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Research Article

Development of Animal Drawn Groundnut Planting Machine for Small Holdings Farmers in North Kordofan of Sudan

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A b s t r a c t

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Field efficiency

An animal drawn groundnut planting machine was designed and fabricated. First a computer simulation was conducted for design optimization of furrow opener and covering device of the machine. Equivalent stress for winged type soil engaging components found to be 1.36 x 10^8 kPa, while for moldboard type was 1.39 x 10^8 kPa, therefore winged type furrow opener and covering device with 45^o rake angle were adopted. Field tests for machine performance were carried out using donkey, mule, and horse as draft animals. The field results showed that the lowest total field time was recorded by mule (1341.3 sec), and the highest total field time was recorded by manual method of sowing (5828.3 sec). The theoretical field capacity values were 0.155 ha/h, 0.175 ha/h, and 0.130 ha/h and they were recorded by donkey, mule, and horse respectively. The values of effective field capacity were 0.128 ha/h, 0.147 ha/h, and 0.105 ha/h and they were demonstrated by donkey, mule, and horse respectively, while in case of manual method of sowing, the effective field capacity was 0.032 ha/h as the lowest value. The field efficiency values were 82.3 % by donkey, 84.3 % by mule and 80.9 % by horse and there was no significant difference between these values at $P < 0.001$, while in case of manual method of sowing, the field efficiency was 35 % as the lowest value as compared to the machine treatments.

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1. Introduction

There are three main sources of power in agriculture, human, animal and motorized power. In the rural areas of developing countries like Sudan, Nigeria and India, farmers use simple implements and tools utilizing human and animal power, therefore their production is low. In spite of many trials for mechanizing and using large machinery for small- scale and traditional farming agriculture, the general recognition is that sophisticated and expensive technology will never be a suitable solution for small farmers [1]. Introduction of animal–drawn implements as intermediate technology for small farmers is becoming increasingly necessary, especially for some critical operations like planting and weeding [2-4]. Animal drought implements compared to manual tools have positively affected the crop production factors through improving field efficiency and capacity, increasing crop yield and reducing costs of production ([5-8]. Sudan grows different types of crops such as millet, sorghum, G/N, water melon and cowpeas in small holdings of western Sudan as traditional agriculture [9] They use many types of small farming tools and implements at different stages of crop production. Animal drawn implements are used by some farmers mainly for weeding of G/N (the most important cash crop in the area). This was observed to increase the cultivable land, reduce the cost of production and improved the general standard of living of the people [8 and 10].

The objectives of this study are to design and fabricate an animal drawn G/N planting machine using local materials, design optimization of soil engaging components of the machine using computer simulation and modeling, and to evaluate the field performance of the developed machine drawn by donkey, mule, and horse as compared to manual sowing.

2. MATERIALS AND METHODS

2.1 Materials

The experimental work was conducted in FaragAlla village north Elobied town. The experimental site characterized as sandy soil and the soil physical properties are shown in Table 1.

Materials used in this study include a desk top computer, ANSYS software, and C++ programming language in addition to materials for manufacturing the planting machine such as mild steel sheets, gears, steel chain, steel rods and pipes, PVC pipes, and rubber wheels. Three animals (donkey, mule, horse) were used for pulling the machine and one labour for manual sowing.

2.2 Methods

2.2.1 Simulation modeling for design optimization of furrow openers and covering devices:

The soil model was developed by using the physical properties of the sandy soil as soil input parameters in ANSYS program.

Table. 1**:** Soil physical properties of the experimental areas

Parameter	Value
Soil bulk density	1.1
Soil cohesion	0
Soil-steel adhesion	26.3 kPa
Soil internal angle of friction	42^0
Soil - steel angle of friction	22^0
Soil-steel friction coefficient	0.41

2.2.1.1 Material definition for mesh generation

Solid with 8 nodes, 185 element type and Drucker-Prager material model with soil physical properties were used for soil meshing. In case of furrow openers (Fig. 1), solid with 10 nodes, 45 element type and elastic isotropic material model were used for furrow opener meshing.

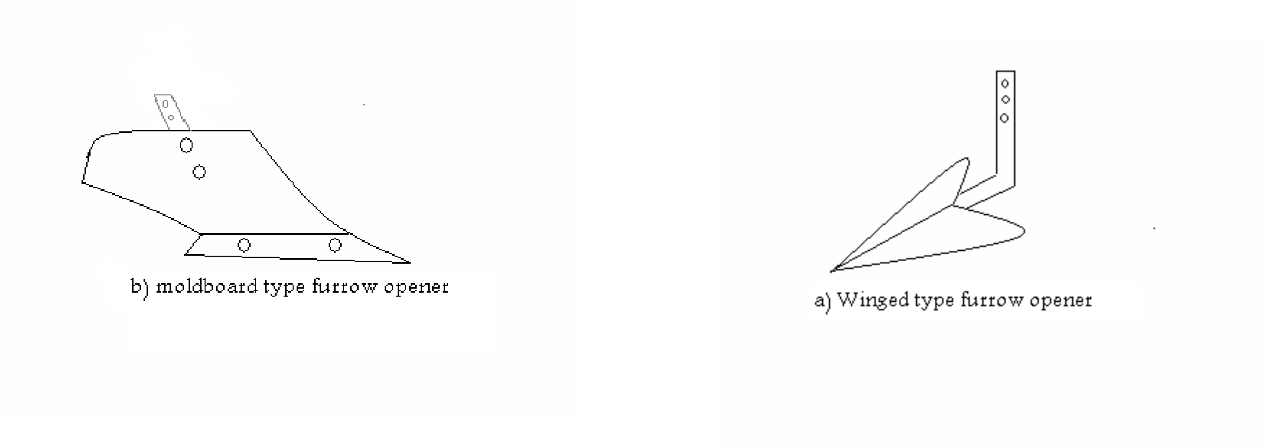


Fig. 1: Furrow opener designs

Soil model was constrained at five sides while the upper face was left unconstrained. For furrow opener, the nodes displacements in X, Y, and Z directions were taken as follows:

$$UX_i = 0 \text{..} (1)$$

$$UY_i = 0 \text{..} (2)$$

$$UZ_i = 200mm \text{..} (3)$$

2.2.1.2 Optimization of furrow opener rake angle:

Winged furrow opener rake angle was modeled in a program developed by C++ computer programming language to adopt a rake angle which gives the lowest resistance force and power requirement.

2.2.2 Fabrication of the planting machine:

The machine was fabricated in a workshop in Elobied town, Sudan. Three winged type furrow openers were manufactured each with 45^0 rake angle, two winged type covering devices were made to perform weeding operation and cover the seeds simultaneously. The frame of the machine was constructed with seed box and was supported by two ground rubber wheels. The seed box was composed of three separated units to prevent the accumulation of the seeds in one side of the box. The metering device of the machine composed of three steel plates each with five holes for seed placement through a seed pipe each plate was supplied with a brush to prevent the seeds holes to be clogged with seeds. The rotational motion was transmitted to the plate by meshed bevel gears welded on a rectangular steel rod. One end of the rod supplied with a toothed gear which receives the motion from other toothed gear fixed on a rear rubber wheal through a steel chain. The rear wheel was connected to the frame by a two bars in a way that it can be idle when the machine is not in operation. A cylinder was connected vertically to bars to be filled with soil for ballasting purposes.

2.2.3 Field Performance Test of the Planting Machine:

The field performance evaluation of the planting machine was conducted in July 2009. The parameters measured include field time, operating speed, theoretical field capacity, effective field capacity, Field efficiency and plant density. The experimental area was 0.86 ha, and it was divided into 16 plots each 5.4 m X 100 m. A completely randomized plot (CRD) experimental design was used. The treatments were distributed randomly in the experimental plots which were replicated four times Seeding operation was performed using 4 treatments namely:

i- Planting machine drawn with donkey.

ii- Planting machine drawn with mule.

iii- Planting machine drawn with horse.

iv- Manual seeding.

2.2.3.1 Measurement of field times

Time for each stroke to cover the length of the plot (100 m) was recorded as a productive time. Time for each turn at the end of the plot was determined. Total time required to cover the plot was computed as follow:

Total time (sec) $= \sum PT + \sum TT$...........................(1)

Where,

PT = productive time, (sec).

TT = Time of turns, (sec).

2.2.3.2 Determination of operating speed

The operating speed was computed as follow

$$S = \frac{L}{t} \text{..(2)}$$

Where,

S = operating speed, (m/sec).

L = Length of the plot, (m).

t = time required to cover one stroke, (sec).

2.2.3.3 Determination of theoretical and Effective field capacities

Theoretical field capacity was calculated as follows:

$$TFC = \frac{W \times S}{C} \text{...(3)}$$

Where,

TFC = theoretical field capacity, (ha/h).

W = machine width, (m).

C = conversion factor.

Effective field capacity was calculated as follow:

$$EFC = \frac{A}{C \times T} \text{...}(4)$$

Where,

EFC = effective field capacity, (ha/h).

A = plot area, (m^2).

T = total time required to cover the plot, (sec).

C = conversion factor.

2.2.3.4 Determination of Field efficiency

$$FE = \frac{EFC}{TFC} \times 100 \text{...}(5)$$

Where,

FE = field efficiency, (%).

2.2.3.5 Determination of plant density

Number of plants per meter square was counted at different locations in the plot.

3. RESULTS AND DISCUSSION

3.1 Furrow opener selection and optimization

The reaction between furrow opener and soil is non-linear problem. The simulation was conducted by adopting the surface-surface contacting. The solution criterion was selected as a large displacement static.

Calculation control, result processing were accomplished within POST1. Equivalent stress, stresses SX, SY, and SZ and displacements UX, UY, and UZ in X, Y, and Z directions were animated, and the results of simulation were shown in Table 2 and Fig. 2. (2.a to 2.h) It was found that the equivalent stress distribution of winged design furrow opener was lower than that of moldboard design, therefore the wing design furrow opener was adopted as an optimum for the machine.

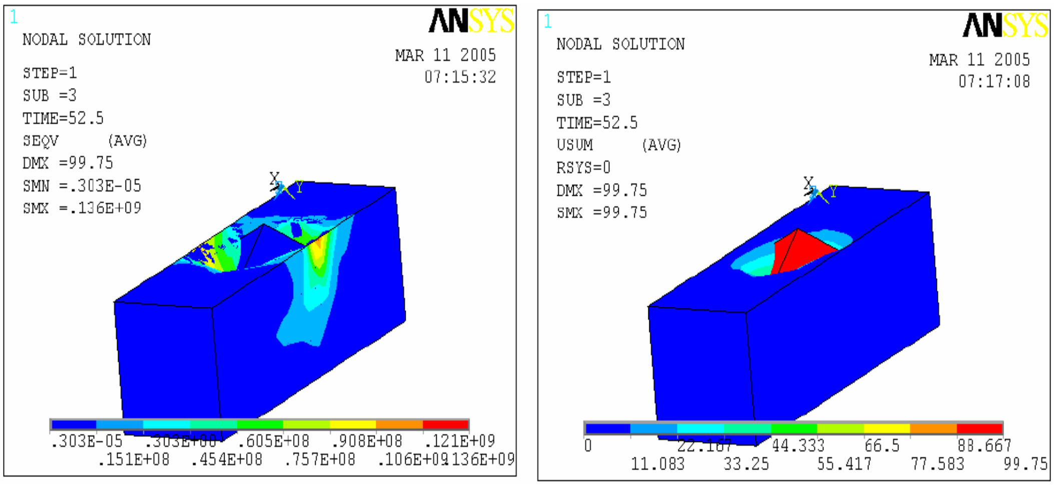
The results of modeling with C++ language were shown in Table 3. It was found that the opener with 45^0 rake angle has the lowest resistance force and power; therefore it was adopted to be attached to the machine.

Table. 2: Stresses distribution and displacement on different furrow opener designs

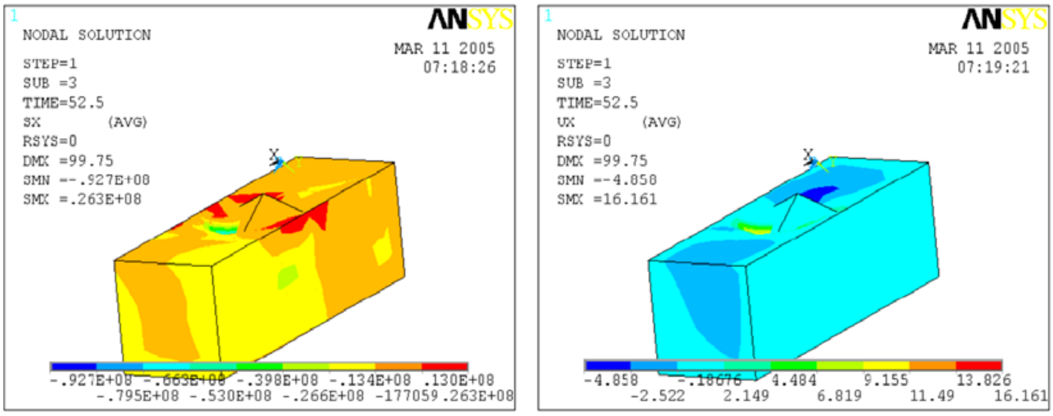
Furrow opener design	Stress distribution (kPa) and displacements (mm)							
	Equivalent stress 1×10^8 (kP)	USUM (mm)	SX 1×10^8 (kP)	UX (mm)	SY 1×10^8 (kP)	UY (mm)	SZ 1×10^8 (kP)	UZ (mm)
Winged type	1.36	99.75	0.263	16.16	0.468	28.75	0.380	99.75
Moldboard type	1.39	2.133	0.574	0.005	0.452	0.035	0.210	0.103

Table. 3**:** Resistance force and power requirement for furrow opener at different rake angles

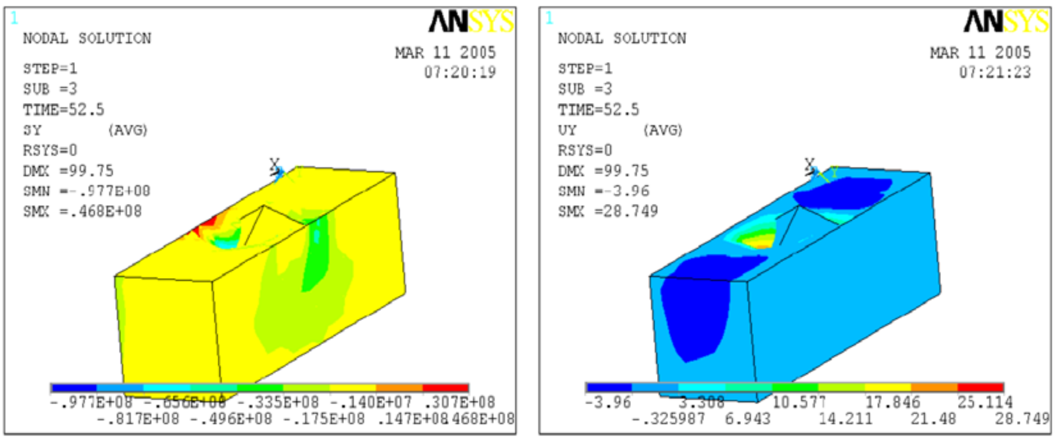
Rake angle (degree)	Resistance force (kN)	Power (kW)
15	0.45	0.37
25	0.42	0.35
35	0.34	0.28
45	0.29	0.24
55	0.41	0.34
65	0.52	0.43
75	0.61	0.51



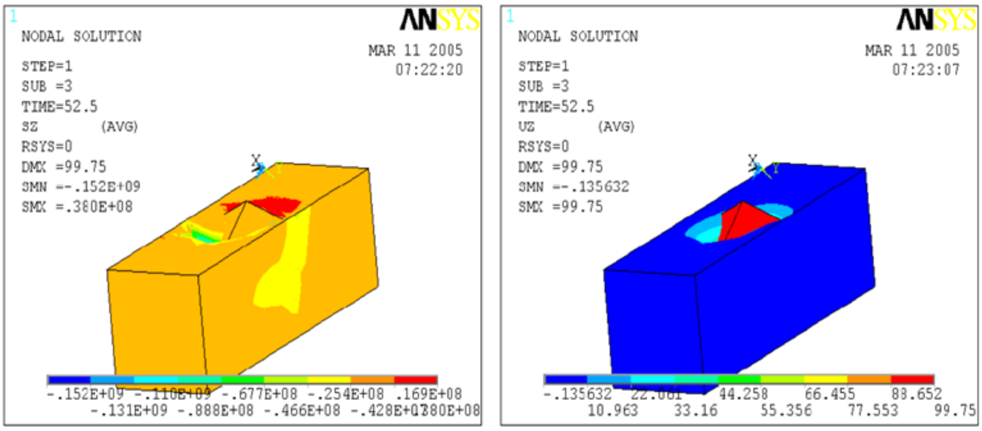
(2.a) Equivalent stress and total displacement for winged type opener



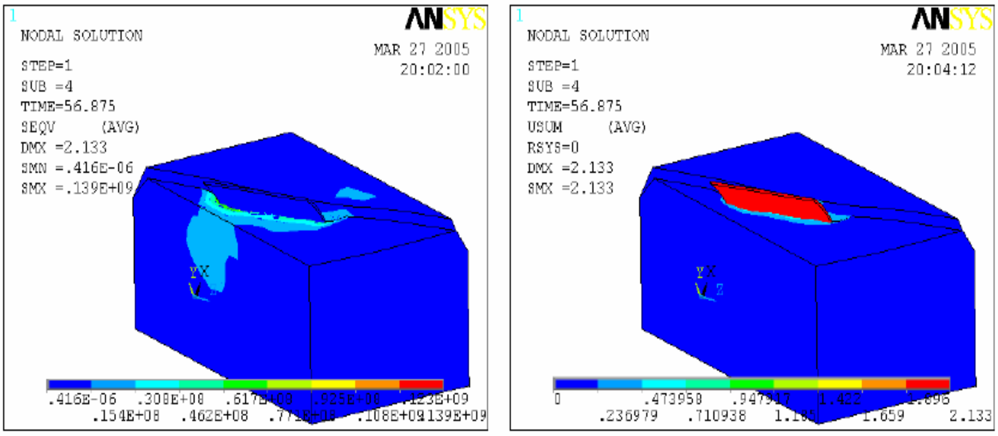
(2.b) Stress and displacement in X direction for winged type opener



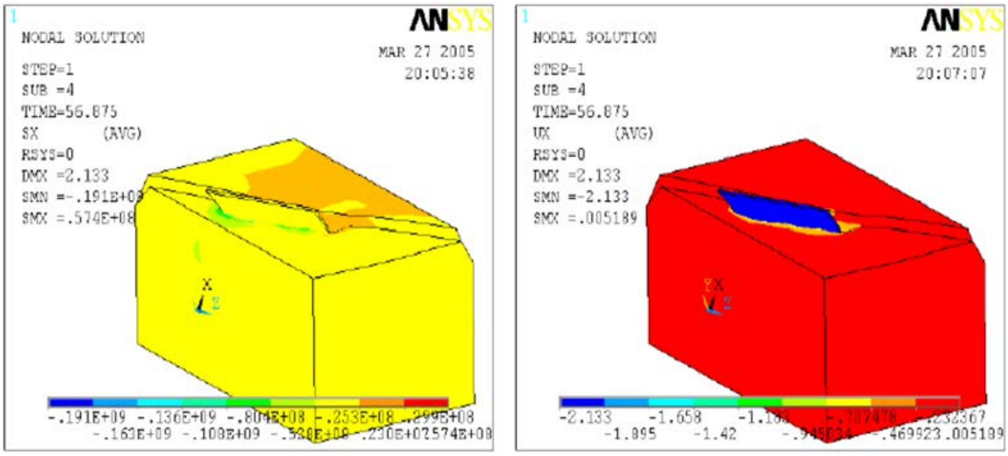
(2.c) Stress and displacement in Y direction for winged type opener



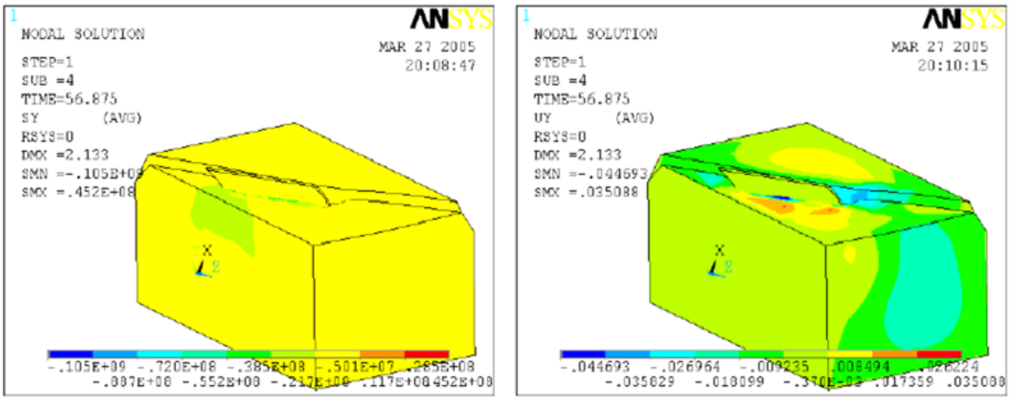
(2.d) Stress and displacement in Z direction for winged type opener



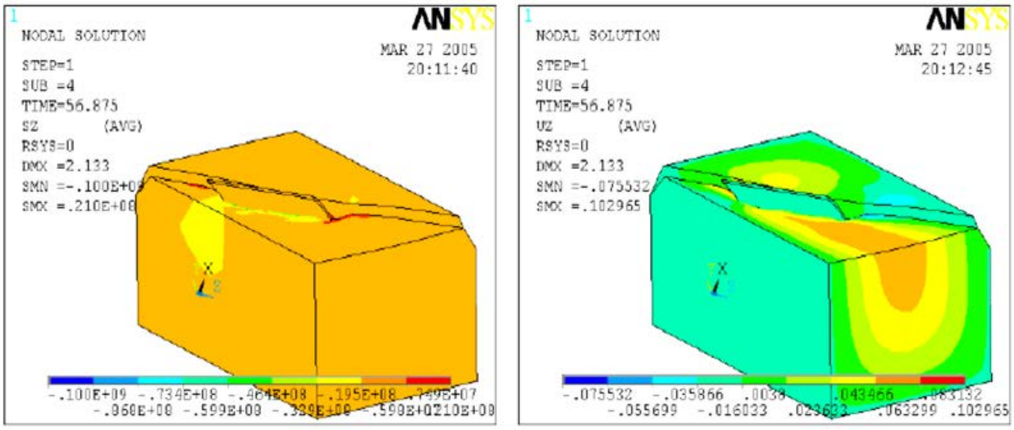
(2.e) Equivalent stress and total displacement for moldboard type opener



(2.f) Stress and displacement in X direction for moldboard type opener



(2.g) Stress and displacement in Y direction for moldboard type opener



(2.h) Stress and displacement in Z direction for moldboard type opener

Fig. 2: Stress distribution and displacement of furrow openers

3.2 The manufactured planting machine

The manufactured machine is shown in Figure 3. (a, b, c, and d).

(a) Front view

(b) Rear view

(c) Side view

(d) Motion transmission chain

Fig.3: The manufactured ground nut planting machine

The specifications of the developed planting machine are given in Table 4 below.

Table. 4**:** Planting machine specifications

Parameter	Value
Number of furrow openers	3
Operating width	0.54 m
Operating depth	0.12 m
Furrow opener rake angle	45^0

3.3 Field performance evaluation of the planter

3.3.1 Field times measurement

The Productive, turning and total field times were demonstrated in Table 5.

Table. 5**:** Means for field times

Treatment	Productive time (sec)	Turning+ loss time (sec)	Total time (sec)
Machine X Donkey	1267.0 ± 50^{ab}	274.8 ± 12^{a}	1541.8 ± 59^{a}
Machine X Mule	1097.5 ± 13^{b}	224.0 ± 8^{a}	1341.5 ± 16^{a}
Machine X Horse	1474.3 ± 65^{a}	452.3 ± 17^{b}	1926.5 ± 76^{b}
Manual	5828.3 ± 77^{c}	3790±146c	5828.3 ± 77^{c}

Each value is mean $\pm$ standard error.

Means in column share same superscript letters showed no significant differences at $P \leq 0.001$.

It can be observed that the mean productive time of the machine when drawn with the three animals was 1279.6 seconds while in case of manual sowing it time was 5828.3 seconds as the highest productive time used. The difference in the productive time between the machine with the three animals showed no significant difference at $P \leq 0.001$, while when compared with manual the difference was highly significant. In case of turning and other loss time, it was observed that there was significant difference between machine drawn with the animals and manual sowing. The total loss time of manual was four times higher than the machine drawn by the three animals. The highest total field time was recorded by manual sowing (5828.3 seconds), while the lowest total field time was recorded by machine with mule (1341.8 seconds) and the difference between the donkey and mule was not significant at $P \leq 0.001$. These values indicate that the animals drawn machine was faster the manual sowing and consumes less time in the field.

3.3.2 Operating speeds, field capacities and efficiencies

Operating speeds, theoretical field capacity, effective field capacity and field efficiency replications for different treatments are given in Table 6. It is clear that the highest operating speed was recorded by machine with mule (0.91 m/sec), while the lowest speed was recorded by manual sowing (0.45 m/sec). The average operating speed of the three animals was higher than the manual by 77% , which means less time in the field.

The highest effective field capacity was given by machine with mule (0.147 ha/h), followed by machine with donkey (0.128 ha/h), while the lowest effective field capacity was recorded by manual sowing (0.032 ha/h). The difference between treatments was highly significant at $P \leq 0.001$. The rate of work of manual was lower than the average rate of the machine with the three animals by 75%, which means more time for carrying out the operation.

Table. 6: Means of speeds, field capacities and efficiencies

Treatments	Speed (m/sec)	Theoretical field capacity (ha/h)	Effective field capacity (ha/h)	Field efficiency (%)
Machine X Donkey	0.80 ± 0.04^{ac}	0.155 ± 0.005^{a}	0.128 ± 0.005^{a}	82.3 ± 1.6^{a}
Machine X Mule	**Plate 2. Groundnut planting machine in Operation**			84.3 ± 1.3^{a}
Machine X Horse	0.68 ± 0.03^{c}	0.130 ± 0.006^{c}	0.105 ± 0.002^{c}	80.9 ± 1.4^{a}
Manual	0.45 ± 0.03^{d}	-	0.032 ± 0.001^{d}	35.0 ± 0.2^{b}

Each value is mean $\pm$ standard error.

Means in column share same superscript letters showed no significant differences at $P \leq 0.001$.

There was no significant difference between the field efficiencies of the machine with the three animals. The average field efficiency of the three animals was 82.5% while that recorded by the manual method of sowing 35.2%.

3.3.3 Plant density

The mean plant density of the treatments is given in Table 7. Analysis of variance for different parameter showed no significant difference between the three animals, but compared to the manual the difference was significant at $P \leq 0.001$. It was shown that the average plant density when the machine drawn with the three animals was 13 plants/ m^2, while in case of manual sowing it was 19 plants/m^2..

Table. 7: Mean plant density for different treatments

Treatments	Plant density (plants/m^2)
Machine X Donkey	13.0 ± 0.3^a
Machine X Mule	13.0 ± 0.6^a
Machine X Horse	13.0 ± 0.4^a
Manual	19.0 ± 0.8^b

Each value is mean $\pm$ standard error.

Means in column share same superscript letters showed no significant differences at $P \leq 0.001$.

4. Conclusions

Computer simulation by ANSYS program and modeling by C++ programming language were used to optimize designs of furrow opener and covering device of the planting machine. The planting machine which developed locally showed higher field performance parameters compared to manual sowing. Manual method of sowing demonstrated higher plant density as compared with the machine drawn by animal.

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