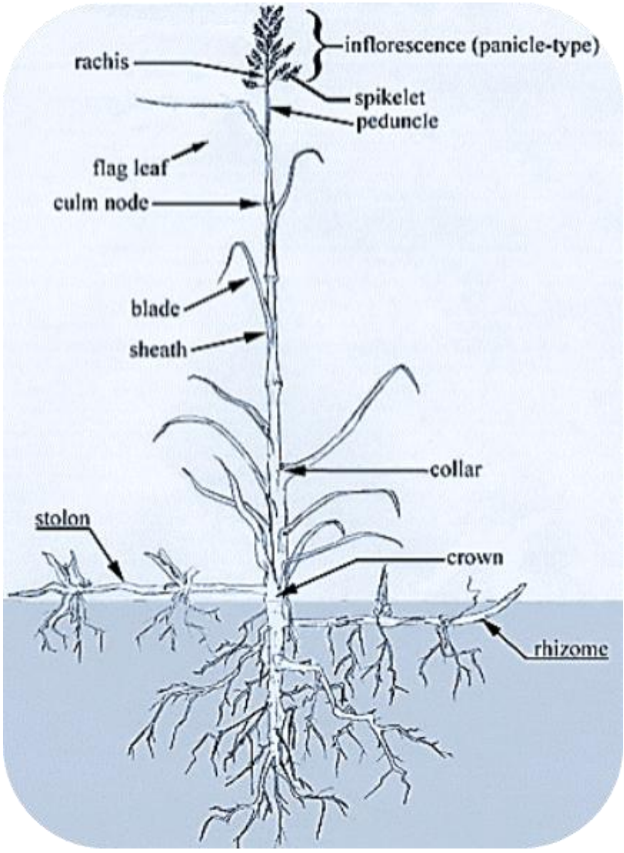


Fig. 1. Structure of turfgrass plant, reprinted from; https://forages.oregonstate.edu/regrowth/how-does-grass-grow/grass-structures.

Despite these efforts, the greatest challenge remains in the manual planting of natural turfgrass. Ryan and Carberry (1958) pointed out that establishing any significant area of turfgrass requires extremely labor-intensive manual planting, complicating the process since some types of grass cannot be grown from seeds. These factors present barriers to the rapid expansion of turfgrass planting, particularly with the growing demand to cover the needs of sports fields and golf courses.

These challenges call for innovative technological solutions to ease the planting process and reduce production costs. Desoky (2005) emphasized the increasing need for machines to support this sector of the economy in order to meet the rising demand for turfgrass and transform it into a sustainable industry. Therefore, this study aims to develop and manufacture a local machine for planting natural turfgrass using local materials in order to improve planting efficiency, reduce reliance on manual labor, and lower costs, which will help enhance turfgrass farm productivity and meet the increasing demand for turfgrass. As well as testing and evaluating the performance of the developed turfgrass planting machine by studying forward speed, applied load, and sizes of turfgrass sprigs that affect the following performance indicators: planting depth, actual performance rate, fuel consumption, field efficiency, and planting efficiency. Additionally evaluating the operating costs of the developed planting machine.

2. Materials and methods

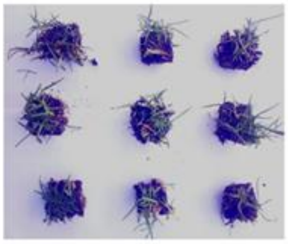
The developed turfgrass planting machine was manufactured in a workshop at Al-Hosayneya center, Al-Sharkeya Governorate, Egypt. All experiments of this study were also carried out at a farm in the same location throughout the years 2023 and 2024.

2.1. Material

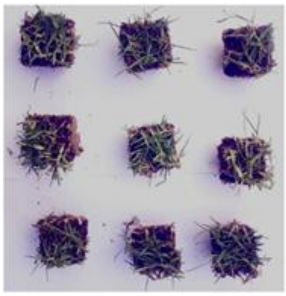
2.1.1. Type of turfgrass used

In this study, one of the warm-season turfgrasses type seashore paspalum (*Paspalum vaginatum Sw.*)] was used. Paspalum is one of the Bermuda hybrids, characterized by the tolerance of coldness, thirst and resistance to many diseases and epidemics, as well as salinity up to 2,500 ppm according to Alkeyey and Nouh (2004)**.** Also, this grass is widely available in Egypt and is suitable for usage on homes, municipalities, sod farms, resorts, and sports fields, as well as distinguished by its ability to reproduce only vegetatively, it also has medium density, coarse texture, creeping growth, a bluish-green color with an attractive appearance throughout the year, and it is also well-known for its tolerance to salinity, furthermore, Seashore paspalum has been cultivated in tropical and sub-tropical regions due to its heat tolerance. Turfgrass germination from seed has proven to be challenging because of its low seed germination rate and delayed germination rate. Therefore, rhizomes and stolons are typically used in the vegetative growth of seashore paspalum (Baker, 2013). The turfgrass sod was obtained from a farm located in Badr Center, Beheira Governorate, Egypt. The turfgrass used in experiments was obtained in form of sod, the width of sod was 45 cm, and the thickness was ranged from 2.5 to 3 cm, and with a different of lengths as shown in Fig. 2. The rolls of sods were cut manually by hand axe made of carbon steel to obtain required sprigs that, when planted, can producing new plants. Three categories/sizes of turfgrass sprigs were prepared in form of squares with side length of 1.5, 2.5, and 3.5 cm for the three sprigs used: small sprigs (SS), medium sprigs (MS), and large sprigs (LS) respectively as shown in Fig. 3.

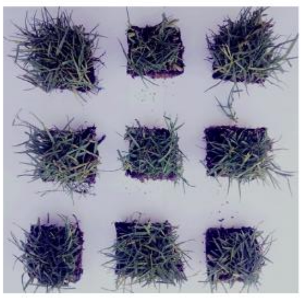
Fig. 2: Seashore paspalum sod.



Small sprigs “SS” (1.5×1.5 cm)



Medium sprigs “MS” (2.5×2.5 cm)



Large sprigs “LS” (3.5×3.5 cm)

Fig. 3. Seashore paspalum sprigs.

2.1.2. Type of soil

A specimen of the soil was taken from experimental field at a depth of 25 cm from various locations, and it was well mixed to achieve homogeneity, the mechanical analysis of the soil revealed that the percentage of silt was 1.6 % and sand was 98.4%, so this soil is considered sandy soil, also the density of soil was 1650 kg/m^3 with a moisture content of 1%.

2.1.3. Turfgrass planting machine

The following criteria were taken into account when developing the machine: The developed planting machine should be manufactured from locally available materials. Also, the machine must be easy to use and maintain, with cost-effectiveness. Moreover, the developed part (planting unit and its inclusions) should be easy to remove and reinstall at any time. The major components of the designed planting machine are as follow; planting unit, engine, power transmission mechanism, driving and steering system. The components indicated above were mounted and installed in the steel machine frame, the developed planting machine is shown in Figs. 4 and 5.

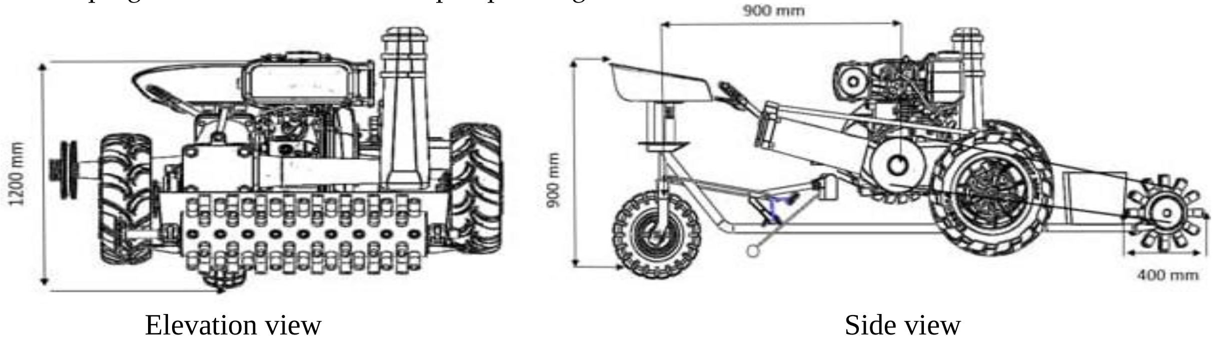
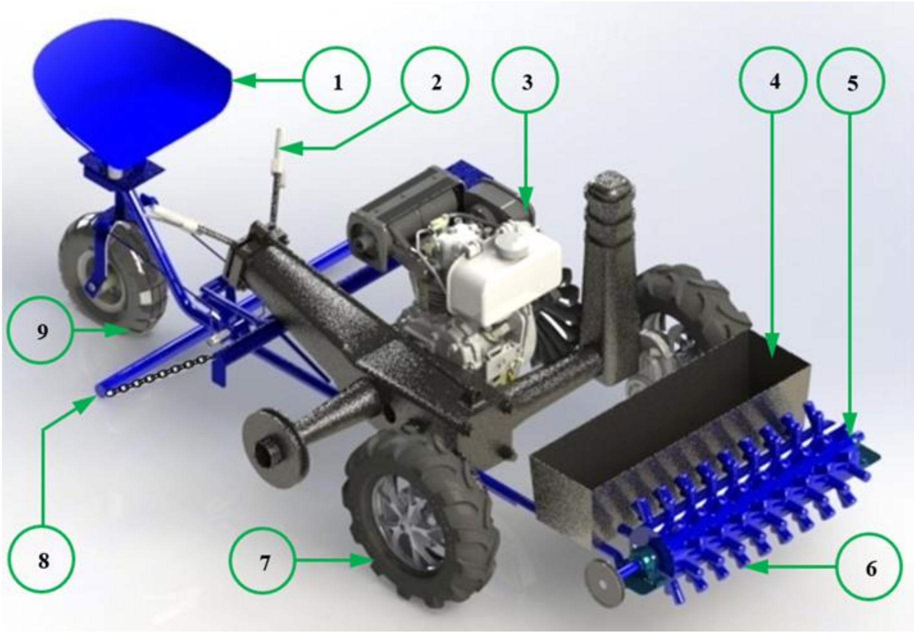


Fig. 4. Elevation and side view of turfgrass planting machine.



(1) Driver seat, (2) Steering arm, (3) Diesel engine,(4) Weight box, (5) Planting cylinder, (6) Finger, (7) Driver wheel, (8) Covering tool, and (9) Driven wheel.

Fig. 5. 3D drawing of the developed turfgrass planting machine.

2.1.3.1. Planting unit

The planting unit is composed of three main parts: planting cylinder, weight box, and covering tool. The planting cylinder is a low-carbon steel hollow cylinder its dimensions of 1000 mm for length, 300 mm for diameter, and 3 mm for thickness. A total of 102 hollow finger bases, each with an internal diameter of 40 mm and a length of 40 mm, were welded on the surface of the hollow cylinder. These fingers bases were distributed in 12 rows, with 8–9 per row, in order to distribute the fingers into zigzag pattern. 102 solid cylindrical fingers made of beech wood were inserted into the finger bases. Each finger measured 100 mm in length and 40 mm in diameter. Finally, the planting cylinder was mounted to the machine's front frame using ball bearings, in order to facilitate its movement on the soil during turfgrass planting. To control turfgrass planting depth, a 30 × 1150 mm rectangular weights box with a depth of 30 mm and a thickness of 2 mm was constructed from galvanized sheet steel, this box was welded to the front frame of the machine for increasing the load on the planting cylinder by filling it with sand. The covering and leveling tool was used to covering the grass and compact the soil around it, in addition to levelling the soil surface, to achieve this goal, a solid cylindrical iron column with a length of 1000 mm, a diameter of 40 mm, and a weight of 11.4 kg was used. The covering and leveling tool was attached to the machine frame by a pair of free metal chains.

2.1.3.2. Engine

The engine is an internal combustion engine, four-stroke, powered by diesel fuel, and its power of 15 hp. The engine is Italian-made and has the Model No. (GK-3). The engine is installed on a 5 mm thick main frame made of medium carbon steel.

2.1.3.3. Power transmission mechanism

The engine is attached to a gearbox which gives the machine four forward speeds. The engine power was transferred to traction device (two front driver wheels) via a series of gears, sprocket wheels and chains. In order to improve the machine's stability, a third driven (supporting wheel) wheel was added to the back of the machine.

2.1.3.4. Driving and steering system.

Driver's seat is positioned above the supporting wheel, and the machine has two steering arms, in addition to a clutch for connecting and disconnecting movement, accelerator pedal, brake handle, and gear shift stick.

2.1.4. Measuring instruments

- Digital balance

The digital electric balance powered by alternating current that was manufactured in Japan and has a measurement range of 0 up to 500 g with an accuracy of 0.05 g, this balance was used to determine the required mass of sprigs for planting and the mass of sprigs left on the soil surface, after the planting machine has passed through.

- Stop watch

The digital stopwatch with an accuracy of 0.01 second was used to measure the time taken for the planting operation of turfgrass sprigs.

- Graduated cylinder

The graduated cylinder was employed to measure the volume of fuel consumed throughout the planting operation for each experiment.

- Measuring bar and ruler

The steel measuring tape and ruler with accuracy of 1 mm were used to measure the dimensions of sprigs during cutting of the turfgrass sod, depth of planting, and layout areas of experiments.

2.2. Methods

2.2.1. Conducting experiments

- The field experiments were carried out on a 3240 m^2 area, large rocks were removed, and the soil surface was leveled. After that the test site was divided into plots of 10 m length and 1 m width per test, with a 0.5 m space between each plot.
- The turfgrass sods were divided into three categories of sprigs (SS, MS, and LS). After the cutting process, the sprig samples were placed in bags to maintain their moisture content and sent to the trial site on the same day.
- The output sprigs from one square meter of turfgrass sod were weighed, and this quantity was then manually distributed on the soil surface per test plot (10 m^2) as evenly as possible.
- The planting depth has been adjusted by adding the specified weight (the appropriate sand mass) to the machine's weight box, in order to increase the machine's load and achieving the required planting depth.
- The designed planting machine was operated, the fuel tank was checked to ensure it was full, the forward speed was adjusted, and then start the planting of the turfgrass sprigs on the soil surface
- Finally, the following measurements were recorded for each experiment: time taken, amount of fuel consumed, and mass of unplanted turfgrass sprigs on the soil surface after the planting machine passed over it.

2.2.2. Variables of study

To evaluate the performance of the developed turfgrass sprigs planting machine, the following variables were studied:

- Four forward speeds of the machine were 1.15, 1.80, 2.90 and 4.40 km/h.
- Three sizes of turfgrass sprigs were [1.5 x 1.5 (SS), 2.5 x 2.5 (MS), and 2.5 x 2.5 cm (LS)].
- Three loads were 100, 150, and 200 kg.

2.2.3. Performance indicators

2.2.3.1. Average planting depth

The average planting depth was measured using a ruler and measuring tape. The surface of soil was taken as a reference. This procedure was carried out to evaluate the effect of tested loads on planting depth under the range of tested speed and range of sprigs size, the average depth was computed by using the following equation:

$$D_p = \frac{\sum D_m}{N_d} \quad ...[1]$$

where;

D_p: average planting depth (cm).

$\sum D_m$: sum of measured depths (cm).

N_d: number of measurements.

2.2.3.2. Theoretical field capacity

The theoretical field capacity is the rate of field coverage that would be obtained if the machine was performing its function 100% of the time at the rated forward speed and always covered 100% of the width (Kepner et al. 1978). The theoretical field capacity was calculated by using the following equation:

$$T_{fc} = \frac{W_m \times S_m}{4.2} \quad ...[2]$$

where;

T_{fc}: theoretical field capacity (fed/h)

W_m: width of the planting machine (m).

S_m: forward speed of the planting machine (km/h).

2.2.3.3. Actual field capacity

Actual field capacity is the actual average rate of coverage by machine, based upon the total effective operating time. It depends on the rated width of the machine, the percentage of rated width actually used, the speed of travel, and the amount of field time lost during operation (Kepner et al., 1978). Thus, it was estimated as:

$$A_{fc} = \frac{1}{T_t} \quad ...[3]$$

where;

A_{fc}: actual field capacity (fed/h).

T_t: is the total operating time (h/fed) which includes actual planting time in addition to other losses times, the estimated amount of lost time assumed (25 % from time of theoretical planting).

2.2.3.4. Fuel consumption per unit area

The fuel consumption per unit area (FC_a "L/fed") was calculated by using the following equation:

$$FC_a = \frac{FC_t}{A_{fc}} \quad ...[4]$$

where;

FC_t: fuel consumption rate (L/h).

2.2.3.5. Field efficiency

The field efficiency (η_f "%") was calculated by using the following equation:

$$\eta_f = \frac{A_{fc}}{T_{fc}} \times 100 \quad ...[5]$$

2.2.3.6. Planting efficiency

The turfgrass sprigs planting efficiency (η_p "%") was calculated by using the following equation:

$$\eta_p = \left[1 - \left(\frac{M_a}{M_b}\right)\right] \times 100 \quad ...[6]$$

where;

M_a: mass of turfgrass sprigs after passing the machine (kg).

M_b: mass of turfgrass sprigs before passing the machine (kg).

2.2.3.7. Operating costs

The total cost of the developed turfgrass sprigs planting machine was found to be 40000 LE, when the American dollar exchange rate was equivalent about of 48.53 LE. The hourly operating cost (C_H, LE/h) of the developed turfgrass sprigs planting machine was estimated according to price level 2023 by using the following equation (7) given by Awady (1978) and the cost of planting one feddan (LE/fed) was computed using equation (8).

$$C_H = \frac{P}{H_y}\left(\frac{1}{e} + \frac{i}{2} + t + r\right) + (1.2\ w \times s \times f) + \left(\frac{M}{H_m}\right) \quad ...[7]$$

where;

P : price of the developed machine (40000 LE),

H_y : estimated yearly hours of operation, (2400 h),

E : life expectancy of machine, (10 years)

I : annual interest rate (19.25%),

T : annual taxes and overhead rates (20%),

R : annual maintenance and repairs ratio (5%),

1.2 : factor of lubricating and greasing cost,

W : engine power (kW),

S : specific fuel consumption in (L/kW.h),

F : price of diesel fuel (11.5 LE/L),

M : average of monthly wage (5000 LE) and

H_m : estimated working hours per month (144 h).

$$\text{Planting cost (LE/fed)} = \frac{C_H}{A_{fc}} \quad ...[8]$$

where;

C_H: hourly operating cost (LE/h).

3. Results and discussions

3.1. Planting depth

Fig. 6 shows the relationship between planting depth and tested forward speeds of the turfgrass planting machine using three loads (100, 150, and 200 kg), and three sizes of sprigs (SS, MS, and LS) without using coverage tool. Generally, the results illustrated that the planting depth increased by increasing the load from 100 to 200 kg, while the planting depth decreased with increasing the forward speed from 1.15 to 4.4 km/h for all tested sizes of turfgrass sprigs. The highest value of planting depth was 4.5 cm at forward speed of 1.15 km/h with a load of 200 kg and category of sprigs "SS", while the lowest value of planting depth was 0.9 cm at a forward speed of 4.4 km/h with load of 100 kg and category of sprigs "LS". The results show a clear relationship between planting depth, load, and forward speed as the applied load increased, the planting depth increased, indicating that heavier loads push the sprigs deeper into the soil. On the other hand, as the forward speed increased from 1.15 to 4.4 km/h, the planting depth decreased, likely due to the larger sprigs may require more loads (greater pressure force) and contact time to achieve the same depth as smaller ones in case of high speeds. Furthermore, the size of the sprigs also influenced on the planting depth, with smaller sprigs ("SS" category) being planted deeper under the same conditions compared the larger sprigs ("LS" category). This shows that the increase in the size of the sprigs reduced planting depth due to the larger sprigs have more resistance to planting process.

3.2. Actual field capacity

Fig. 7 demonstrates the relationship between the actual field capacity and forward speed of the turfgrass planting machine using three loads, and three sizes of sprigs with using coverage tool. In general, the results illustrated that the actual field capacity increased with increasing the forward speed from 1.15 to 4.4 km/h (Nasr et al., 2015; Zaalouk et al., 2024 confirmed that). However, it decreased with increasing the load, and size of larger sprigs. The highest actual field capacity was 0.40 fed/h at forward speed of 4.4 km/h with load of 100 kg and category of sprigs "SS". Conversely, the lowest actual field capacity was 0.15 fed/h at forward speed of 1.15 km/h with load of 200 kg and category of sprigs "LS". The results of this study highlight key factors that influence the actual field capacity of the turfgrass planting machine. A clear positive relationship was found between forward speed and the actual field capacity.

As the forward speed increased from 1.15 km/h to 4.4 km/h, the actual field capacity also improved. This can be attributed to the machine's ability to cover more area in less time at higher speeds, thus enhancing overall actual field capacity. However, the actual field capacity decreased with the increase in used loads and sizes of sprigs. Heavier loads likely imposed greater resistance and load on the machine, reducing its operational speed and effectiveness. Similarly, category of larger size sprigs may have caused more obstruction and required more energy to planting process, further lowering the actual field capacity. These findings suggest that managing the used loads and category of larger volume sprigs is crucial for maintaining high efficiency in turf planting operations.

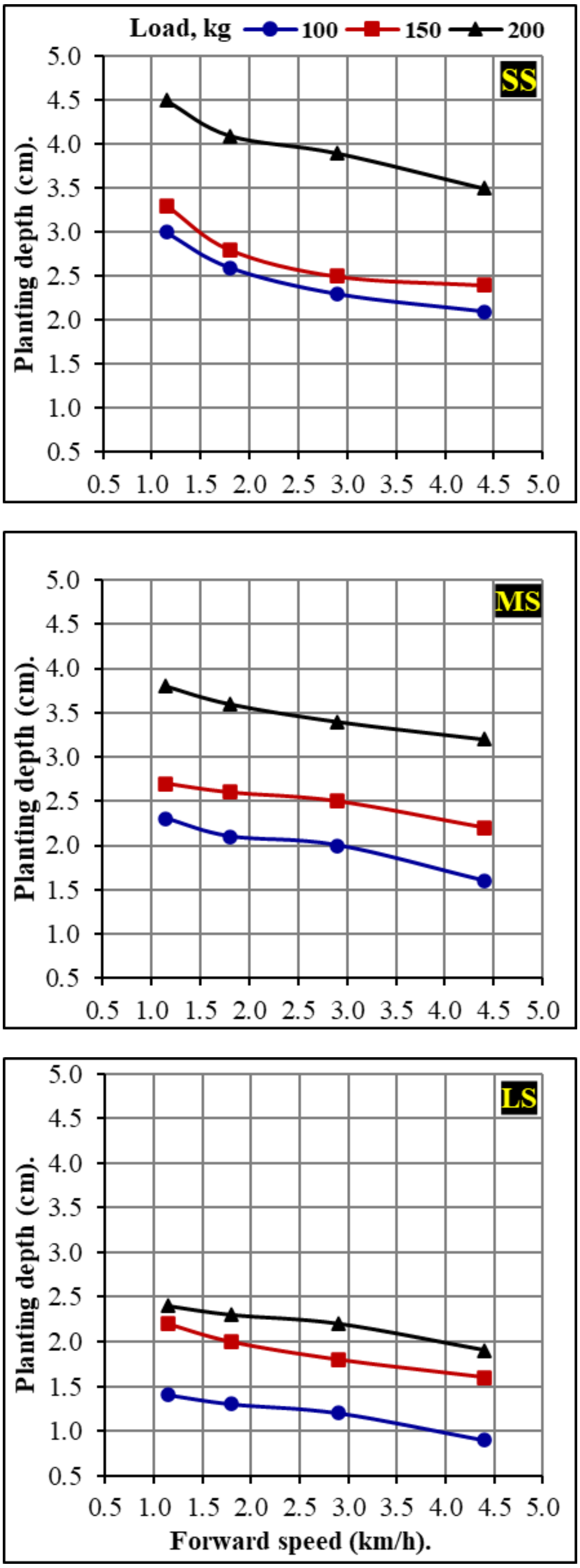


Fig. 6. Effect of forward speed on planting depth at different loads, and sizes of sprigs.

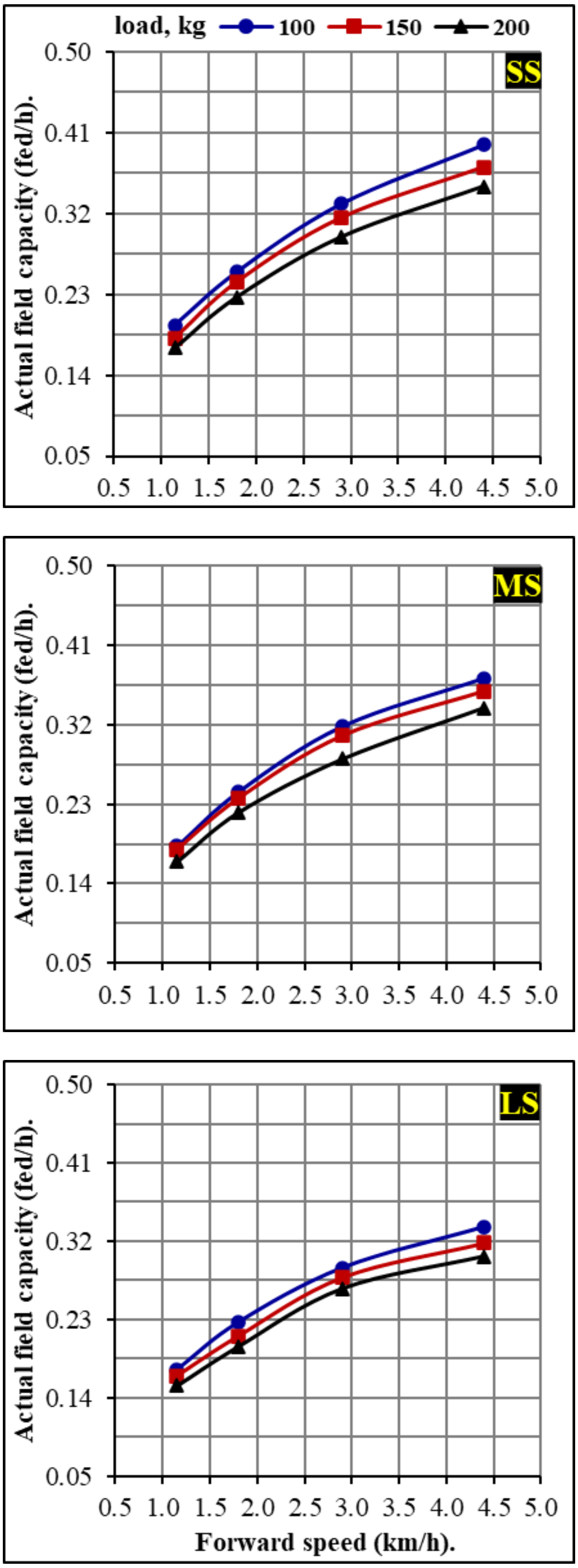


Fig. 7. Effect of forward speed on actual field capacity at different loads, and sizes of sprigs.

3.3. Fuel consumption per unit area

Fig. 8 shows the relationship between fuel consumption per unit area (L/fed) and forward speed of the turfgrass planting machine using three loads (100, 150 and 200 kg), and three sizes of sprigs (SS, MS, and LS). Generally, the results illustrated that the fuel consumption decreased with increasing the forward speed from 1.15 to 4.4 km/h (this result was observed in a previous study by Madlol (2012), however it increased with increasing the load, and size of sprigs.

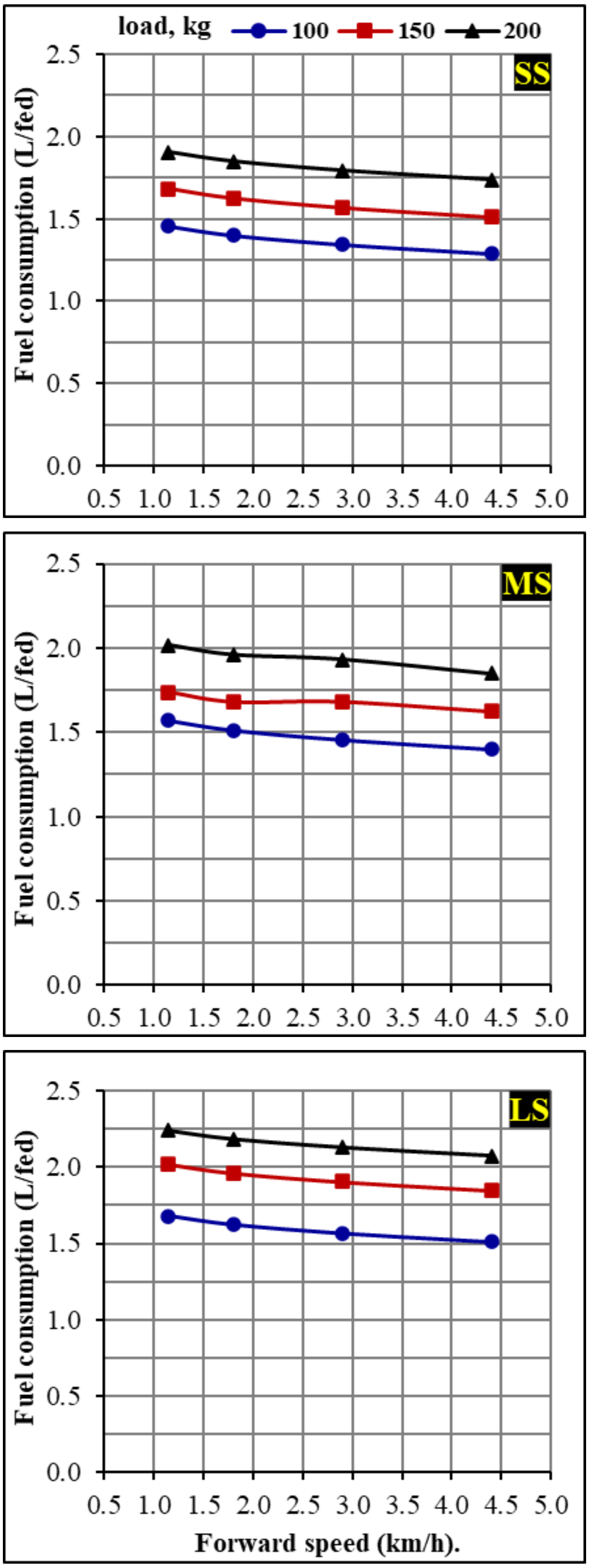


Fig. 8. Effect of forward speed on fuel consumption at different loads, and sizes of sprigs.

The lowest value of fuel consumption was 1.29 L/fed at forward speed of 4.4 km/h with load of 100 kg and category of sprigs "SS", whereas the highest value of fuel consumption was 2.24 L/fed at forward speed of 1.15 km/h with load of 200 kg and category of sprigs "LS". It was observed that the fuel consumption per unit area increased with higher loads, and larger sprig sizes, this increase can be attributed to the additional energy required to handle the increased load and the larger sprigs volume of turfgrass being planting. Conversely, an increase in forward speed from 1.15 to 4.4 km/h resulted in a decrease in fuel consumption, this relationship suggests that operating the machine at higher speeds reduces the energy consumed per unit area. This could be due to the more efficient use of power as speed increases, reducing the time the machine operates under load per unit area covered. in general, spending less fuel is necessary and vital to reduce input costs of agricultural production operations (Al-Sager et al., 2024). Our findings agree with the data obtained by Aday et al. (2003) they reported that the fuel consumption per hectare decreased as the tractor forward speed increased 0.38 to 0.85 m/s (1.37 to 3.06 km/h) during plowing process. Also, Jalaliet al. (2015) reported that increasing the speed of tillage lowered fuel consumption per hectare.

3.4. Field efficiency

Fig. 9 illustrates the relationship between field efficiency and forward speed of the turfgrass planting machine at tested loads, and sizes of sprigs. According to the obtained results, the values of field efficiency decreased with increasing of both the forward speed (similar result was also reported by Jebur et al. (2013), applied load, and size of sprigs. The reason for the decrease in field efficiency with the increasing forward speed may be attributed to the rise in the slippage percentage, as noted by Madlol (2012). This had a negative impact on the forward speed during the planting process, resulting in a lower actual performance rate than expected and, consequently, a reduction in the field efficiency. The highest value of field efficiency was 73.41 % at forward speed of 1.15 km/h with load of 100 kg and category of sprigs "SS". Conversely, the lowest value of the field efficiency was 28.92 % at forward speed of 4.40 km/h with load of 200 kg and category of sprigs "LS". The results indicate a clear inverse relationship between field efficiency and factors such as forward speed, load, and sprigs size. As these factors increased, field efficiency declined. This can be explained by the mechanical and operational limitations that arise when higher speeds, heavier loads, and larger sprigs.

3.5. Planting efficiency

Fig. 10 demonstrates the relationship between planting efficiency and tested forward speed range from 1.15 to 4.4 km/h of the turfgrass planting machine using three loads (100, 150 and 200 kg), and three sizes of turfgrass sprigs (SS, MS, and LS). In general, the results illustrated that the planting efficiency increased with increasing the load, however it decreased with increasing forward speed from 1.15 to 4.4 km/h and size of larger sprigs. The highest planting efficiency recorded was 99 % at forward speed of 1.15 km/h with load of 200 kg and category of sprigs "SS". Conversely, the lowest planting efficiency was 59 % at forward speed of 4.4 km/h with load of 100 kg and category of sprigs "LS". The results indicate that planting efficiency is influenced by several factors, including forward speed, applied load, and sprigs size. Specifically, planting efficiency increased with higher loads but decreased with higher forward speeds and larger sprig sizes.

Effect of forward speed: Interestingly, the results show a decrease in planting efficiency with increasing forward speed. At the highest speed of 4.4 km/h, the lowest planting efficiency was observed at 59.31%, with a load of 100 kg and larger sprigs (category "LS"). This decline in efficiency at higher speeds may be due to reduced precision and control over the planting process, leading to less effective sprig placement. The machine's ability to handle and distribute the material efficiently might be compromised at higher speeds, resulting in lower planting efficiency.

Impact of applied load: The increase in planting efficiency with higher loads suggests that this factor play a crucial role in optimizing the planting process. A higher load, such as 200 kg, ensures that more material is being processed at once, which can enhance overall efficiency. The highest planting efficiencies recorded were 99.00% for small sprigs and 96.84% for medium sprigs, achieved at a forward speed of 1.15 km/h, with a load of 200 kg and smaller sprigs (category "SS"). This combination maximizes the effectiveness of the planting process by ensuring optimal material distribution and handling.

Influence of sprig size: The size of the sprigs also impacted planting efficiency, with larger sprigs leading to decrease the planting efficiency. Larger sprigs (category "LS") may require more careful handling and placement, which can slow down the planting process and reduce overall efficiency. In contrast, small sprigs "SS" and medium sprigs "MS" are easier to manage and distribute, contributing to higher planting efficiency, especially when combined with higher loads and the use of a low forward speeds.

3.6. Operating and planting costs

The total hourly operating costs of the developed turfgrass planting machine were 44.98, 45.09, and 45.26 L.E./h. Also, the planting cost were calculated with dividing the total hourly operating cost on the actual field capacity and gave the following values of 263.43, 272.85, and 293.58 LE/fed for small turfgrass, medium, and large sprigs respectively at optimum operating condition, forward speed of 1.15 km/h and applied load of 200 kg. Manual planting involves digging a hole, putting turfgrass sprigs, and covering it. The cost of manual turfgrass planting was 960 LE/fed, with a field capacity of 0.125 fed/h when using three workers for eight hours.

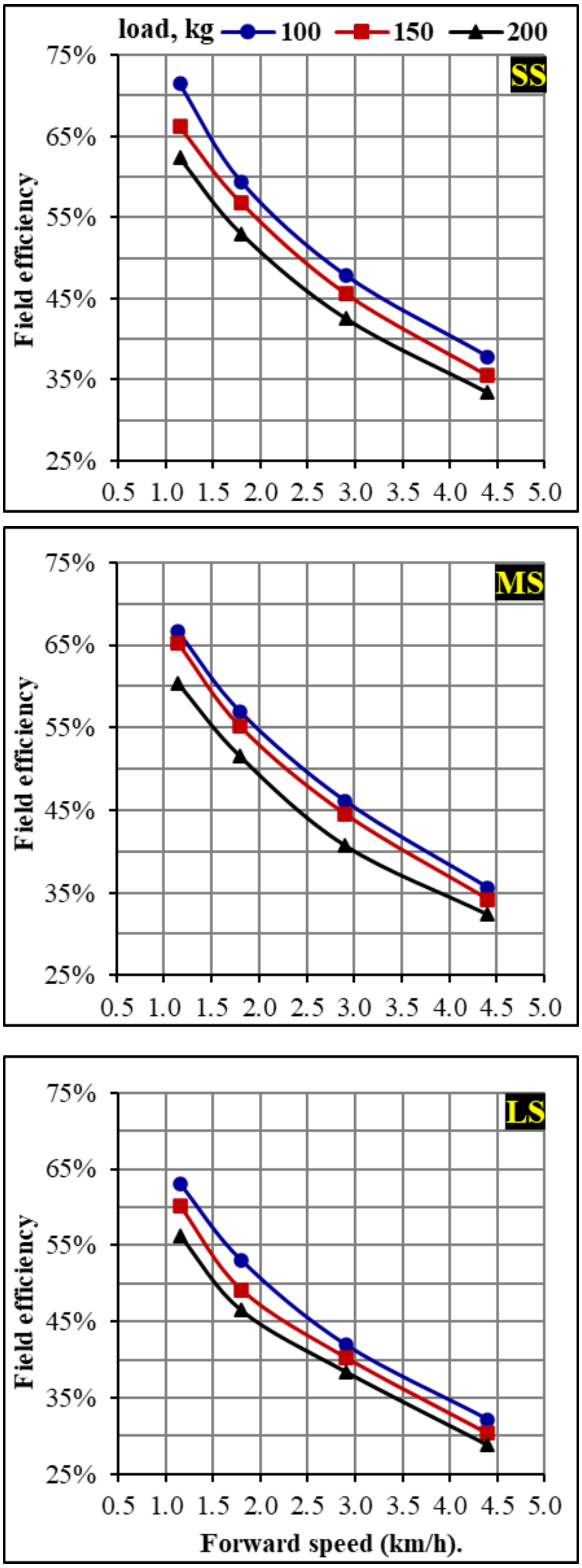


Fig. 9. Effect of forward speed on field efficiency at different loads, and sizes of sprigs.

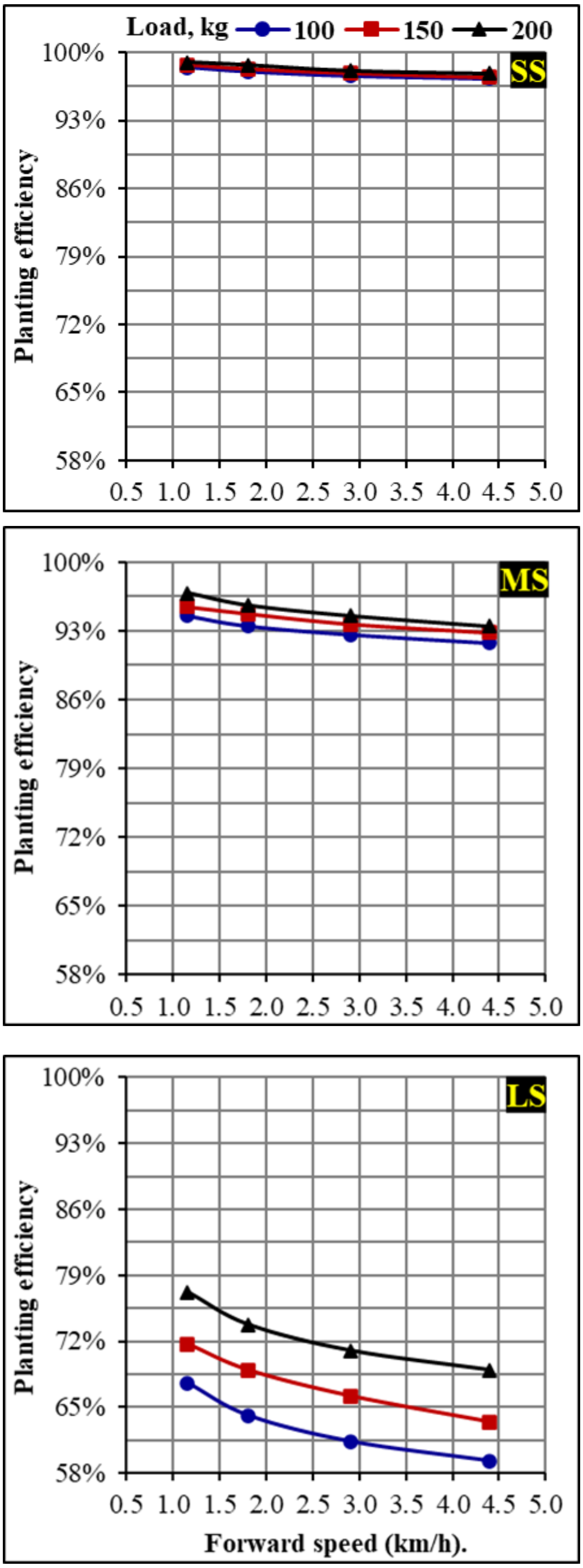


Fig. 10. Effect of forward speed on planting efficiency at different loads, and sizes of sprigs.

4. Conclusions

- The results showed that the planting depth increased with decreasing the forward speeds and increasing the load. Additionally, increasing the size of the sprigs reduced planting depth because larger sprigs have more resistance to planting process.
- The actual performance rate of the developed turfgrass planting machine increased with increasing the forward speed and decreased with the increasing the load and size of sprigs.
- The fuel consumption per unit area increased with increasing the load and sprigs size, but decreased with increasing the forward speeds
- The values of field efficiency increased with decreasing the forward speeds, load, and sprigs size.
- For small, medium, and large turfgrass sprigs, the highest planting efficiencies were 99.00, 96.84, and 77.24% with actual performance rates of 0.171, 0.165, and 0.154 fed/h, fuel consumption rates of 1.90, 2.02, and 2.24 L/fed, and field efficiencies of 62.36, 60.63, and 56.30% respectively. Whereas the operational costs of the developed machine were 44.98, 45.09, and 45.26 LE/h, while the turfgrass planting costs were 263.43, 272.85, and 293.58 LE/fed, respectively at forward speed of 1.15 km/h and applied load of 200 kg.

Recommendations

- The study recommends using the developed planting machine for planting turfgrass sprigs at forward speed of 1.15 km/h and load of 200 kg. Concerning the sprigs size, small and medium sprigs appeared to be the most suitable for obtaining a high turfgrass planting efficiency, so the size of sprigs should be 2.5×2.5 cm^2 or less.
- Future investigation of possibility using single turfgrass sprigs and single nodes for effectively propagating and producing new plants, with an examination of the spacing or number of sprigs per square meter, as well as germination efficiency, time required for propagation, and spread necessary to cover or fill in the gaps, etc.

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تطوير وتقييم آداء آلة لزراعة النجيل

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الملخص العربي

تسعى مصر جاهدة لتحسين نصيب الفرد من المسطحات الخضراء من خلال تعزيزها في المجتمعات العمرانية الجديدة والتي تصل نسبتها الى ٢٥٪ من المساحة الكلية، يأتي هذا التوجه كجزء من جهود الدولة المصرية لتحقيق بيئة حضرية مستدامة تساهم في تحسين جودة الحياة وتواجه التحديات البيئية بما في ذلك تأثير التغيرات المناخية، نتيجة لذلك زاد الطلب بشكل ملحوظ على المسطحات الخضراء سابقة التجهيز مما أدى إلى التوسع في المساحات المخصصة لإنتاجها في المزارع الإنتاجية لتلبية الطلب عليها. ومع ذلك، فإن عملية زراعة النجيل في المزارع الإنتاجية، والمنتجعات السياحية، الملاعب، الحدائق، ... الخ تتم باستخدام الطرق اليدوية، وهو ما يتطلب الكثير من العمالة والوقت، مما يؤدي إلى زيادة تكاليف الإنتاج لذلك، فهناك حاجة ملحة لتطوير آلات تساهم في خدمة هذه المجال ذات العائد الاقتصادي الكبير ... وفي هذا السياق هدفت هذه الدراسة إلى تطوير وتصنيع آلة لزراعة النجيل مصنعة باستخدام خامات محلية، اختبار أدائها ودراسة تكاليف تشغيلها. تم استخدام نجيل صنف "باسبيلم"، هو أحد أنواع النجيل المناسب للجو الدافئ، ويتميز هذا النوع من النجيل بتكاثره نباتيًا. تم قطع لفات النجيل للحصول على الشتلات المطلوبة، تضمنت الآلة المطورة وحدة زراعة تتألف من ثلاثة أجزاء رئيسية: اسطوانة الزراعة، صندوق لزيادة الوزن على الآلة، وأداة التغطية، محرك ديزل بقدرة ١٥ حصان، آليات نقل القدرة، ونظام القيادة والتوجيه، والتي تم تركيبها جميعاً على إطار معدني للآلة، وتم اختبار آلة الزراعة المطورة في تربة رملية من خلال دراسة المتغيرات التالية:

- أربع سرعات أمامية للآلة: ١,١٥، ١,٨٠، ٢,٩٠ و٤,٤٠ كم/ساعة.
- ثلاثة أحمال مضافة للآلة: ١٠٠، ١٥٠، و٢٠٠ كجم.
- ثلاث فئات لشتلات النجيل (١,٥ × ١,٥)، (٢,٥ × ٢,٥) و (٣,٥ × ٣,٥ سم).

وكانت أهم النتائج المتحصل عليها كالتالي:

- أظهرت النتائج أن عمق الزراعة يزداد بانخفاض السرعة الأمامية وزيادة الحمل المطبق على الآلة، كما أظهرت النتائج أنه بزيادة حجم الشتلات انخفض عمق الزراعة والسبب في ذلك يرجع الى أنه كلما زادت حجم أو مساحة الشتلة زادت مقاومتها لعملية الغرس.
- بينت النتائج أن معدل الآداء الفعلي لآلة زراعة النجيل يزداد بزيادة السرعة الأمامية وينخفض بزيادة الحمل المطبق وزيادة حجم الشتلة.
- لوحظ أن الوقود المستهلك لزراعة شتلات النجيل يزداد بزيادة الحمل المطبق على الآلة وحجم الشتلات بينما ينخفض الوقود المستهلك بزيادة السرعة الأمامية لآلة الزراعة المطورة.
- أوضحت النتائج أن القيم المتوسطة للكفاءة الحقلية ازدادت بانخفاض السرعة الأمامية، والحمل المطبق وحجم شتلات النجيل.
- أعلى كفاءة زراعة كانت ٩٩,٠٠، ٩٦,٨٤ و٧٧,٢٤ % بمعدل آداء فعلي ٠,١٧١، ٠,١٦٥ و٠,١٥٤ فدان/ ساعة، ومعدل استهلاك الوقود ١,٩٠، ٢,٠٢ و٢,٢٤ لتر/فدان وكفاءة حقلية ٦٢,٣٦، ٦٠,٦٣ و٥٦,٣٠ %، كما كانت تكلفة تشغيل الآلة المطورة ٤٤,٩٨، ٤٥,٠٩ و٤٥,٢٦ جنيه/ساعة بينما كانت تكلفة زراعة الفدان ٢٦٣,٤٣، ٢٧٢,٨٥ و٢٩٣,٥٨ جنيه/فدان لحجم شتلات النجيل الصغيرة، المتوسطة والكبيرة على التوالي عند ظروف التشغيل الأمثل للآلة (سرعة أمامية ١,١٥ كم/س، وحمل ٢٠٠ كجم).