Advances in Natural Science **ISSN 1715-7862 [PRINT]**
Vol. **3**, No. **2**, **2010**, pp. 100-107 **ISSN 1715-7870 [ONLINE]**
www.cscanada.net **www.cscanada.org**

The 3rd International Conference of Bionic Engineering

Soil Adhesion Preventing Mechanism of Bionic Bulldozing Plates and Mouldboard Ploughs

Rashid Qaisrani[1]

LI Jian-qiao[2]

M. Azam Khan[3]

Iram Rashid[4]

Abstract: Soil adheres to the surfaces of soil engaging components of various tools. The adhesion of soil increases the draft and adversely affects the quality of work. For example, up to 50% of the gross energy required for tillage operations may be consumed by adhesion and friction between soil and tillage tools. Therefore, it is important to find out the ways to reduce adhesion of soil to the surfaces of various tools. Soil animals such as ground beetles stay in moist sticky soils for extended periods without soil sticking to their bodies. The soil adhesion preventing mechanisms of such animals can be used as guide for improving the scouring properties of various tools. Both the surface morphology and chemical composition of soil animal's cuticle play important role in preventing adhesion of soil to their bodies. The surfaces of mouldboard ploughs and bulldozing plates were modified based on the surface morphology of ground beetle and tested in the laboratory. Two materials such as Steel-45 and Ultra High Molecular Weight – Polyethylene (UHMW-PE) were used for convexes. The modified ploughs and plates have better scouring properties and required less draft than conventional tools. The size of convexes, their arrangement and the material of these convexes played important role in reducing adhesion and scouring soil. UHMW-PE had better scouring properties and improved wear resistances than steel-45. This paper covers the modified ploughs and bulldozing plates where UHMW-PE convexes were used for modification. The distribution of these convexes on the surfaces of bulldozing plates and mouldboard ploughs resulted in changes in mechanical characteristics and the state of water film at soil-tool interface. The unsmoothed surface morphology broke down the continuity of water film, reduced the area of contact and increased pressure at soil tool interface. The higher pressure squeezed out more water and reduced the water tension. This process was helpful in reducing friction and adhesion of soil to the surfaces of modified tools.

[1] Manager (Research and Development), Thermal Solutions International Pty Ltd, Lugarno, NSW, Australia.
[2] Professor, The Key Laboratory for Terrain-Machines, Jilin University, Changchun, China.
[3] Associate Professor, Gomal University, Dera Ismail Khan, Pakistan.
[4]Department of Biological and Environment Sciences, University of Canberra, Australia. Email: rashid.qaisrani@biosecurity.gov.au.
*Received 4 May 2010; accepted 7 July 2010

The drafts of modified plough by bionic using UHMW-PE convexes were reduced by 25% and 30% at 3.6 km/h and 4 km/h working speeds respectively. The draft reductions in bionically modified bulldozing plates were 27%, 27% and 29% less than the conventional plates operating at 0.01, 0.02 and 0.06 m/s speeds.
Key words: adhesion; bionic; unsmoothed; mouldboard ploughs; bulldozing plates; draft

1. INTRODUCTION

Soil adheres to the surfaces of machines and tools that remain in contact with soil most of the time. It not only affects the performance of these machine and quality of work but also increases energy consumption. Moreover, the vehicles that take soil as an actuating medium, or farm implements, earthmoving machinery and hand tools that take the soil as a working object, all suffer from soil adhesion. In extreme cases, adhesion of soil does not allow the machine to move and work. The phenomenon of soil 'stickiness' has always occupied a prominent place among soil scientists, engineers and farmers as it is one of the soil's most troublesome physical properties. An excessive sticky soil makes cultivation difficult and prevents the harvesting of root crops in a clean condition (Qaisrani 1993). Qian and Zhang (1984) reported that the energy consumed by adhesion and friction between soil and tillage tools to be 30-50% of the gross energy required for the tillage operation. These results were supported by research conducted by Qaisrani *et al*. (1992) and Qaisrani (1993).

Therefore, it is important to find out the ways to reduce adhesion of soil to the surface of soil engaging components of various tools without compromising on the quality of work. Tong *et al*. (1990) reported that soil adhesion can be reduced by techniques such as lubrication, electro-osmosis and vibration. They further stated that phosphorus has the ability of reducing adhesion between two surfaces. Ren *et al*. (2001) reported that adhesion between soil and hydrophobic materials is very poor. Salokhe and Gee-Clough (1987, 1988) used another approach for reducing adhesion by coating lug surfaces with different materials such as silicon lubricant oil, lead oxide paint, gloss paint and varnish, chromium painting, teflon tape, teflon sheet, ceramic tile and enamel coating. However, they reported some practical problems (expensive and low durability, etc.) in using silicon lubricant oil, teflon tape, ceramic tile and enamel coating.

Experience showed that soil animals possess significant ability of reducing adhesion and friction. Surface morphology and chemical constitution of their outer surfaces are two of the important factors in reducing adhesion. Chen *et al*. (1990) reported that soil animals prevent adhesion of soil to their bodies because of a combination of factors such as outer shape and structure of their bodies, presence of anti-adhesive elements and biological electrical system in their body surfaces, and secretion of some special elements. This study examines the surface morphology of dung beetle and its role in preventing adhesion of soil to its body. The surfaces of bulldozing plates and mouldboard ploughs were modified according to the surface morphology of dung beetle. The affects of unsmoothed surface morphology of these tools on soil adhesion and draft were evaluated in the laboratory.

2. MATERIALS AND METHODS

2.1 Surface morphology of dung beetle

Various body parts of dung beetle were collected and analysed in the laboratory using the Scanning Electron Microscope (SEM). All the parts of dung beetle contained a number of small convexes distributed across their surface. However, the surface morphology of the head of dung beetle was selected for modification of bulldozing plates and mouldboard plough surfaces. Keeping in view the soil adhesion preventing characterises of dung beetle, a number of bulldozing plates and mouldboard plough surfaces

were modified. The small convexes were made from UHMW-PE and stuck to the surfaces of bulldozing plates (250x130mm) and mouldboard plough. The bulldozing plates were made from cast iron. Suminitrado *et al*. 1988 found that most of soil movement on the plough surface is at an angle of 62˚. Therefore, these convexes were distributed on the surfaces of bulldozing plates and mouldboard ploughs were glued at an angle of 62˚ with the horizontal.

2.2 Bionically modified mouldboard plough

The experiment was conducted in a laboratory soil bin (Fig. 1). A number of ploughs were modified using different materials and arrangement of convexes on their surfaces. The convexes were made from UHMW-PE because of its better scouring and wear resistance (Qaisrani 1993). This paper compares the performance of a bionically modified plough with lowest draft and excellent scoring properties (Fig. 2a) with a conventional plough (Fig. 2b) operating under identical conditions.

Both the ploughs were assessed at two working speeds 3.6 km/h and 5.0 km/h. The average depth of cut was maintained at 170 mm throughout the experiment. The soil used during this study was black clay with an average moisture content of 25.95% on dry basis. The soil was compacted in 100 mm layers using an electrical vibrator. Each treatment was replicated four times. The draft was measured using strain gages and the output was recorded on magnetic tapes. The values of draft were averaged for analysis. The plough surfaces were cleaned before each treatment. Photos were taken before and after each operation to compare the adhesion of soil to plough surfaces.

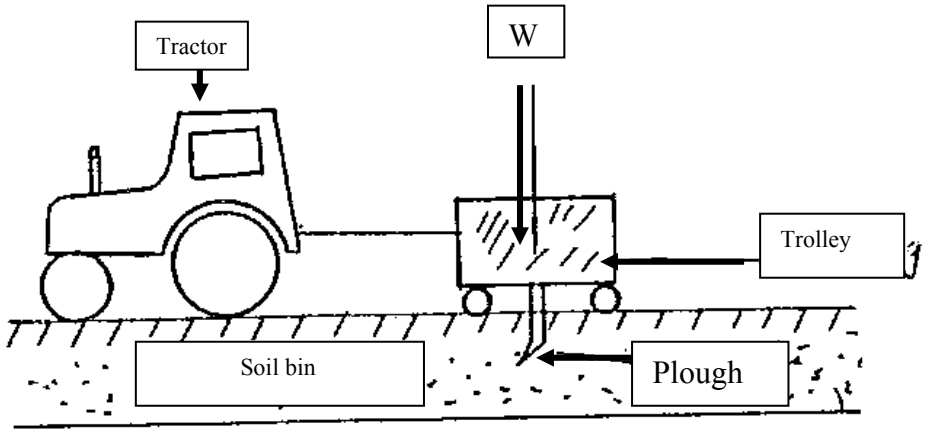

Fig. 1: Schematic diagram of laboratory soil bin used for testing mouldboard plough

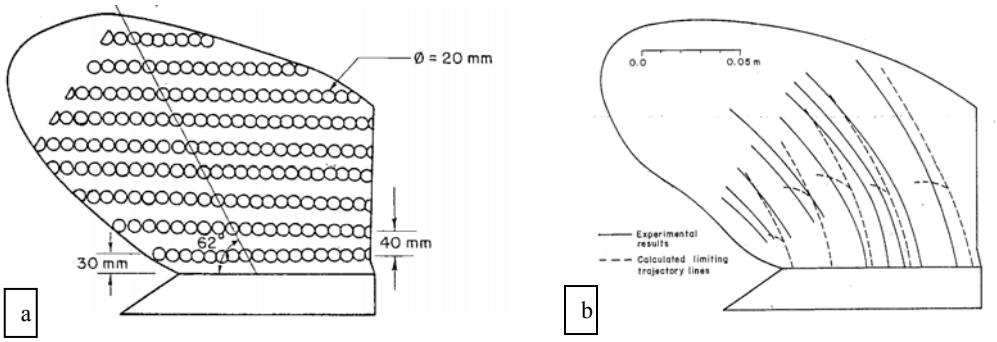

Fig. 2: a) unsmoothed plough surface based on the surface morphology of dung beetle (Qaisrani *et al.* 1992)
b) Trajectory of soil movement on mouldboard plough surface (Suminitrado *et al.* 1988)

2.3 Bionically modified bulldozing plates

The experiment was conducted in a laboratory using a work bench designed specially for bulldozing plates as shown in Fig. 3. A number of bulldozing plates were modified using various materials and a number of arrangements of convexes on their surfaces. However, this paper compares the performance of one of the bionically modified plates with lowest draft and better scouring properties with a conventional plates made from steel 45. The convexes were made from UHMW-PE because of its better scouring and wear resistance (Qaisrani 1993). The angle of cut was maintained at 35˚ at a constant depth of cut 15 mm at three working speeds (0.01 m/s, 0.02 m/s and 0.06 m/s).

The soil used during this study was black clay with average moisture contents of 30.38% on dry basis. The soil was compacted manually before each treatment. Each treatment was replicated four times and drafts of bulldozing plates were measured using strain gages. The output of draft was recorded on magnetic tapes and averaged for analysis. The surfaces of plates were cleaned before each treatment. Photos were taken before and after each operation to compare the adhesion of soil to surfaces of conventional and modified bulldozing plates.

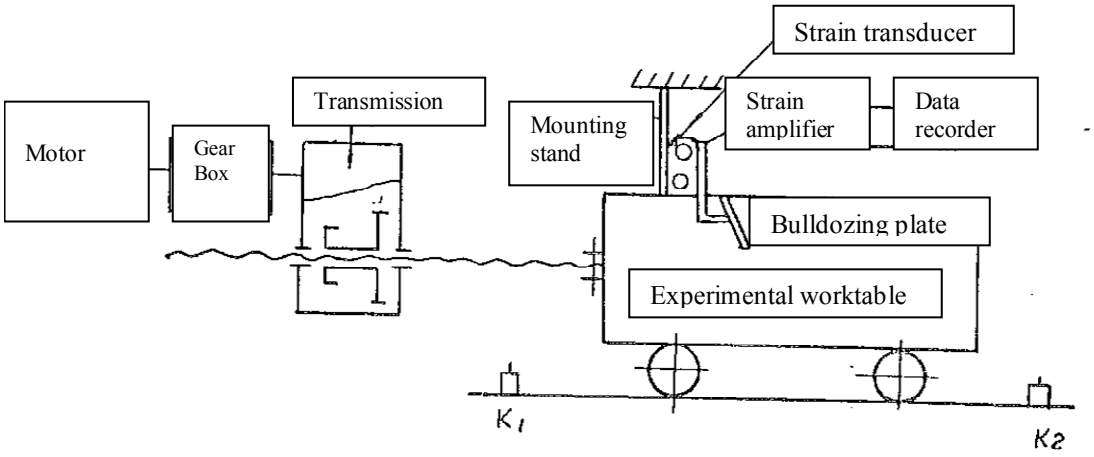

Fig. 3: Schematic diagram of experimental work table used for bulldozing plates testing

3. RESULTS AND DISCUSSION

3.1 Importance of reducing adhesion to the surfaces of ground engaging components of tillage tools and terrain machinery

Tillage tools are the mechanical devices used to apply forces to the soil to cause some desired effects such as pulverisation, cutting, inversion or movement of soil. These tools normally produce several effects simultaneously. Soil adheres to the surfaces of machines and tools that remain in contact with it most of the time. It not only affects the performance of the machine and quality of work but also increases energy consumption (Qaisrani 1993). In extreme cases, it does not allow the machine to move. It is therefore, important to explore the means of reducing adhesion to the surfaces of soil engaging components of various machines and tools operating in sticky soil conditions.

3.2 Soil adhesion preventing mechanism of soil animal's cuticles

Soil animals possess excellent ability of scouring soil from their bodies. This is the result of their adaptation to the environment over a long period. Surface morphology of dung beetle was analysed using scanning electron microscope. This SEM analysis showed that there are a number of unsmoothed structures varying

in size and shape on its surface. The distribution of small convexes also varied from one part of the body to the other (Fig. 4). The body surfaces were curved and convex-concave forms. The convex-concave nature of their body surfaces created some soil free zones as they move through moist sticky soil. There unsmoothed surface morphology of these animals reduced adhesion of soils to their bodies by a number of ways. For example the break down of water film as soil move over an unsmoothed surface, the reduction in the surface area in direct contact with moving soil, air trap in the concave portion, increase in compressive forces of soil squeezes out any extra water which act as lubricant, all play important role in reducing adhesion of soil to their bodies (Qaisrani 1993).

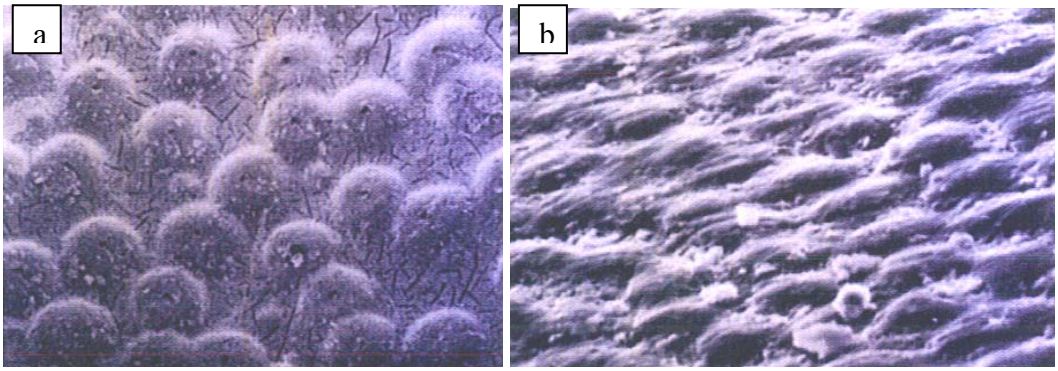

Figure 4: Unsmoothed surface morphology of heads of a) dung beetle, b) desert beetle (Tong *et al.* 2005)

3.3 Bionic bulldozing plates

The draft of bulldozing plates varied with a number of factors such as depth of cut, spade angle, working speed and soil moisture contents. The draft of bionically modified bulldozing plate can be mathematically described by eq. 1 assuming that the moisture contents were constant at the time of testing.

$$D = -0.436 + 0.22d + 0.925\text{Sin}\theta + 1.317V \quad [1]$$

D = draft, kN
d = depth of cut, mm
θ = angle of cut, degrees
V = working speed, m/s

Although, the draft increases with the increase in any of these factors but working speed has very significant impact on the draft of bulldozing plate. The draft of bulldozing plates is minimum when operating at a spade angle of 45˚. The equation was developed for black soil at soil moisture content of 35.5%. The draft of bulldozing plates was directly proportional to the amount of soil adhered to the surface of these plates. The drafts of bionic bulldozing plate were 27%, 27% and 29% less than that of conventional bulldozing plate operating at 0.01 m/s, 0.02 m/s, 0.06 m/s speed as shown in Table 1.

Table 1: Drafts of bionically modified and conventional plates at three working speeds (at 30.38% mc (db), 15 mm depth of cut and 35˚ angle of cut)

Plate	Speed, m/s	Draft, kN	Relative draft
Conventional bulldozing plate	0.01	0.80	1.00
	0.02	0.85	1.00
	0.06	0.97	1.00
Bionically modified bulldozing plate using UHMW-PE convexes	0.01	0.58	0.73
	0.02	0.62	0.73
	0.06	0.69	0.71

The results of this study indicated that draft of these plates varied from plate to plate. A number of factors have sound impact on drafts of bulldozing plates and adhesion of soil to their surfaces. The material of convexes and the distribution and arrangement of convexes on their surfaces have significant effects on soil adhesion. Steel-45 has higher coefficient of friction with poor scouring properties as compared to UHMW-PE (Qaisrani 1993). Soil stuck to whole of the surface of conventional bulldozing plate made from steel 45 (Fig. 5b) and it has to be cleaned before each operation. On the other hand the binically modified bulldozing plate with UHMW-PE scoured the soil very well (Fig. 6b) and did not require cleaning between each operation. Therefore, the conventional bulldozing plate has higher draft at all the three working speeds as compared to the bionically modified bulldozing plate (Table 1). The bionic modification based on surface morphology of the head of dung beetle, reduced the draft of modified plate through improved soil scoring and reduced s friction.

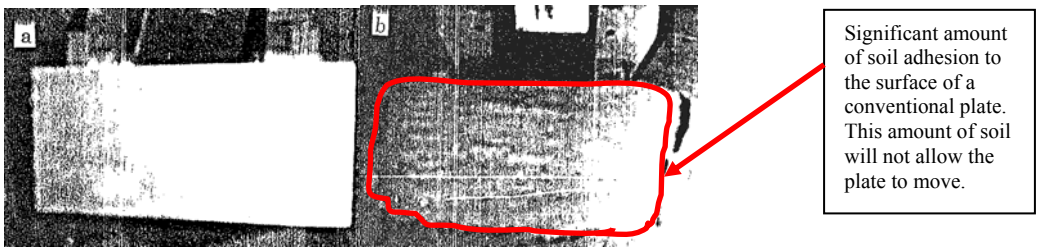

Figure 5: Adhesion of soil to Conventional (Steel-45) bulldozing plate
a) before operation; b) after operation

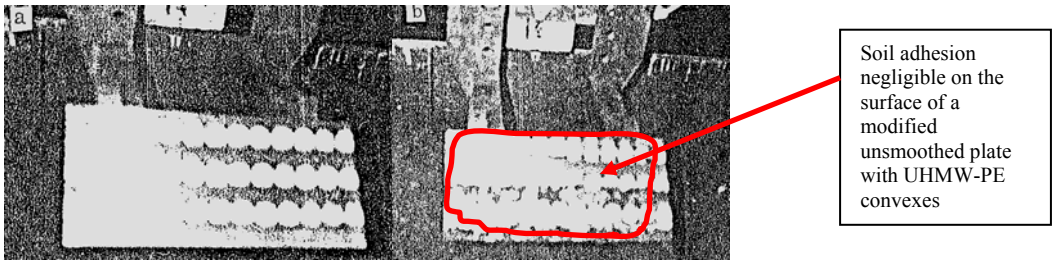

Figure 6: Adhesion of soil to unsmoothed bionically modified (UHMW-PE convexes) bulldozing plate
a) before operation; b) after operation

3.4 Modified mouldboard ploughs

The draft of mouldboard ploughs varied with the type of modification and coating applied on their surfaces. It also depended on working speed (increased with the speed). There was significant reduction in draft forces when bionically modified plough was operated at higher speeds as compared to the conventional plough. The results of this study showed that the average draft of plough varied from 1.27 kN (conventional) to 0.94 kN (bionically modified plough using UHMW-PE convexes) when operating at 3.60 km/h. These values were 1.46 kN and 0.97 kN respectively at 5 km/h working speeds in the laboratory soil test bin (Table 2). A significant amount of soil adhered to the surface of the conventional plough (Fig. 7b). The increase in draft was proportional to the quantity of soil adhesion to the surfaces of these ploughs. On the other hand, the modified plough surface scoured the soil well (Fig. 8b). The soil scouring resulted in the smooth flow of soil and reduced the draft of the plough significantly as compared to the conventional plough. The cost of the bionically modified plough was comparatively higher than the conventional plough. However, the cost of modification can be reduced by producing these ploughs on commercial scales. The results of present study indicated that UHMW-PE can be used for modifying the surfaces of soil engaging components of tillage and other tools for improving soil scouring properties. The modified ploughs with

UHMW-PE convexes reduced the draft by 26% and 30% at 3.6 km/h and 5 km/h working speeds respectively. The scouring of plough surface improved the working quality of these ploughs as well.

Table 2: Average draft of ploughs at two working speeds (3.6 km/h and 5 km/h)

Ploughs	Average draft, kN		Relative draft to conventional plough	
	3.6 km/h	5.0 km/h	3.6 km/h	5.0 km/h
Conventional	1.27	1.46	1.0	1.0
Bionically modified	0.95	1.02	0.74	0.70

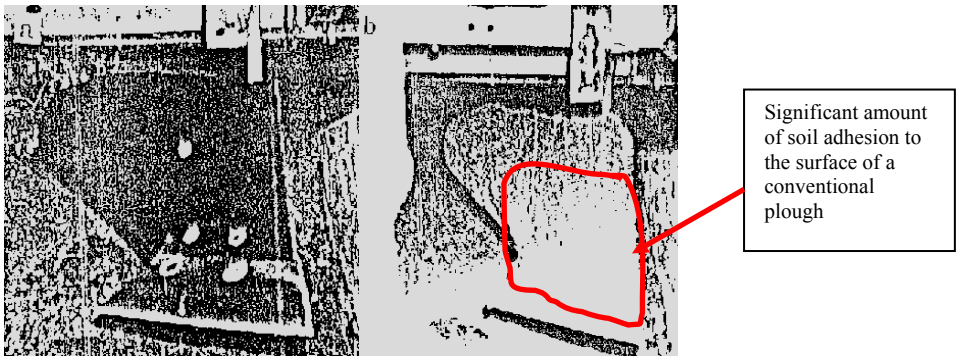

Fig. 7: Adhesion of soil to conventional mouldboard plough a) before operation; b) after operation

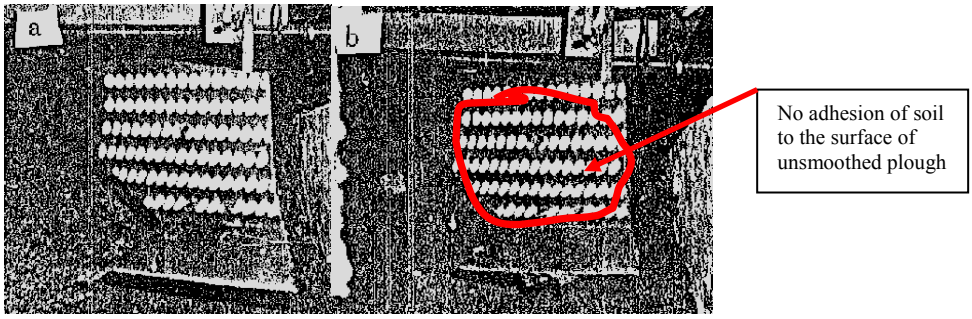

Fig. 8: Adhesion of soil to unsmoothed bionically modified (UHMW-PE convexes) mouldboard plough a) before operation; b) after operation

4. CONCLUSION

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

1. The unsmoothed surface morphology of dung beetle plays important role in reducing adhesion of soil. The application of its surface morphology on bulldozing plates and mouldboard ploughs improved soil scouring properties and reduced the draft of these tools as a result.
2. UHMW-PE has excellent soil scouring properties and may be used for modification of the surfaces of soil engaging components of various tools.
3. This study was conducted under laboratory conditions and needs to be further investigated in field conditions. This will be helpful in producing bionically modified machines and tools that can be used in practical field conditions.

4. The cost of modification can be brought down by producing these tools on commercial sacles.

REFERENCES

CHEN BC, RE LQ, CHEN DX, TON J, CONG Q. (1990). Theory and Techniques of reducing adhesion and scouring soil for terrain machines by bionics. *Technical Report of Jilin University of Technology,* Changchun, China.

CONG Q, REN LQ, CHEN BC. (1990). Research on reducing adhesion by soil electro-osmosis and its affecting factors. *Proceedings Of the 8th Conference of International Society for Terrain Vehicles*, Kobe, Japan, 45-55.

Fisher RA, Baver LD. (1928). Further notes on the capillary forces in an ideal soil. *Journal of Agricultural Sciences, 18:* 406-410.

Fountain EE. (1954). Investigation into the mechanism of soil adhesion. *Journal of Soil Science, 5*: 251-263.

McFarlane JS, Tabor D. (1967). *Dynamic properties of soil. In Soil dynamics in tillage and traction (eds Gill WR, Vanden Berg GE).* Agricultural Research Service, US Department of Agriculture Handbook 316.

Nichols ML. (1931). The dynamic properties of soil II, Soil and metal friction. *Journal of Agricultural Engineering, 12*: 321-324.

Qaisrani AR. (1993). *The effects of modified and unsmoothed surfaces on the draft of bulldozing plates and mouldboard plows.* A Ph.D. Dissertation, Jilin University of Technology, Changchun, China.

Qaisrani AR, CHEN BC, REN LQ. (1992). Modified and unsmoothed surfaces - a means to reduce plowing resistance. *Agricultural Engineering Journal, 1*: 115-124.

QIAN DH, ZHANG JX. (1984). Research on adhesion and friction of soil against metallic materials. *Acta Agromechanica, 15*: 70-78.

REN LQ, TONG J, LI JQ, CHEN BC. (2001). Soil adhesion and biomimetics of soil-engaging components: a review. *Journal of Agricultural Engineering Research, 79*: 239-263.

Salokhe VM, Gee-Clough D. (1989). Applications of enamel coating in agriculture. *Journal of Terramechanics*, *28*: 275-286.

Salokhe VM,Gee-Clough D, Suharno. (1990). *Field testing of an enamel coated mouldboard plow*. ASAE Paper No. 901552. ASAE St. Joseph, MI, USA.

Suminitrado DC, Koike M, Konaka T, Yuzawa A, Kurioshi I. (1988). A mathematical model to predict the trajectory of soil motion on a mouldboard plow surface. *Proceedings of the 2nd Asia-Pacific Conference of the International Society for Terrain Vehicle System,* Bangkok, Thailand, 195-204.

TONG J. (1993). *Study on reducing adhesion and resistance of soil to soil engaging components of machinery for land locomotion by bionics*. A Ph.D. Dissertation, Jilin University of Technology, Changchun, China (in Chinese).

TONG J, SUN JU, CHEN DH, ZHANG SJ. (2005). Geometrical feature and wettability of dung beetles and potential biometric engineering applications in tillage implements. *Soil & Tillage Research, 80*: 1-12.