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EVALUATION THE PERFORMANCE OF THE SOLAR-POWERED SEED DRILL

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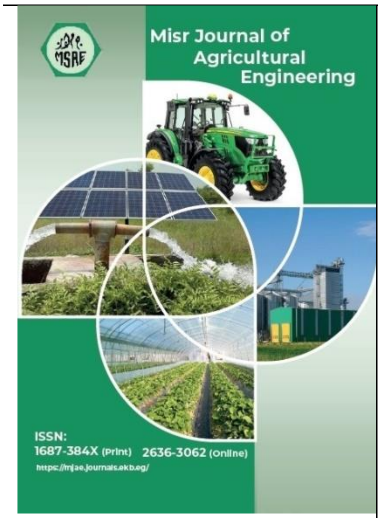


Keywords:
Seed drill; Renewable energy; Prototype machine; Solar seed drill; Solar panel; Remote control.

ABSTRACT

The division of land into small holdings presents an obstacle to the use of large agricultural machinery due to the difficulty of maneuvering in limited spaces and the high operating costs. Therefore, the importance of small agricultural machinery lies in enhancing efficiency and productivity, facilitating the management and cultivation of small holdings more effectively. Solar energy is one of the renewable energy sources utilized to mitigate the impacts of climate change and the rising energy prices. The aim of this study is to evaluate the performance of a solar-powered seed drill. This machine is considered one of the modern applications of renewable energy in agriculture and offers numerous advantages. The prototype solar-powered seed drill consists of the main frame, hopper, seed metering device, seed delivery tube, furrow openers, ground wheel, solar power system, remote control unit, and self-directed unit. The results indicate that increasing forward speed and the number of planting rows raised power requirements, wheel slip, and field capacity, while reducing specific energy and field efficiency. Similarly, increasing planting depth led to an increase in power requirements, slip, and specific energy but decreased field capacity and efficiency. The highest value of required power and slip percentage 0.173 kW and 26.18 % respectively were recorded at 5 cm of the planting depth and 5 of planting rows at 1.23 km/h of forward speed. General studies suggest that electrical energy generated from photovoltaic solar energy can help reduce high energy costs and can be utilized in various agricultural production applications.

INTRODUCTION

The basic objective of the sowing operation is to place seeds in rows at the desired depth and spacing, cover them with soil, and ensure proper compaction over the seeds. The recommended row spacing, seed rate, seed-to-seed spacing, and depth of seed placement vary depending on the crop and the specific agricultural and climatic conditions to achieve optimal yields. An efficient sowing machine should aim to meet these requirements. Additionally, using improved machinery for these operations can result in savings in operation time, labor, and energy. Wheat is one of the most vital cereal crops globally, and it holds strategic importance for Egypt. As a staple food, wheat production in Egypt is critical for national food security. In 2023, Egypt's wheat production was approximately 9 million tons, cultivated on about 1.395 million hectares, with an average yield of 6.45 Mg per hectare **(USDA, 2023).** Planting operation is one of the most crucial practices in crop production. Increases in crop yield and cropping reliability depend on the uniform and timely establishment of optimal plant populations. The traditional planting method results in very low production due to improper seed rates and spacing, and it consumes more time. To achieve optimal performance from a seed planter, proper design and careful selection of components are needed to meet the specific requirements of the crop. **UNDP (2013)** reported that wheat, a winter crop, is typically planted either by drilling the seeds in rows with a row-to-row distance of 15 cm or by manually broadcasting the seeds on a leveled soil surface. After broadcasting, the seeds are incorporated into the soil with shallow tillage, followed by flood irrigation, especially in irrigated areas. **Adisa and Braide, (2012)** reported that the basic requirements for small-scale cropping machines are: suitability for small farms, simplicity in design, improved planting efficiency, and reduced drudgery associated with manual planting methods. A row planter was developed that achieved a planting rate of 0.20 ha/h with a field efficiency of 88%. The primary functions of the planter include opening the seed furrow to the proper depth, metering the seeds, depositing the seeds in the furrow, and covering the seeds to the appropriate degree for the specific crop. The main components of the planter are a hopper, metering system, and furrow opener **(Ani et al., 2016)**. The metering mechanism is the heart of a planter machine, and various types of metering systems are available for seeding. The primary function of the metering system is to drop seeds at the correct rate, ensuring the precise spacing required for high yield **(Khan et al., 2015 and Rabbani et al., 2016)**. A seed tube is a channel that transfers seeds from the seed hopper into the opened furrow **(Bashiri et al., 2013)**. Furrow openers create the soil openings where seeds, metered out and falling through the seed tube, are dropped and covered. The planting depth must be considered when designing furrow openers **(Ani et al., 2016)**. One of the major constraints is the availability of row planting machines that meet timeliness and precision needs. The most important factors for increasing production are the uniform distribution of seed germination at the proper depth. This leads to a better crop stand, thereby increasing crop yield **(Behera et al., 1995)**. **Jat et al. (2004)** reported that uniform planting distribution through cross sowing reduced weed growth rates and increased yield and its attributes. The entire specified energy consumption of the farm can be provided using the total daily value of electrical energy produced by the solar panels. Any agricultural production application can benefit from the use of solar energy, which is a renewable energy source that also helps reduce the high cost of electricity **(Omar et al., 2021).** The total daily electrical energy productivity from PV for the trial day was reported by **Samak et al. (2022)** for the different seasons. The data shows that the solar irradiance was 7783, 5108, 3660 W $m^{-2}.day^{-1}$, and so on during the summer, spring, fall, and winter. The PV's electrical energy production changes during the day; in the summer, spring, autumn, and winter, it was 552, 460, and 330 W $m^{-2}day^{-1}$ overall. The temperatures over 25°C had an impact on the actual efficiency, which went from 13 to 16.6%. PV energy productivity for electrical energy is used to calculate the machine's energy consumption. A solar cell system was designed and identified as a novel, renewable energy source (as an example of solar energy used in agriculture) in order to power the evaporative cooling system.

8.76 MJ of power was produced every day using solar panels. 8.33MJ day^{-1} of the energy needed for the ECP system was generated by solar cell energy **(Omar et al., 2022).** The solar planter is designed as an innovative technology for multi-row planting, utilizing renewable energy specifically for smallholder farmers. This is essential because a significant portion of the farming population cannot afford to buy or hire tractor-drawn planting machinery due to the small size of their farms. The planter aims to minimize laborious tasks by eliminating the need for continuous bending, standing, and the time-consuming hand methods of seed metering, furrow opening, and covering. Therefore, the objective of this study is to fabricate and evaluate the performance of a prototype row planter operated by solar energy.

MATERIAL AND METHODS

The prototype seed drill was fabricated at a private workshop from locally available materials and does not require sophisticated fabrication techniques. All the experiments are conducted and carried out under climate conditions on the farm of Faculty of Agricultural, Menoufia University, Shibin El-Kom, Menoufia, Egypt (Geographically, the chosen place’s latitude angle is 30^{o} 54' degrees). The readings of the experiments are taken during winter 2023.

To achieve the study objective, the following subjects were identified.

1- Fabricate a prototype of the solar powered seed drill
2- Laboratory experiments were done.
3- Evaluate the performance of a prototype seed drill.

Fabricate a prototype of the solar powered seed drill

The fabricated seed drill prototype was based on ease of fabrication using local materials for most of the components, simplicity of the machine operation for small holding farmers

Machine Description

The seed drill was fabricated from the principal components as illustrated in figure 1. The prototype seed drill consists of the main frame, solar cells, remote control, hopper, battery, electric motor, sprocket wheels, metering device, delivery tube, furrow opener, furrow closer, shafts, frame support and ground wheels. The electric motor powers the rear ground wheel by a chain and a sprocket wheel, which in turn powers the shaft that drives the metering device through a chain and sprocket wheel. The motor is connected to sprocket wheels, which helps to change the speed of the ground wheels which in turn determine the rate at which the metering device meters the seed.

Fig. (1): Front view of the prototype solar-powered seed drill

The metering device consist of five nylon wheels are attached on horizontal shaft in a very way that each circular point collects wheat seeds at a time from the hopper and delivers them steadily into the delivery tube which drops the seed to an already opened soil by the furrow opener. The dropped seeds are then covered by the soil by the seed covering unit located at the rear end of the planter. The elevation and plan view of the prototype seed drill is shown in Fig. 2.

1. Main frame

The main frame, measuring 100×50 cm, which supports all other units of the planter, was constructed using a mild steel flat bar. The main frame is equipped with four wheels, each with a diameter of 30 cm. The front two wheels are steering wheels, and the rear two wheels are power wheels. The anterior wheels are affixed to the chassis in a manner that permits their movement in the right, left, upward, and downward directions, thereby facilitating effective steering and enabling the vehicle to navigate uneven terrain.

2. Hopper

The seed hopper was shaped as a trapezoid using a 2 mm mild steel sheet. The seeds flow freely by gravitational force into the metering device at the bottom of the hopper.

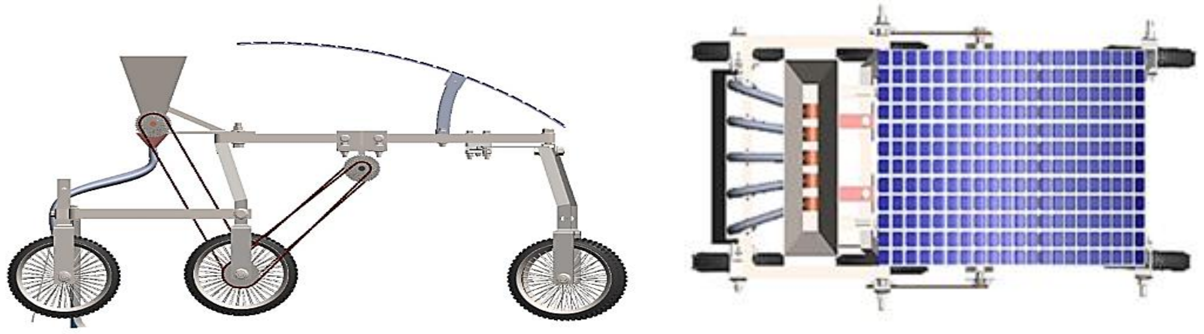


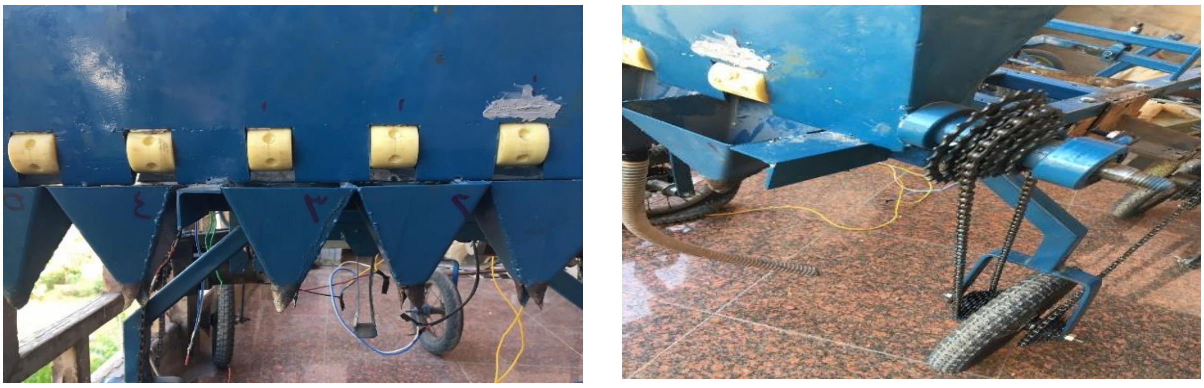
Fig. (2): Elevation and plan view of the prototype seed drill

3. Seed metering device

The seed metering device is composed of a steel shaft equipped with five nylon wheels designed to facilitate the planting of five rows of plants Fig. 2a. Sprocket wheels are affixed to the metering shaft, which transmits power from the ground wheel through a chain mechanism as shown Fig. 3a. The nylon wheel, with a 51 mm diameter, is used to distribute seeds uniformly at the desired rates. It transfers the seeds from the hopper and drops them into the exposed furrow through the seed tube. The number of cells on the circumference of the seed metering wheel consisted of six cells, exhibiting circular diameters measuring 1 cm and a depth of 0.4 cm. The nylon wheels are readily interchangeable based on the specific type of seed utilized as shown Fig. 3b.

4. Seed delivery tube

The seed delivery tubes were made from pressurized pipes and attached to the metering device, allowing seeds to drop directly into the furrow. The distance between the tubes is adjustable to suit the spacing needs of the specific seed planted. Experiments were performed on the machine with a spacing of 10 cm between each pair of seed delivery tubes.



a b

a- Seed metering unit, and b- Power transfer to the metering shaft

Fig. (3): Prototype solar-powered seed drill

5. Ground wheel

Ground wheels were used to drive the seed metering device. The wheels are made of rubber with 300 mm in diameter. The prototype contains six wheels, four wheels to carry the main frame. The other two wheels carry the planting unit, to control the planting depth.

6. Seed covering device

The seed covering device shown in Fig. 1 is made from a solid steel sheet with a thickness of 2 mm and is mounted at the rear of the machine. It is attached to the machine's frame, enabling it to be adjusted up or down as required for optimal performance.

7. Solar system characteristic

With the help of a photovoltaic panel and a solar battery, electrical energy is produced by sunlight. Sunlight cells, batteries, and a charge controller make up the photovoltaic panel system (fig. 4). The goal of the current study is to provide electrical energy for the operation of the Seed Drill and machine movement using a 100 W mono-crystalline PV type photovoltaic flexible panel that weighs 1.8 kg, measures 1050*540*3 mm, and occupies 0.567 m^2 with an 18% catalog efficiency. It was positioned to constantly face south and to change positions such that the sun's rays would fall perpendicular to the solar panel, maximizing solar radiation. The ambient air temperature (T_a) and the temperature coefficient (C_v) affect the actual electrical energy produced from the solar panel. The temperature coefficient (C_v) is not a constant and it may change a little from 0.35% to 0.5% (**Kumar et al., 2018**) for different cell manufacturers and the ambient air temperature is the present atmospheric temperature at the panel. Eq. (1) **Kumar et al. (2018)** give the relation between the solar panel output and the ambient air temperature.

$$\text{Actual efficiency} = \eta_{panel} - [C_v \times (T_a - 25)] \quad (1)$$

Where: η_{panel} is the maximum panel efficiency, C_v is the temperature coefficient which was taken −0.35 %/°C in the theoretical calculations of the actual efficiency.

In order to store the electricity produced and provide the necessary energy for the system's motors to run, the solar system has solar batteries. Energy was stored in the battery. The selected battery was lead acid one, its power 540 W.h with a voltage 12 V and DC 45 A. When the energy output exceeds the required quantity, the excess electricity is stored in the solar batteries.

Fig. (4): Photo and isometric view of solar panel system applied in the empirical study

The operating unit

The selected operating unit was two DC electric motor with the follow's specifications:

Power 100 W – voltage 24 V – rotating speed 17 rpm. Expected rotating torque

Laboratory experiments.

Several laboratory experiments were conducted on the machine model, including calibration, testing of the machine's forward speeds and measuring some physical properties of wheat seeds.

1. Seed rate

The seed rate is adjusted through the alteration of the chain's positioning on the sprockets situated on both the machine wheel and the metering shaft.

The recommended seeding rate for the "Giza 171" wheat variety is based on the recommendations of the Egyptian Ministry of Agriculture and the Agricultural Research Center, which typically suggest a rate ranging from 60 to 70 kilograms per feddan under optimal conditions. These recommendations consider factors such as soil type, cultivation methods, and the irrigation system used to ensure the best possible yield.

The optimum seeding rates across the two seasons for the six wheat cultivars Sids12, Giza 171, Gemmeiza11, Misr3, Shandaweel1 and Sakha 95 were 73.22, 71.27, 80.19, 59.19, 46.76 and 56.66 kg fed.-1, respectively (**Moussa, 2019)**. Laboratory calibration was carried out to determine the seeding rate levels, as illustrated in Table 1.

Table 1: Calibration of seed rate (kg/fed) and (kg/ha) at different sprocket wheels.

No. of seed rate	T_1 Ground wheel (teeth)	T_2 Metering device (teeth)	Seed rate (kg/fed)	Seed rate (kg/ha)
1	28	14	127.13	302.57
2	24	16	99.35	236.45
3	22	18	82.15	195.52
4	20	20	65.56	156.03
5	18	22	52.25	124.36
6	16	24	44.71	106.41
7	14	28	33.77	80.37

2. Operation forward speed

The machine is equipped with six forward speed levels. The desired speed can be adjusted by utilizing a chain and a reduction sprocket that connects the motor to the machine's wheels.

The forward speed of the machine (km/h) corresponding to different sprocket wheels is provided in Table 2.

Table 2: Forward speed for the machine (km/h) at different sprocket wheels.

No. of speed	T_1 Motor (teeth)	T_2 Ground wheel (teeth)	Theoretical forward speed (km/h)	Actual Forward speed (km/h)
1	14	28	0.48	0.45
2	16	24	0.64	0.58
3	18	20	0.86	0.76
4	20	18	1.07	0.91
5	24	16	1.44	1.23
6	28	14	1.92	1.62

The performance of the prototype machine was tested at three forward speeds: 0.58, 0.91, and 1.23 km/h. These speeds were selected to ensure symmetry and consistency between the different speed levels.

3. Physical properties of wheat seeds

Some physical properties of wheat seeds were measured, including length, width, thickness, and bulk density.

3.1 Thousand grain mass

One thousand wheat seeds (Giza 171) were randomly selected and weighed to determine the thousand-grain mass in grams.

3.2 Bulk density of wheat seed

The bulk density was determined by taking wheat in a graduated cylinder. The weight of the grain in the cylinder weighed and divided by volume of cylinder (**Varnmakasti et al., 2007**).

$$B_D = \frac{W}{V} \tag{2}$$

Where, B_D= Bulk density (g/mm^3), W = Weight of sample (g) and V = Volume (mm^3)

The physical properties of wheat seeds are shown in Table 3.

Table 3: Main physical properties of wheat seeds.

Properties	**Wheat**
Length, mm	7.20
Width, mm	3.73
Thickness, mm	3.26
Bulk density (g/mm^3)	0.833

Evaluate the performance of a prototype seed drill.

The performance of the prototype seed drill was evaluated by measuring several key parameters it carried out in a field, including field calibration, power requirements, specific energy consumption, machinery slip, seed damage, and field efficiency.

1. **Field calibration**

Field calibration of planter machines is essential for achieving accurate seeding rates, improving planting precision, and optimizing crop performance. Proper calibration helps to ensure uniform seed distribution, minimize wastage, and enhance field efficiency by accounting for variations in soil conditions and machine settings.

The seed rate in the field was determined by measuring the mass of seeds before and after the sowing operation. The final mass of the seeds was subtracted from the initial mass to obtain the seed rate, and the results were expressed in kg/ha. This was established considering the mass of seeds planted per hectare.

Field calibration was conducted on gear set No. 4 to achieve the desired seeding rate at three forward speeds: 0.58, 0.91, and 1.23 km/h. The results of the calibration are presented in Table 4.

$$\text{Seed rate (kg/ha)} = \frac{\text{mass}}{\text{area of the plot}} \qquad (3)$$

Table 4: Calibration of seed rate (kg/fed) and (kg/ha) in field at different sprocket wheels in field.

No. of seed rate	T_1 Ground wheel (teeth)	T_2 Metering device (teeth)	Seed rate (kg/fed) (Lab)	Seed rate (kg/ha) (Lab)	Forward speed (km/h)	Seed rate (kg/fed) in field	Seed rate (kg/ha) in field
4	20	20	65.56	156.03	0.58	67.15	159.817
					0.91	68.15	162.197
					1.23	69.21	164.72

2. **Draft force measurement:**

The draft forces were measured for the following configurations: the machine without furrow openers, the machine with 5 furrow openers (3 cm depth), the machine with 3 furrow openers (3 cm depth), the machine with 5 furrow openers (5 cm depth), and the machine with 3 furrow openers (5 cm depth). In each case, the draft forces were measured using a Digital Scale mounted between the tractor and the machine. The readings were recorded at different forward speeds, and the average was calculated.

The specifications of the Digital Scale are as follows: the device is Digital Scale, with a maximum load capacity of 200 kg and accuracy 50g.

3. **Power requirements:**

The power required (W) was estimated according to the following known formula:

$$P = F \times V \qquad (4)$$

Where, P = Power requirements (W), V = Speed (m/s), F = Force (N).

4. **Specific energy consumption (Ec)**

It was estimated for each investigate sowing modes according to the following equation:

$$E_c = \frac{P}{A_c} \qquad (5)$$

Where, E_c = Specific energy consumption (Kw.h/ha), P = Power requirement (KW), Ac= Actual field capacity (ha/h).

5. **Machinery Slip:**

The machinery slip (%) was measured as a function of power loss due to attaching the Furrow openers unit. The slip was measured under different speeds for the fabricated drill. The slip was calculated from the following equation:

$$S = \frac{V_1 - V_2}{V_1} \times 100 \qquad (6)$$

Where, S= slip, (%), V_1= speed without load, V_2= speed with load.

6. **Operation speed**

To determine the operation speed in the field, the time required for covering 25 m length was recorded with digital stopwatch. Three measurements were recorded, and mean values were computed as km/h calculated.

$$\text{Speed(km/h)} = \frac{\text{Distance(m)}}{\text{Time(sec)}} \times 3.6 \qquad (7)$$

7. **Determination of Seed Damage Percentage**

The hopper was loaded with 5 kg of wheat seeds. A transparent nylon sheet was laid on the ground on which the seed drill moved to evaluate the seeds after the laboratory experiment. The seeds discharged in each row were observed for any external damage, the procedure was repeated three times. Equation 10 was used to calculate the seed damage percentage.

$$\text{Damage\%} = \frac{N_d}{N_t} \times 100 \qquad (8)$$

Where, N_d = total number of the damaged seeds in the sample, N_t = total number of the seeds in the sample.

8. **Theoretical field capacity**

The seed drill theoretical field capacity is the rate of field coverage that would be obtained if the drill performing its function 100 % of the time at the rated forward speed and cover 100 % of its rated width. It is expressed as hectare per hour and determined as follows **(Kepner et al., 1978).**

$$TC = \frac{W \times S}{10} \qquad (9)$$

Where, TC = Theoretical field capacity, (ha/h), W = Effective width of implement, (m); and S = Speed of operation, (km/h).

9. **Actual field capacity**

The actual field capacity refers to the effective rate at which the seed drill covers the field, factoring in the total operating time and the portion of the machine's width that is utilized. It is measured in hectares per hour. **(Kepner et al., 1978).**

$$Ac = \frac{A}{T} \qquad (10)$$

Where, Ac = Actual field capacity, (ha/h), A = Actual area covered, (ha); and T = Time required to cover the area, (h).

10. **Field efficiency**

Field efficiency is the ratio of effective field capacity to theoretical field capacity. It was determined by the following formula:

$$FE = \frac{Ac}{Tc} \times 100 \qquad (11)$$

Where, FE = Field efficiency (%), Ac= Actual field capacity, (ha/h); and Tc=Theoretical field capacity, (ha/h).

11. **Solar energy measurements**

To evaluate the performance of the suggested PV system, measurements were made of the air temperature, solar radiation, output voltage, and current over the course of three days, from 7 a.m. to 5 p.m. A TES 1333 solar power meter was used to monitor solar radiation, an air temperature sensor was used to measure air temperature, and a digital multimeter was used to measure output voltage and current.

RESULTS AND DISCUSSION

Evaluation of prototype seed drill

The operation of the prototype machine was evaluated under various parameters and conditions. Measurements were taken to determine the following: power required (kW), specific energy (kWh/ha), seed damage rate, wheel slip (%), actual field capacity (ha/h), and field efficiency (%).

1. Required power:

The power requirements are shown in Figure 5 as affected by forward speed, number of planting rows and planting depth. Figure 5 indicates that increasing the forward speed led to an increase in required power for all levels of planting rows and both levels of planting depth. This can be explained by the relationship between forward speed and required power is direct: as the forward speed increases, so does the power needed to operate the seed drill efficiently. This trend is consistent regardless of the number of planting rows or the depth at which seeds are planted.

Increasing the planting depth resulted in a higher required power at all levels of forward speed and for all numbers of planting rows. This could be attributed to the additional force needed to penetrate the soil and the increased soil movement. Additionally, increasing the number of planting rows from 3 to 5 led to an increase in required power at all levels of forward speed and planting depth. The increase in the number of planting rows led to covering a wider area in a single pass. This increased coverage means the machine requires more power to cover a larger surface area.

The lowest required power, 0.111 kW, was observed at a planting depth of 3 cm and 3 planting rows with a forward speed of 0.58 km/h. The highest required power, 0.173 kW, was recorded at a planting depth of 5 cm and 5 planting rows with a forward speed of 1.23 km/h.

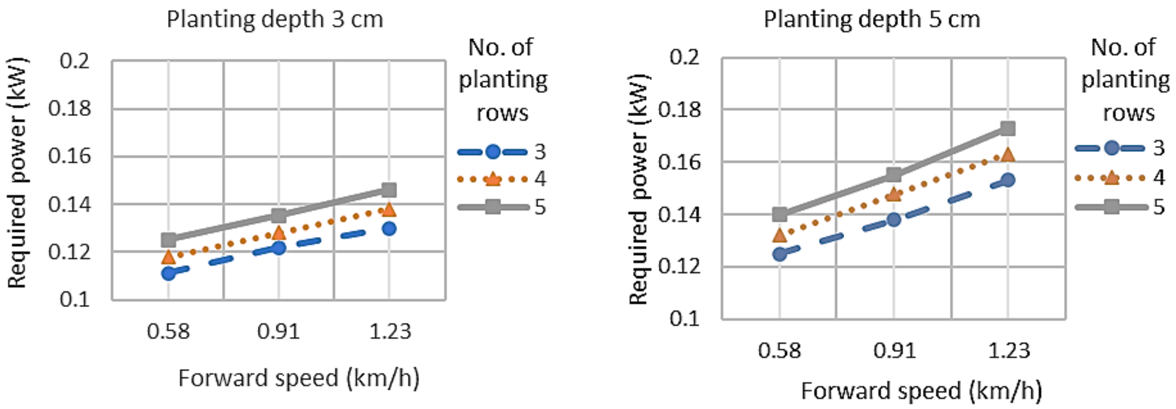


Fig. (5): Effect of forward speed (km/h) and number of planting rows at 3 and 5 cm planting depth on required power(kW)

2. Specific energy:

The influence of forward speed and number of planting rows at planting depth 3 and 5 cm on specific energy, is illustrated in figure 6. The figure indicates that increasing forward speed led to a decrease in specific energy consumption at all levels of planting rows for both planting depths. This may be due to the machine covering more area in less time, which leads to energy use over a larger surface. This makes the energy required per unit area lower. Additionally, increasing the number of planting rows from 3 to 5 also leads to a decrease in specific energy consumption at all forward speeds for both planting depths. This might be due to more rows planted in a single pass leads to lower energy required per unit area. Furthermore, increasing the planting depth results in increased specific energy consumption for all forward speeds and numbers of planting rows. This might be because of the additional force needed to penetrate the soil, the increased resistance from moving more soil.

The lowest value of specific energy consumption 2.58 kWh/ha was observed at 3 cm of planting depth and 5 of planting rows at 1.23 km/h of forward speed. The highest value of specific energy consumption 7.99 kWh/ha was recorded at 5 cm of the planting depth and 3 of planting rows at 0.58 km/h of forward speed.

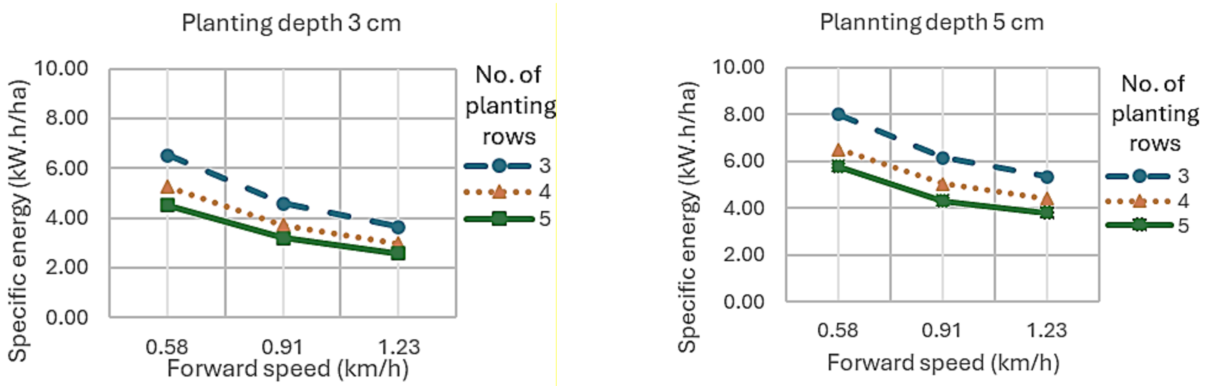


Fig. (6): Effect of forward speed (km/h) and number of planting rows at planting depth 3 and 5 cm on specific energy (kW.h/ha)

3. Seed damage rate:

In the field experiment, 50 wheat grains were taken as a control sample before the experiment began. A random sample of 50 grains was collected for each treatment by placing bags under each seed tube. Germination tests were carried out on all samples to evaluate seed damage, with germination rate used as the evaluation criterion. The seed damage rate was nonexistent at all tested forward speeds. This indicates that no seed damage occurred within this range of operational speeds. This absence of seed damage suggests that the seed drill machine was effective in handling seeds.

4. **Wheel slip (%)**

The slip data for the seed drill are presented at three different forward speeds, three numbers of planting rows and two planting depths as shown in figure 7. The figure indicates that increasing forward speed results in higher slips at all levels of planting rows for both 3 and 5 cm planting depths. Increasing forward speed leads to higher slip due to increased draft force requirements and reduced traction efficiency. Additionally, increasing the number of planting rows leads to an increase in slip at all forward speeds for both planting depths. This could be attributed to the increase in the planting width of the seed drill machine. The additional rows create more resistance against the soil. This added resistance causes the wheels to slip more frequently as they struggle to push the wider machine through the soil. Furthermore, increasing the planting depth results in increased slip for all forward speeds and numbers of planting rows. This is due to the deeper planting depths requiring more force to penetrate the soil. This additional force creates more resistance against the machine's wheels and results in increased slip.

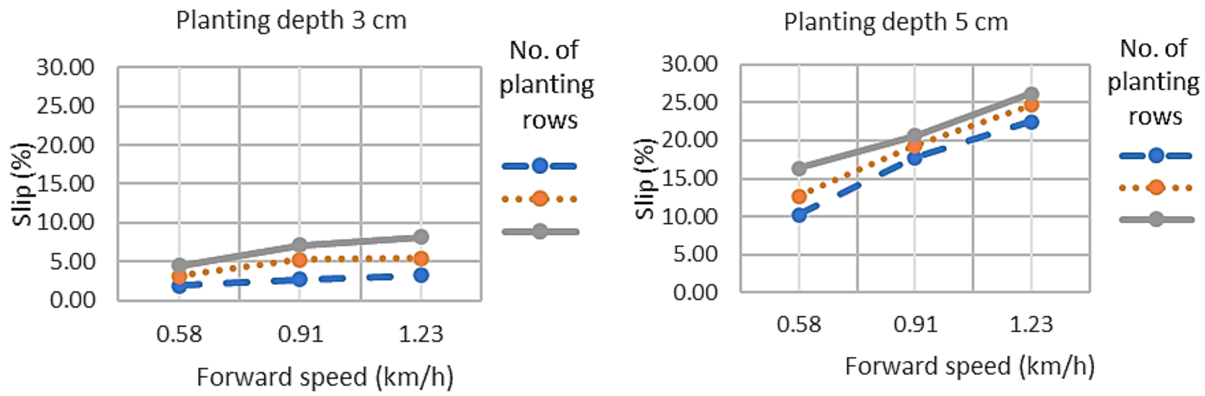


Fig. (7): Effect of forward speed and number of planting rows at 3 and 5 cm planting depth on wheel slip (%)

The lowest value of the slip 1.90 % was observed at 3 cm of planting depth and 3 of planting rows at 0.58 km/h of forward speed. The highest value of the slip 26.18 % was recorded at 5 cm of the planting depth and 5 of planting rows at 1.23 km/h of forward speed.

5. Actual field capacity

Figure 8 illustrates the effect of forward speed and the number of planting rows at planting depths of 3 and 5 cm on actual field capacity. The data show that increasing the forward speed results in an increase in actual field capacity for all levels of planting rows. This may be due to the machine moving faster, it can plant seeds over a larger area per hour, thereby increasing the actual field capacity. Similarly, increasing the number of planting rows leads to a higher actual field capacity at all forward speed levels. The greater number of seeds planted per pass, fewer passes needed to cover the field. Thereby increasing the overall coverage area per hour and increasing the field capacity. Increasing the planting depth led to a decrease in actual field capacity at all levels of forward speed and for all numbers of planting rows. This could be a result of increased soil resistance, which caused more wheel slippage and required additional time for deeper planting.

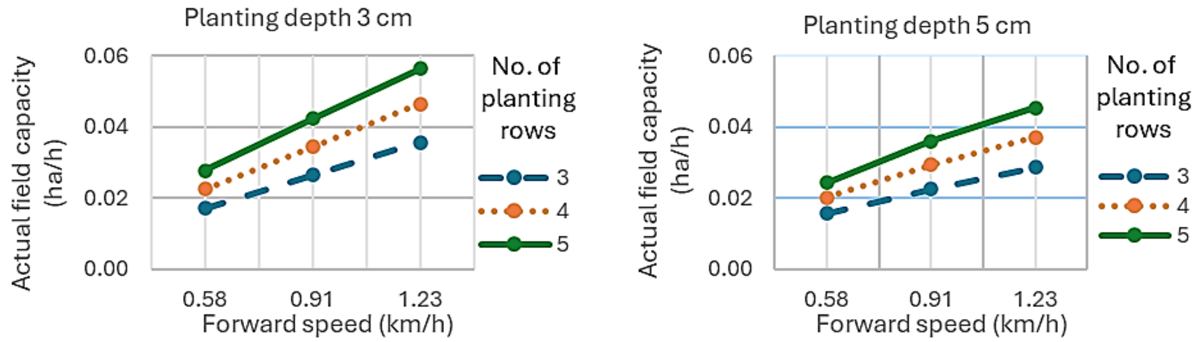


Fig. (8): Effect of forward speed (km/h) and number of planting rows at 3 and 5 cm planting depth on actual field capacity (ha/h)

The lowest value of actual field capacity 0.016 ha/h was observed at 5 cm of planting depth and 3 of planting rows at 0.58 km/h of forward speed. The highest value of actual field capacity 0.057 ha/h was recorded at 3 cm of the planting depth and 5 of planting rows at 1.23 km/h of forward speed.

6. Field efficiency

The effect of forward speed and number of planting rows at 3 and 5 cm planting depth on the field efficiency is shown in figure 9. The figure shows that increasing the forward speed led to a decrease in field efficiency for all levels of planting rows at both 3 and 5 cm planting depth. Additionally, increasing the number of planting rows resulted in a decrease in field efficiency at all forward speed levels at both planting depths. Similarly, increasing the planting depth led to a decrease in field efficiency at all forward speed levels and for all numbers of planting rows. The reduced field efficiency may be attributed to the increase in forward speed, planting depth, and number of planting rows, which caused increased slippage between the machine's wheels and the ground.

The lowest value of the field efficiency 64.86 % was observed at 5 cm of planting depth and 5 of planting rows at 1.23 km/h of forward speed. The highest value of the field efficiency 91.77 % was recorded at 3 cm of the planting depth and 3 of planting rows at 0.58 km/h of forward speed.

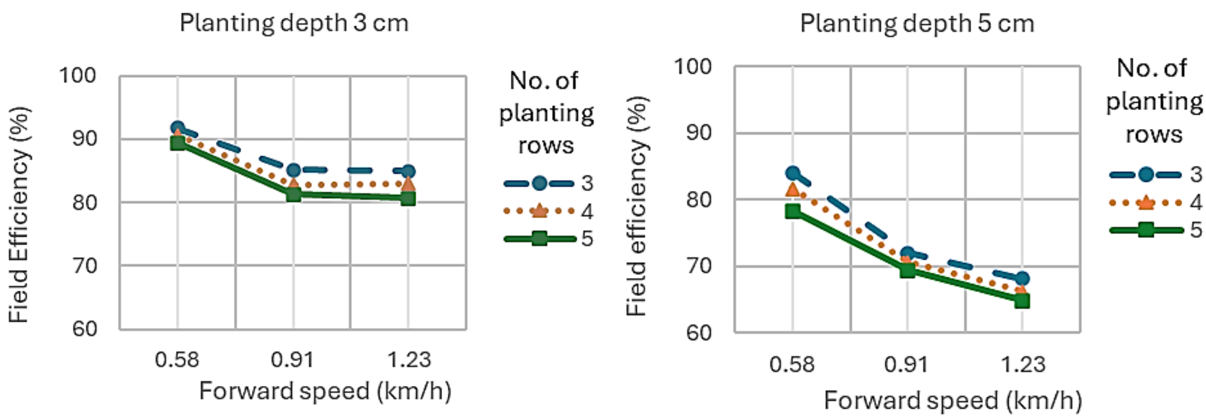


Fig. (9): Effect of forward speed (km/h) and number of planting rows at 3 and 5 cm planting depth on the field efficiency (%)

The Variance analysis table presents the effects of planting depth, forward speed, and number of planting rows and their interactions on required power, specific energy, field efficiency, actual field capacity, wheel slip. Depth has a significant effect on required power, slip, field efficiency, and specific energy, but not on actual field capacity. Speed significantly influences all variables. Number of rows significantly effects on required power, actual field capacity and specific energy, but has no significant effect on slip and field efficiency. The interaction between depth, speed, and number of rows is highly significant for all variables. This highlights the importance of depth and speed in optimizing the performance, with limited influence from the number of rows except for power requirements and specific energy consumption.

Table 5: Analysis of Variance for the effects of planting depth, forward speed, number of planting rows, and their interactions on required power, wheel slip, field efficiency, Actual field capacity and specific energy consumption.

		R. power (kW)	slip (%)	FE (%)	AC (ha/h)	Ec (kW.h/ha)
Depth	Mean Square	0.005	2767.354	2194.976	0.000	25.363
	F	30.717	185.095	73.950	3.718	17.010
	Sig.	0.000	0.000	0.000	0.059	0.000
	Probability	**	**	**	N.S.	**
Forward speed	Mean Square	0.003	216.622	644.786	0.002	25.014
	F	19.142	3.551	13.428	37.790	24.128
	Sig.	0.000	0.036	0.000	0.000	0.000
	Probability	**	*	**	**	**
No. Rows	Mean Square	0.001	75.629	60.867	0.001	12.957
	F	5.132	1.137	0.858	10.730	8.584
	Sig.	0.009	0.329	0.430	0.000	0.001
	Probability	**	N.S.	N.S.	**	**
Interaction	Mean Square	0.001	208.462	219.860	0.000	6.047
	F	223.325	7827.125	10329.401	96719.620	2013.814
	Sig.	0.000	0.000	0.000	0.000	0.000
	Probability	**	**	**	**	**

Source: Own calculation based on program of SPSS Ver.22 - *: Significant at 5% level of significance, **: Highly significant at 1% level of significance and N.S.: Non-Significant

Table 6: Mean ± SE. of the interaction effects between planting depth, forward speed, and number of planting rows on power requirements, wheel slip, field efficiency and specific energy consumption.

Depth	Speed	No. rows	R. power (kW)	slip (%)	FE (%)	Ec (kW.h/ha)
3	0.58	3	0.111 ± 0.000^{m}	1.89 ± 0.058^{p}	91.77 ± 0.052^{a}	6.51 ± 0.021^{b}
		4	0.118 ± 0.001^{l}	3.14 ± 0.006^{n}	90.61 ± 0.006^{b}	5.25 ± 0.025^{f}
		5	0.125 ± 0.001^{ij}	4.45 ± 0.029^{m}	89.39 ± 0.026^{c}	4.51±0.022h
	0.91	3	0.122 ± 0.001^{k}	2.72 ± 0.015^{o}	85.12 ± 0.015^{d}	4.59 ± 0.024^{h}
		4	0.128 ± 0.001^{hi}	5.32 ± 0.047^{l}	82.85 ± 0.041^{f}	3.72 ± 0.033^{kl}
		5	0.135 ± 0.002^{f}	7.09 ± 0.080^{k}	81.30 ± 0.070^{h}	3.19 ± 0.039^{m}
	1.23	3	0.130 ± 0.001^{gh}	3.26 ± 0.019^{n}	84.99 ± 0.015^{d}	3.64 ± 0.016^{l}
		4	0.138 ± 0.001^{ef}	5.46 ± 0.019^{l}	83.06 ± 0.015^{f}	2.97 ± 0.024^{n}
		5	0.146 ± 0.002^{d}	8.16±0.006 j	$80.e69\pm0.006^{i}$	2.59 ± 0.031^{o}
5	0.58	3	0.125 ± 0.001^{ij}	10.22 ± 0.140^{i}	83.99 ± 0.131^{e}	7.99 ± 0.030^{a}
		4	0.132 ± 0.001^{g}	12.71 ± 0.145^{h}	81.66 ± 0.135^{g}	6.52 ± 0.047^{b}
		5	0.140 ± 0.001^{e}	16.35 ± 0.058^{g}	78.25 ± 0.055^{j}	5.77 ± 0.028^{d}
	0.91	3	0.138 ± 0.001^{ef}	17.73 ± 0.115^{f}	71.99 ± 0.102^{k}	6.15 ± 0.044^{c}
		4	0.148 ± 0.001^{d}	19.35 ± 0.058^{e}	70.57 ± 0.052^{l}	5.03 ± 0.018^{g}
		5	0.155 ± 0.001^{c}	20.68 ± 0.160^{d}	69.41 ± 0.139^{m}	4.29 ± 0.040^{j}
	1.23	3	0.153 ± 0.001^{c}	22.48 ± 0.171^{c}	68.10 ± 0.151^{n}	5.35 ± 0.038^{e}
		4	0.163 ± 0.002^{b}	24.66 ± 0.168^{b}	66.19 ± 0.148^{o}	4.39 ± 0.038^{i}
		5	0.173 ± 0.001^{a}	26.18 ± 0.044^{a}	64.86 ± 0.041^{p}	3.81 ± 0.028^{k}

a, b, c, and ....exe means within the same row with each different superscript are significantly different (P≤0.05)

Based on the data in table 6, the two optimal cases that balance required power, field efficiency, slip, and specific energy consumption are: First case: planting depth 3 cm, forward speed 0.58 km/h, number of planting rows 3. This case shows, required power 0.111 kW (lowest), slip 1.897% (lowest), field efficiency 91.773% (highest), and specific energy 6.513 kWh/ha. This case provides the highest efficiency and lowest power requirements, making it the best case for minimal energy use and maximum performance. Second case: planting depth 3 cm, forward speed 1.23 km/h, number of planting rows 5. This case shows required power 0.146 kW, slip 8.16%, field efficiency 80.690% and specific energy 2.585 kWh/ha (lowest). This case provides the best energy efficiency (lowest) while maintaining a reasonable balance of power requirements and field efficiency. Ideal for operations needing faster speeds and more planting rows. Both cases maximize efficiency with low energy and power requirements, suitable for different operational needs.

7. Electrical productivity from PV

Table (7) gives the total daily electrical productivity from PV during the winter for the experimental day. The data shows that the solar irradiance was 3660 $Wm^{-2}.day^{-1}$. The value of electrical energy productivity from PV has different values throughout the day and the total value was 330 $Wday^{-1}$ in the winter. This result is an agreement with **Ruiz et al., (2020**) and **samak et al., (2022)**. Electrical energy productivity variation during the light day affected by changes in both of solar irradiance and temperature during the day. The energy consumption for the machine was fixed and obtained from electrical energy productivity from PV. The excess electricity of the amount required is stored in the battery to regain it at time of poor production from PV.

8. The Energy required to operate the machine

The power required according to the results and recommendation for operating the Seed Drill is 146 W. It can be operated continuously for up to some hours after one full charging which consumes only 0.146 kWh of electricity obtained from electrical energy productivity from PV. Table 7 shows the total solar radiation falling during the day in the winter season, it was, 3660 W day^{-1}. The electrical productivity of the PV system was 330 W day^{-1}. The total energy required to operate the machine was 146 W h^{-1}. The number of possible hours to operate the machine was 2.26 hour. The performance rate at recommended treatment was 0.0612 ha h^{-1} with the operation width being 0.5 m and the velocity of the machine being 1.23 km h^{-1}. The actual daily performance rate was 0.138 ha day^{-1}.

Table (7): The hourly solar irradiance, PV efficiency and electrical productivity from PV.

Time	6 am	7 am	8 Am	9 am	10 am	11 am	12 am	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	Total power (W/day)
During the winter															
Solar irradiance (W/m^2)	**0**	**12**	**180**	**337**	**539**	**592**	**623**	**557**	**413**	**258**	**144**	**5**	**0**	**0**	**3660**
Solar panel efficiency (%)	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	**18**	
Electrical productivity from PV system, (W)	**0**	**1.08**	**16.2**	**30.33**	**48.51**	**53.28**	**56.07**	**50.13**	**37.17**	**23.22**	**12.96**	**0.45**	**0**	**0**	**330**

CONCLUSION

Small agricultural machines are essential for farmers with small plots, as they increase efficiency, reduce labor costs, and improve productivity, making it easier to manage and cultivate limited land. Similarly, renewable energy is crucial for sustainable development. Egypt's abundant land, sunny weather, and strong winds create ideal conditions for renewable energy projects. Moreover, the energy needs of agricultural activities are crucial for maintaining and enhancing production. Based on Egypt's renewable energy potential, utilizing these resources in agriculture would provide economic and environmental benefits. Currently, traditional planting methods are labor-intensive and time-consuming. Moreover, large planting machinery is expensive and uneconomical for small farms, as it requires a tractor to operate. Thus, there is a need to fabricate and evaluate a prototype seed drill powered by solar energy, especially for smallholding farms, as a solution to these problems. The general objective of this study is to develop and evaluate the performance of a prototype machine powered by solar energy via a flexible solar panel system. The development and evaluation process of the seed drill machine was carried out in several steps. The first step involved fabricating and developing the prototype with a remote-control unit and solar power system. In the second step, the prototype seed drill was evaluated in a laboratory. The third step was to evaluate the prototype machine under field conditions. This study investigated the effects of various operational parameters, including forward speed, number of planting rows, and planting depth, on the required power, specific energy, seed damage rate, wheel slip, actual field capacity, and field efficiency. The results indicate that increasing forward speed and the number of planting rows raised power requirements, wheel slip, and field capacity, while reducing specific energy and field efficiency. Similarly, increasing planting depth led to an increase in power requirements, slip, and specific energy but decreased field capacity and efficiency. It is recommended to operate the prototype machine at a high forward speed of 1.23 km/h and a planting depth of 3 cm. Use five seed tubes to achieve optimal performance. Additionally, using wide ground wheels will increase the contact area with the ground, further minimizing slippage. This machine represents a new application of renewable energy in agricultural machinery, offering several advantages:

1- The machine is powered by solar energy, making it environmentally friendly with no exhaust emissions.
2- It is suitable for small areas that cannot accommodate large traditional farm machinery.
3- Its light weight prevents soil compaction and the formation of soil bane layers, thereby avoiding long-term deterioration of soil drainage and root growth, unlike large tractor-drawn planters.
4- It causes less damage to seeds.
5- It is economical, with very low variable costs during operation compared to manual farming and tractor-related agricultural machinery.
6- It is suitable for planting different types of crops.

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تقييم أداء آلة زراعة تعمل بالطاقة الشمسية

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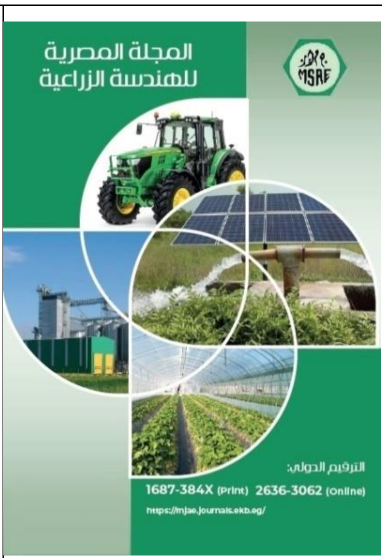

الكلمات المفتاحية:
آلة زراعة البذور؛ الطاقة المتجددة؛ نموذج أولي للآلة؛ آلة زراعة البذور بالطاقة الشمسية؛ لوحة شمسية؛ جهاز التحكم عن بعد.

الملخص العربي

يشكل تقسيم الأراضي إلى حيازات صغيرة عقبة أمام استخدام الآلات الزراعية الكبيرة، نظرا لصعوبة المناورة في المساحات المحدودة وارتفاع تكاليف التشغيل. وبالتالي، تكمن أهمية الآلات الزراعية الصغيرة في تعزيز الكفاءة والإنتاجية، مما يسهم في تسهيل إدارة وزراعة الحيازات الصغيرة بشكل أكثر فعالية. الطاقة الشمسية هي أحد مصادر الطاقة المتجددة المستخدمة للتخفيف من تأثيرات تغير المناخ وارتفاع أسعار الطاقة. الهدف من هذه الدراسة هو تقييم أداء آلة زراعة البذور تعمل بالطاقة الشمسية. تعتبر هذه الآلة واحدة من التطبيقات الحديثة للطاقة المتجددة في مجال الزراعة وتوفر العديد من المزايا. يتكون نموذج آلة زراعة البذور التي تعمل بالطاقة الشمسية من الإطار الرئيسي والقادوس وجهاز تلقيم البذور وأنبوب توصيل البذور وفجاجات وعجلة الأرض ونظام طاقة شمسية ووحدة تحكم عن بعد ووحدة ذاتية التوجيه. تشير النتائج إلى أن زيادة السرعة الأمامية وعدد صفوف الزراعة أدت الي زيادة في متطلبات القدرة وانزلاق العجل والسعة الحقلية الفعلية، مع انخفاض في الاستهلاك النوعي للطاقة والكفاءة الحقلية. وبالمثل، أدى زيادة عمق الزراعة إلى زيادة متطلبات القدرة والانزلاق والاستهلاك النوعي للطاقة، ولكن انخفض كلا من السعة الحقية الفعلية والكفاءة الحقلية. تم تسجيل أعلى قيمة لمتطلبات القدرة ونسبة الانزلاق ٠,١٧٣ كيلو واط و٢٦,١٨٪ على التوالي عند عمق الزراعة ٥ سم وعدد صفوف الزراعة ٥ صفوف وسرعة أمامية ١,٢٣ كم / ساعة. تشير الدراسات العامة إلى أن الطاقة الكهربائية المولدة من الطاقة الشمسية الكهروضوئية يمكن أن تساعد في تقليل تكاليف الطاقة المرتفعة ويمكن الاستفادة منها في تطبيقات الإنتاج الزراعي المختلفة.