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# Design and Field Performance of Biomimetic Moldboard Plough for Three Soi Types

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## ABSTRACT

*Biomimetics is the application of characteristics of living things to improve the engineering designs of machines. The present study was conducted in Elobied, North Kordofan State in three different locations of clay, gardud and sandy soils. The objectives of the research were to determine the geometrical structures on the body surface of mole cricket as a soil burrowing animal and to use these structures for biomimetic design of moldboard plough body. An experimental field work was conducted to investigate draft force, rear wheel slippage and fuel consumption, for conventional and biomimetic non-smooth moldboard body surfaces. Soil physical and mechanical properties were determined for the three soil types at 30 cm depth. The results showed that the non-smooth surface with convex domes reduced the draft force by 0.8 kN, 0.6 kN and 0.9 kN, the rear wheel slippage was reduced by 12.5 %, 3.8 % and 9.7 % and the fuel consumption rate was reduced by 9.3 L/ha, 6.7 L/ha and 10 L/ha in clay, gardud and sandy soils respectively, compared to the smooth surface. Statistical analysis showed highly significant differences at $P < 0.01$ between the two factors for the measured parameters. It was concluded that geometrical shape and characteristics of claws of soil digging animals may improve the design and performance of soil engaging tools at different soil types.*

## Keywords
Moldboard, Mole cricket, Biomimetic, Geometric, Conventional.

## Introduction

Tools, equipment, implements and powered machinery are essential and major requirements to agricultural production, it can be argued that they are one of the most important inputs for crops production. The interaction between tillage tools and soil is of primary interest to the design and use of these tools for soil manipulation [1]. Soil tillage contributes considerably to production cost because manipulation of soil to a proper state consumes large amount of energy. Therefore, reduced, conserved and combined tillage systems have become widely used during the last few decades [2]. At the same time, from the point of view of agricultural production, the quality of soil manipulation is also of great importance, and there is a need to improve equipment design for energy saving, wear resistance, soil protection against erosion, and proper quality of land preparation [3]. Improving the design of agricultural implements can be achieved using two techniques, namely by experimental method, and simulation method. The experimental method is costly, while applying simulation method by biomimetic technique can be lower in cost, if it can be well established [4]. In case of biomimetic technique, the characteristics of animals and insects were used to design the implements [5,6]. The biomimetic is defined as the application of characteristics of living things to improve the engineering designs of machines. Adhesion, friction and abrasive wear are three tribological phenomena occur during the operation of soil engaging tools against the soil. These phenomena have a sever negative impact on working quality, energy consumption, operation performance and life span of the tools [7,8]. These phenomena increase the stresses distribution, draft force, and power requirement of soil engaging tools and accelerate tool surface deterioration [9]. Therefore, it is necessary to look for designing methods to minimize the impact of tribological factors on soil engaging tools of agricultural machines [10,11]. Rapid development of biological principles and methods has resulted in the fast development of the field of biomimetic engineering. The soil engaging tools have been designed based on these features of living things which represent biomimetic anti-adhesion, anti-friction, and anti-abrasion of soils [12]. All soil-burrowing animals have geometrically textured structures on their body surface [13-15]. Observed that different morphological features with non-smooth structures on the body surfaces of earthworm and centipede, and they concluded that all soil-burrowing animals have geometrically non-smooth structures or rough structures on their body surfaces [16,17] examined the geometrical surfaces of earthworm, cockroach (*Blattaria*), cricket (*Gryllidae*), of different shapes and size of the non-smooth construction units that may prevent soil from sticking on the body surface of these animals. Therefore, biomimetic designs may have a remarkable effect on improving implement performance [18] indicated biological structures of some soil-burrowing or soil-digging animals, such as beetle, mole cricket, earthworm, mole, vole, and snake, as well as their mechanisms of antiadhesion or reducing resistance forces [3,19] concluded that biomimetic non smooth with convex domes and non-smooth electro osmotic bulldozing blade surface considerably reduce mass of soil adhered to the blade as well as fuel consumption rate.

Moldboard ploughs are used as soil engaging implements and the moldboard bodies are subjected to tribological factors. These factors increase the stresses distribution, resistance force and consequently the power requirements of the implement will increase, moreover, these factors will result in implement wearing, the problem which increases repair and maintenance costs [20]. Therefore, the objectives of the present study were to examine the geometrical structures on body surface of mole cricket as a soil burrowing insect and use these structures in biomimetic design of moldboard body surface and to investigate their effect on draft force, rear wheel slippage and fuel consumption in three different soils.

## Materials and Methods

### Location

The present study was carried out in Aldago village 17 km Southeast Elobied town in North Kordofan State. Soil tests were conducted in laboratory of department of Civil Engineering, University of Kordofan. Soil samples were taken at 30 cm depth from three different locations, and the moisture content was determined on dry base. Tri-axial soil test apparatus and shear box were used to measure soil cohesion and internal angle of friction. Soil mechanical properties are shown in Table 1.

**Table 1:** Soils Mechanical properties.

| Property | Soil type | | |
|---|---|---|---|
| | **Clay** | **Gardud** | **Sand** |
| m.c (%) | 31.7 | 25.4 | 19.2 |
| ρ (g/cm$^3$) | 1.90 | 1.50 | 1.3 |
| ϕ (deg.) | 20.0 | 31.0 | 34.0 |
| δ (deg.) | 14.0 | 17.0 | 19.0 |
| C (k Pa) | 15.3 | 10.0 | 7.0 |
| E(M Pa) | 150 | 120 | 95 |
| μ | 0.32 | 0.35 | 0.39 |

m.c = moisture content, ρ = soil bulk density, ϕ = soil internal angle of friction, δ = soil-steel angle of friction, C = soil cohesion. E =Elasticity modulus, μ = soil friction.

### Materials used

Materials used in the present study include the following items: Tri-axial soil test apparatus, Hydraulic cylinder, Pressure gauge, High pressure hose, two farm tractors, two ridgers, Steel chain, Metering tape, solid cast iron 5 cm in diameter hemispheres Stopwatch, Diesel fuel, Hydraulic oil, one liter measuring cylinder, Digital camera.

### Examination of body surface of mole cricket

Mole crickets were collected, and their body surfaces were cleaned with distilled water, alcohol of 98 % concentration, sprayed with carbon powder and then examined with digital camera according to Ji WF [21]. Figure 1 demonstrated the geometry of non-smooth domes structures found on the body surface of the cricket.

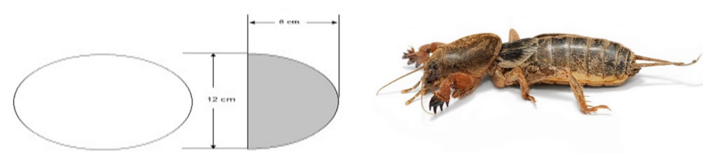


**Figure 1:** Mole cricket and dimensions of solid hemispheres convex domes.

### Modification of Moldboard plow surface

The modification of the moldboard surface was carried out in the workshop in Elobied Industrial Area. Numbers of seven solid cast iron hemi spheres were welded on the inner surface of moldboard uniformly in rows to imitate the body surface of soil burrowing animal namely, mole crickets (Plate 1a, Plate 1b).

### Field Work Experiment

Six experimental units each of 4.1×100 m were prepared in each location to conduct the field work where Complete Random Design was used. Ridger with conventional smooth moldboard surface and modified non- smooth one are used for ten strokes in each location. Working parameters were operating speed 4.2 km/h, working width and depth, 0.41m and 0.21m respectively.

**Plate 1a:** Smooth conventional surface moldboard.

**Plate 1b:** Non smooth modified surface moldboard.

## Measured Parameters

### Measurement of Fuel consumption

In each experimental plot and for each moldboard surface type, time for each stroke and each turn was recorded by stopwatch. The tractor started operation in the plot with full tank of fuel, when finishing the plot, the tank was refilled using the graduated cylinder, the reading of cylinder was recorded, and the fuel consumption rate was calculated according to James CF [22] as follows.

$Fc = V/A \times C$ ………………………………………(1)

Where,

F c = Fuel consumption rate, L/ha.

V = reading of cylinder, L.

A = area of plot, $m^2$.

C = constant = 10000.

### Measurement of draft force

The rear tractor was pulled by front tractor through the dynamometer while the rear tractor was unloaded then the reading of the dynamometer was recorded. Then the rear tractor was loaded with moldboard, and the reading of dynamometer was determined, and the implement draft force was calculated according to Igbal M [23] as follows.

$D = D_L - D_W \times f$ …………………………………(2)

Where,

D = draft force, kN.

$D_L$ = reading of dynamometer at loading, bar.

$D_W$ = reading of dynamometer without loading, bar.

$f$ = conversion factor,

### Measurement of rear wheel slippage

Time taken by unloaded tractor to cover distance of 100 m at operating gear was recorded, the tractor was then loaded and operated at the same gear, and the time taken to cover same distance was determined, then the speed for each case was calculated according to Ranjbarian S [24] as follows.

$S = d/t$ ……………………………………………….(3)

Where,

S = speed with unloading, m/sec.

d = distance, m.

t = time, sec.

The rear wheel slippage computed.

Where,

$S_V$ = speed without load, m/sec.

$$\text{Slippage (\%)} = \frac{S_V - S_L \times 100}{S_V} \quad (4)$$

$S_L$ = speed with load, m/sec.

## Results and Discussion

### Modification of moldboard body surface biomimetically

Moldboard body surface was designed biomimetically imitating body surface structure of a soil burrowing animal, namely, mole cricket by modeling convex domes on the moldboard surface as shown in plate 1 and 2. This is in line with that reported by [14,18,25].

### Draft Force as affected by moldboard surface in different types of soil

Table 2 and Figure 2 showed that the draft force was generally lower on non-smooth surface than that of smooth surface in the three types of soil. This in in agreement with the findings of [26-28]. The clay soil recorded the highest values for both moldboard surfaces. It was observed also that the non-smooth surface with convex domes reuced the draft force by 0.8 kN, 0.6 kN and 0.9 kN in clay, gardud and sandy soil respectively compared to the smooth surface. and the differences between the two surfaces for the measured parameters were significant at $p<0.1$

**Table 2:** Draft force as affected by moldboard plough surfaces in different types of soil.

| moldboard surface and soil type | Force , KN |
|---|---|
| smooth x clay | $3.6 \pm 0.2^{c}$ |
| smooth x gardud | $2.6 \pm 0.15^{cd}$ |
| smooth x sandy | $1.8 \pm 0.12^{a}$ |
| domes x clay | $2.8 \pm 0.15^{c}$ |
| domes x gardud | $2.0 \pm 0.1^{ad}$ |
| domes x sandy | $0.9 \pm 0.16^{b}$ |

*Each value means of three replicates standard error, *Values in column share same superscript letter show no significant difference at P ≤ 0.0.1

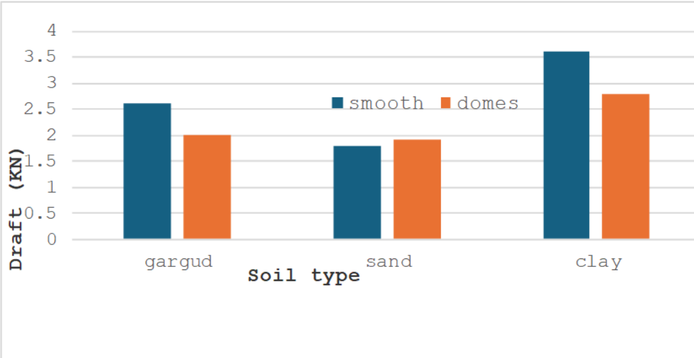


**Figure 2:** Effect of soil type and moldboard surdace on draft force.

## Wheel Slippage as affected by moldboard surface in different types of soil

Table 3 and Figuer 3 demonstrated that the wheel slippage values in case of non-smooth moldboard surface were generally lower than that of smooth surface one in all soil types and the clay soil recorded the highest values for the smooth surface while gardud soil recorded the highest value for non-smooth of domes surface. This is in line with that reported by [29]. It was also observed that the non-smooth surface with convex domes reduced the slippage by 12.5 %, 3.8% and 9.7 % in clay, gardud and sandy soils respectively. The differences between the two surfaces for all measured parameters were highly significant at p< 0.01.

**Table 3:** Wheel slippage as affected by moldboard plough surface in different types of soil.

| moldboard surface and soil type | Slippage % |
|---|---|
| smooth x sandy | 13.5±1.3$^{cef}$ |
| smooth x gardud | 14.3±2.2$^{ce}$ |
| smooth x clay | 17.8±2.7$^{c}$ |
| domes x sandy | 3.8±0.12$^{dg}$ |
| domes x gardud | 8.1±1.6$^{defg}$ |
| domes x clay | 5.3±1.4$^{fg}$ |

*Each value is mean of three replicates standard error. *Values in column share same superscript letter show no significant difference at P ≤ 0.0.1

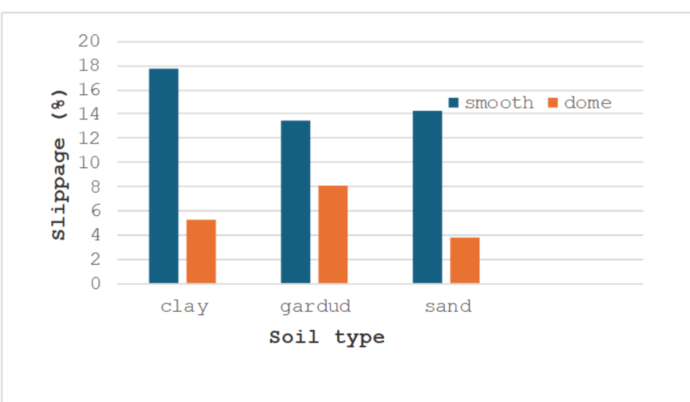


**Figure 3:** Effect of soil type and moldboard surface on slippage (%).

## Fuel consumption rate of moldboard plough surfaces in different types of soil

Table 4 and Figure 4 revealed that the fuel consumption of the smooth moldboard plough surface was generally higher than the non-smooth one for all types of soil. This is in line with the findings of [30]. Clay soil in the smooth surface and gardud soil in the non-smooth surface recorded the highest fuel consumption rate as 15.3 and 8.2 L/ha respectively, and the non-smooth surface with convex domes reduced the fuel consumption rate by 9.3 L/ha, 6.7 L/ha and 10 L/ha for clay, gardud and sandy soil respectively. This agrees with that reported by [31]. The differences in fuel consumption rate between the two moldboard body surfaces for the three soil types were significant at p< 0.01.

**Table 4:** Fuel consumption rate as affected by moldboard plough surface in different types of soil.

| moldboard surface and soil type | F C, L/ha |
|---|---|
| smooth x clay | 15.3±1.6$^{c}$ |
| smooth x gardud | 14.9±2.2$^{be}$ |
| smooth x sandy | 14.6±2.1$^{af}$ |
| domes x clay | 6.00±1.4$^{f}$ |
| domes x gardud | 8.2±2.3$^{ace}$ |
| domes x sandy | 4.6±0.1$^{df}$ |

* Each value is mean of three replicates standard error. *Values in column share same superscript letter show no significant difference at P ≤ 0.01.

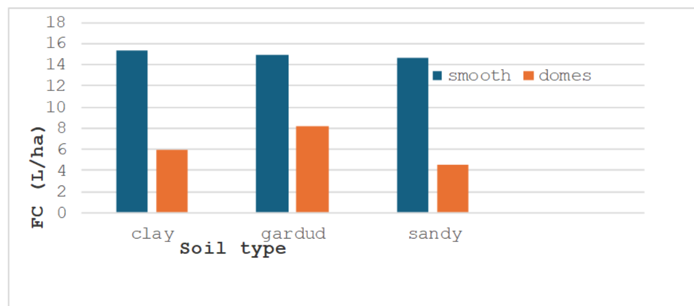


**Figure 4:** Effect of moldboard surface and soil type on fuel comsumption rate (L/ha).

## Conclusions

The following conclusions may be drawn from the present studt:

- Moldboard plow surface was designed biomimetically imitating body surface structure of a soil burrowing animal namely, mole cricket by modeling convex domes on the plow surface.
- The values of soil draft force, rear wheel slippage and fuel consumption rate for non-smooth surface were found lower than that of smooth surface in each of the three soil types.

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