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Development of non smooth surface pattern mould board plough based on surface morphology of soil burrowing insects

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Abstract
This article aims at the application of biomimetics design in development of non smooth surface pattern mould board plough. From past research works, it can be concluded that non-smooth surfaces can generally reduce soil resistance however the extent of reduction is still a gray area. The main factors affecting soil adhesion are the nature and properties of the soil, the geometry of the soil-engaging component surfaces and the experimental conditions. The soil burrowing insects' *viz*., dung beetle, mole cricket and termite were investigated under SEM for the development of non smooth surface pattern plough. All the body parts of investigated soil burrowing insects exhibited irregular arrangement and complicated shapes except head portion of the dung beetle. The different morphological features of the body surfaces exist in investigated species of soil burrowing insects as well as in different segments of the same insect. The geometry of investigated species exhibited embossed morphology with small convex domes, dimpled morphology with small concave hollows, wavy morphology, scaly morphology and corrugated morphology with ridges. The surface morphology of dung beetle with protuberance of 0.25 to 0.5 height base diameter ratio pertains to semi-oblate and semi-sphere was arrived under SEM. Based on the surface morphology of dung beetle head portion, two on smooth surface pattern mould board ploughs of semi-oblate protuberances with a height base diameter ratio of 0.25 and semi-sphere protuberances with a height base diameter ratio of 0.5 were developed.

Keywords: mould board, mole cricket, dung beetle, termite and scanning electron microscope

1. Introduction
The body surface morphology of soil burrowing insects have non-smooth units such as convex domes, concave dips, ridges or wavy structures, which play important roles in their anti-soil adhesion and anti-friction functions. The soil-burrowing insects have led to some improvement on conventional methods for reducing soil adhesion like in the design of implement surface shapes, selection of surface materials for soil engaging components. These soil burrowing insects prevent soil from sticking to their bodies because of evolution of their biological systems through exchange of matter, energy and information with soil over centuries. They can comfortably move in even clay soil without sticking of soil to their bodies. Soil-engaging tools have been designed based on these features of living organisms which are efficient in biomimetic anti-adhesion, anti-friction and anti-abrasion against soil. (Li *et al.*, 1990; Chen *et al.*, 1990; Ren *et al.*, 1992b; Tong *et al.*, 1994d; Ren *et al.*, 1995c; Soni and Salokhe, 2006 and Qaisrani *et al.*, 2010) [4, 13, 9, 12, 11, 7].

Improvement of shape and surface configuration design of soil engaging tools are two methods for reducing soil adhesion and interfacial friction. Biomimetic method is a technique to transfer biological solutions to engineering techniques and has been developed as the application of biological principles and methods to engineering. It was found that the cuticle surfaces of soil-burrowing animals have ability to reduce adhesion and friction against soil. (Chen *et al.*, 2002; Li *et al.*, 2004 and Zhang *et al*., 2004) [1, 5, 14].

The geometrical surface morphologies of earthworm (*Lumbricidae*), centipede (*Chilopoda*), dung beetle (*Copris ochus* Motschulsky), ground beetle (*Carabidae*), ant (*Formicidae*), mole cricket (*Gryllotalpidae*) and others were examined and the cuticle surfaces of many soil animals have a strong inherent hydrophobic nature, indicating that the attraction force between the cuticle surface and water molecules is very small, so, the cuticle surfaces of soil animals have ability to reduce adhesion and friction against soil.

2. Materials and Methods
The soil burrowing insects namely dung beetle, mole cricket and termite were collected at Tamil Nadu Agricultural University campus, Coimbatore-3.

The different body parts like wing, leg, abdomen and head portion of collected soil burrowing insects were analyzed in the laboratory using the Scanning Electron Microscope (SEM) as shown in figure 1. (Ren *et al*., 1992b; Tong *et al*., 1994d and Chen *et al*., 2002) [1, 8, 9]. The images captured under Scanning Electron Microscope (SEM) of dung beetle head portion, dung beetle leg part, abdomen part of mole cricket, leg portion of mole cricket, head part of mole cricket, back part of termite and abdomen part of termite are shown in the figures 2, 3, 4, 5, 6, 7 and 8 respectively. All the body parts of investigated soil burrowing insects exhibited irregular arrangement and complicated shapes except head portion of the dung beetle.

Fig 1: Soil burrowing insects under scanning electron microscope

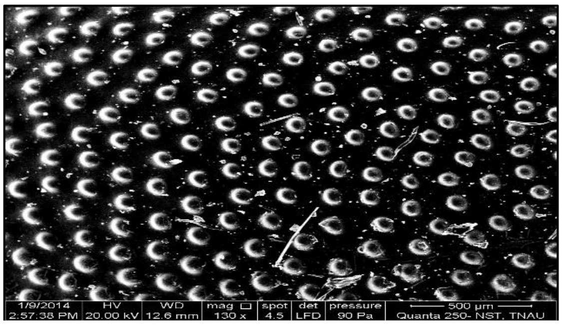

Fig 2: Head portion of dung beetle under SEM image

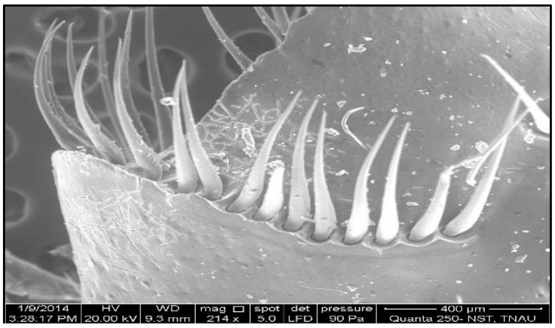

Fig 3: Leg portion of dung beetle under SEM image

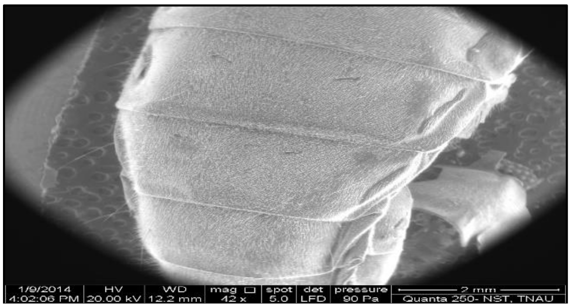

Fig 4: Abdomen part of mole cricket under SEM image

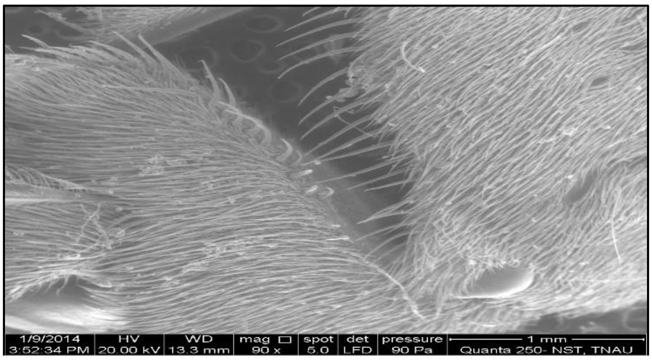

Fig 5: Leg portion of mole cricket under SEM Image

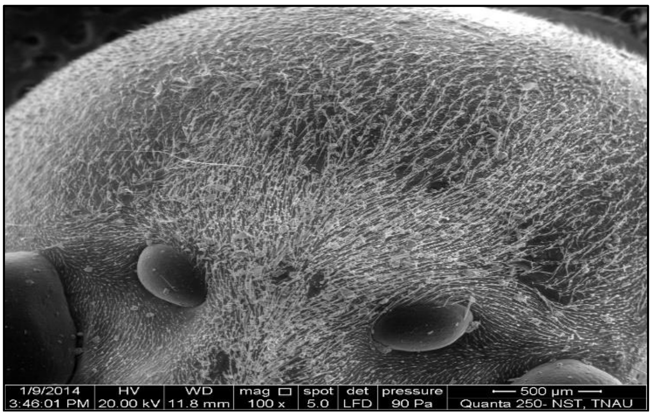

Fig 6: Head portion of mole cricket under SEM Image

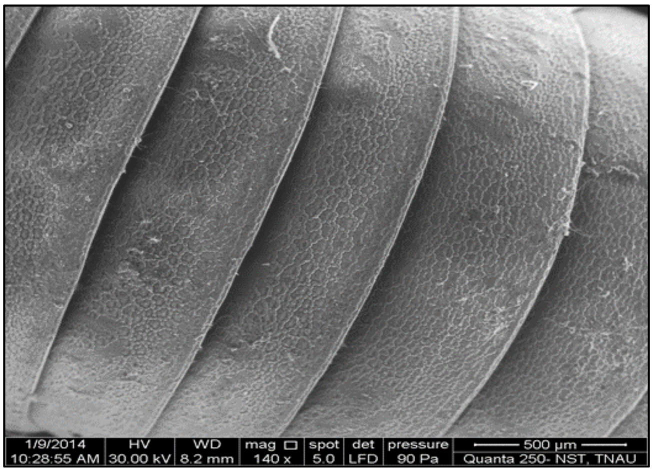

Fig 7: Back portion of termite under SEM Image

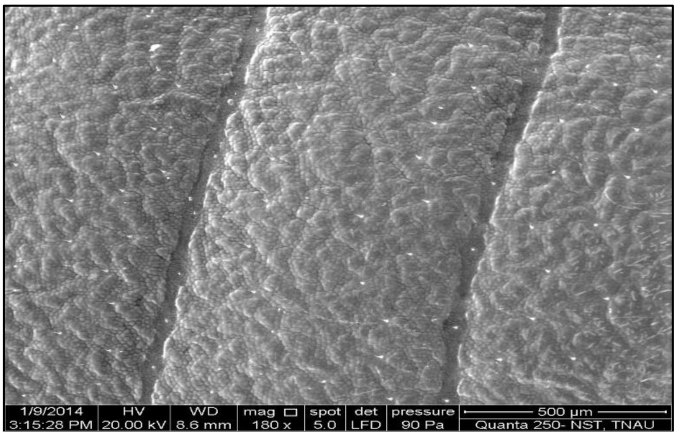

Fig 8: Abdomen part of termite under SEM Image

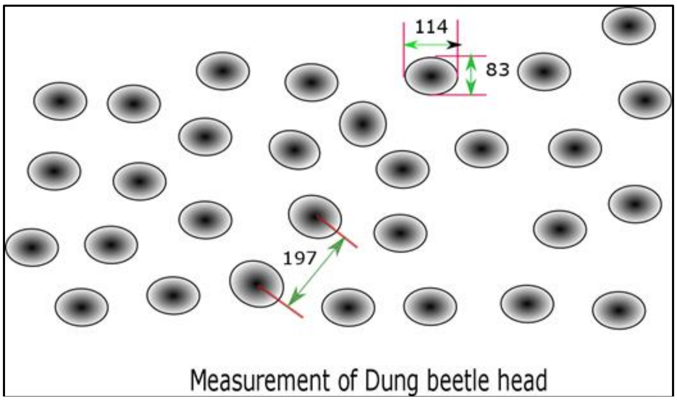

Fig 9: Representative digitized image of dung beetle head

Fig 10: Semi-oblate mould board surface

Fig 11: Semi-sphere mould board surface

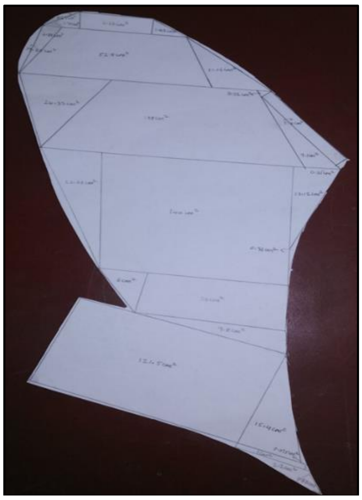

Fig 12: Surface area of conventional smooth plough by segmentation technique

The different morphological features of the body surfaces exist in investigated species of soil burrowing insects as well as in different segments of the same insect. The geometry of investigated species exhibited embossed morphology with small convex domes, dimpled morphology with small concave hollows, wavy morphology, scaly morphology and corrugated morphology with ridges.

Dung beetle contained a number of small convexes distributed across its entire head. The arrangement of convex domes was in parallelogram fashion. The head portion of the dung beetle was digitized and the average ratio of mean diameter of the convex domes to the row to row spacing was found to be 0.8. A representative digitized image of dung beetle head portion is shown in figure 9. Hence, considering the soil adhesion preventing characteristics of dung beetle and arrangement of convex domes, the surface morphology of the head of dung beetle was selected for the modification of mould board plough surface.

2.1 Development of non-smooth surface pattern on mould board plough

The imitation of surface morphology of the head of a dung beetle on mould board plough surface reduced the average sliding resistance by 13.2 per cent when compared to conventional plough surface. The parameters used for designing the convex domes were mild steel with a base diameter of 25 mm and height of 7 mm.

The modified mould board plough surface with arrays of polyethylene protuberances with height base diameter ratio of 0.25, 0.5 and more than 0.5 reduced the ploughing resistance when compared to conventional smooth surface. The reduction in ploughing resistance for protuberances with height base diameter ratio (HDR) of 0.25 was 2 to 7 per cent in dry soil, 18 to 36 per cent in sticky soil 17 to 33 per cent in wet soil and 15 to 28 per cent in flooded soil. The reduction in ploughing resistance for protuberances with height base diameter ratio (HDR) of 0.5 was 10 to 16 per cent in sticky soil, 6 to 17 per cent in wet soil and 12 to 26 per cent in flooded soil. The ploughing resistance was increased by 7 to 29 per cent when height base diameter ratio (HDR) more than 0.5 (Soni *et al*., 2007) [12]. Hence the height and base diameter of protuberances on mould board plough was used as parameters for the development of non-smooth surface pattern.

The surface morphology of head of a dung beetle adopted by the various researchers is furnished in table.1.

Table 1: Surface morphology of dung beetle head

S No	Type of implement	Height (mm)	Base (mm)	Height base ratio (HDR)	Row to row spacing (mm)	Authors
i	Bulldozing blades	3	25	0.12*	50	Qaisrani *et al.*, (1993) [6]
ii	Bulldozing blades	2 to 8	16 to 32	0.125 to 0.5 (0.28*)	150 to 500	Ren *et al.*, (1995c)
iii	Bulldozing blades	2, 4 and 8	20, 30 and 40	0.1 to 2.5 (1.33*)	40, 50 and 60	Ren *et al.*, (2006) [10]
iv	Mould board	5 to 10	20	0.25 to 0.5	30 to 40	Ren *et al.*, (2006) [10]
v	Mould board	0, 20, 30, 40 and 50	5 to 50	0 to 1 (0.25*)	25, 38, 50 and 63	Soni *et al.*, (2007) [12]
vi	Disc plough	10	1 and 3	0.1 and 0.3*	Random	Chirende *et al*, (2010) [3]

*- Optimized value

The height base diameter ratio of surface morphology of dung beetle adopted by various researchers on various farm implements vary from 0 to 1.33 as seen from table 1. But, the height base diameter ratio of surface morphology of dung beetle adopted for mould board plough vary from 0.25 to 0.5. Since the present investigation pertains to mould board plough, height base diameter ratio of 0.25 to 0.5 was selected for the investigation. The surface morphology of dung beetle with different protuberances height base diameter ratios *viz.*, 0.25, 0.5, 0.75 and 1.0 was classified as flat, semi-oblate, semi-sphere, semi short-prolate and semi long-prolate respectively (Soni *et al.*, 2007) [12]. The surface morphology of dung beetle with protuberance of 0.25 to 0.5 height base diameter ratio pertains to semi-oblate and semi-sphere.

The grid lines were sketched on a mould board plough in a parallelogram pattern with equal dome to dome and row to row spacing to mark location of protuberances before mounting. The protuberances were machined in lathe with height base diameter ratio of 0.25 (semi-oblate) using mild steel with the base diameters of 20 mm and with height of 5 mm. With a row spacing of 25 mm, 65 units of semi-oblate convex domes were mounted on the mould board surface of mild steel of 4 mm thickness as shown in figure 10. The protuberance with height base diameter ratio of 0.5 (semi-sphere convex domes) was mounted by following the method employed for semi-oblate as shown in figure 11.

2.2 Surface area and weight of plough bottoms

The surface area of conventional smooth surface mould board was calculated by segmentation technique as shown in figure12. For non - smooth surface pattern plough bottom, semi-oblate surface area was arrived as detailed below.

Surface area of conventional smooth surface (S)	= 65000 mm^2
Surface area of semi- oblate one unit	= X mm^2
Surface area of 65 semi- oblate units	= 65 x X
	= Y mm^2
Base radius (r)	= 10 mm
Area of 65 units (20 mm base diameter)	= πr^2 x 65
	= Z mm^2
Surface area of the semi- oblate plough bottom	= (S+Y) - Z mm^2

The surface area of semi-sphere plough was found similarly. The weights of semi-oblate and semi-sphere plough bottoms were measured in weighing scale.

3. Results and Discussion

The salient features *viz.*, reduced the ploughing resistance, minimum soil adhesion, reduced soil metal friction angle, lesser draft and better soil scouring performance were the prime reasons attributed to the development of ploughs with semi-oblate protuberances with a height base ratio of 0.25, semi-sphere protuberances with a height base ratio of 0.25.

The surface area and weight of ploughs were measured and computed values are 65000 mm^2 and 4.520 kg, 72800 mm^2 and 4.840 kg and 1,05,820 mm^2 and 5.140 kg for the developed mould board of smooth without any protuberances as control, semi-oblate protuberances with a height base ratio of 0.25, semi-sphere protuberances with a height base ratio of 0.25 respectively.

4. Conclusion

Based on the result of this study, it was concluded that

1. All the body parts of investigated soil burrowing insects exhibited irregular arrangement and complicated shapes except head portion of the dung beetle.
2. The different morphological features of the body surfaces exist in investigated species of soil burrowing insects as well as in different segments of the same insect.
3. The geometry of investigated species exhibited embossed morphology with small convex domes, dimpled morphology with small concave hollows, wavy morphology, scaly morphology and corrugated morphology with ridges.
4. The surface morphology of dung beetle with protuberance of 0.25 to 0.5 height base diameter ratio pertains to semi-oblate and semi-sphere was developed for draft related studies.

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