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Evaluating the draft force and soil-tool adhesion of a UHMW-PE coated furrower

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ABSTRACT

To reduce soil-tool adhesion followed by an improvement in draft force, many attempts have been made on the surface modification of moldboard ploughs by applying plastic coatings to them. Like moldboards, furrowers may also show adherence to soil according to its physical condition. This research aimed at draft force improvement of furrowers using surface coatings. Due to the self-scouring ability and low frictional characteristics of ultra high molecular weight polyethylene (UHMW-PE), a narrow metal furrower has been coated with the plastic. For comparison, a steel tine equal in shape and dimension to the plastic-coated tine has been built. The tines were designed like the furrowers and were tested for draft force in a linear soil bin filled with heavy clay soil. Each experiment was repeated three times over a depth of 20 cm with two different compactions and gravimetric moisture content of 4% and 18% dry based. The average draft force value of the polythene coated tine was significantly lower at both moisture levels. In high compacted soil with 18% MC (gravimetric moisture content), the draft force of the UHMW-PE coated tine measured 29% less than that of the steel tine. In conclusion it has been found that the modification to the furrower tines by UHMW-PE coating can reduce draft force significantly.

1. Introduction

Improving the efficiency of agricultural operations has always been important for farmers and engineers. Agricultural systems are both consumers and producers of energy it (Hamzei and Seyyedi, 2016). Tillage is a very fundamental and historical process of improving soil physical and biological conditions to satisfy the requirements of soil protection and cropping. (Gliński et al., 2011). In modern agriculture, tillage is known as an energy and money consuming process. A suitable system of tillage must take minimum energy input while producing maximum tillage output (Singh and Singh, 1986), hence it is logical to carry out studies on methods to improve tillage efficiency, which not only develops competitiveness by reducing the costs but can also control and reduce energy-related environmental pollutions, therefore, contributing to sustainable development (Ozkan et al., 2004).

McKyes and Ali (1977) described the force required to cut soil using narrow blades as a function of soil and environmental physical properties, tool shape geometry and tool surface characteristics in their commonly used soil cutting model.

In simple terms, adhesion occurs when two surfaces tend to stick together. Soil adhesion occurs when soil sticks to a solid surface such as a tillage tool. Soil-tool adhesion can reduce ploughing efficiency and quality; it may also block the movement of tillage machines under severe conditions like ploughing a heavy and sticky clay soil. Moreover, soil adhesion may be responsible for a significant reduction in the machine performance by disabling some of its functions (Ying and Guoquan, 1992).

When tillage tools move through soil, some sliding resistance between soil and tool occurs which is known as the tangential component of adhesive force and is a function of soil-tool friction, adhesion and normal pressure applied on the tool surface. This tangential component can be mathematically expressed such as in equation 1 (Payne, 1956; Stafford and Tanner, 1977a, 1977b).

$$\tau = C_a + \mu.N \quad (1)$$

τ = tangential component of the adhesive force, N/cm^2
C_a = coefficient of adhesion, N/cm^2
μ = soil metal coefficient of friction, Dimensionless
N = normal pressure, N/cm^2

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The soil sticky limit is defined as the minimum moisture content in which the soil starts to show adherence to a steel spatula (Lal and Shukla, 2004). Fountaine (1954) reported that soil-tool adhesion is affected by the soil moisture content. Regardless of the soil adhesion level, many soil animals are able to move freely in soil. This was an inspiration to many scientists working on bionics to design tools with low adhesive characteristics against soil (Ren et al., 2001; Tong et al., 2005; Gao et al., 2010; Tong et al., 2014). They reported that the hydrophobic characteristics along with the porous surface of the skin of some animals could be the reason for their ability to avoid sticking to soil. These characteristics motivated scientists to apply hydrophobic treatments, e.g., coating the surface of tillage tools with polymer materials.

Ultra-high molecular weight polyethylene (UHMW-PE) is an aliphatic polymer with ultra long molecular chains and is well known for its exceptional corrosion and abrasion resistance. The UHMW-PE has been promising due to its inherent properties. It has many applications throughout numerous engineering fields such as medicine, which used UHMW-PE as a replacement for artificial human joints due to its chemical stability, abrasive wear resistance and bio-compatibility (McGloughlin and Kavanagh, 2000; Wang et al., 1998). Based on the characteristcs of the dung beetle skin, Soni et al. (2007) applied hemisphere bio-mimetic surface structures made of UHMW-PE on the surface of moldboard ploughs and reported that the surface modification of the moldboard plough reduced draft up to 36% in sticky soil and improved the self cleaning characteristics of the moldboard plough. Ren et al. (1990) used Teflon as a coating on the surface of a moldboard plough to reduce soil-tool friction. Chen et al. (1990) reported that the Teflon friction coefficient is up to 50% less than ASTM 45 steel against soil and it has much better self-cleaning characteristics. They also coated a moldboard plough with Teflon and reported this modification reduced draft force by up to 25%. Salokhe et al. (1990) reported hat the enamel coated ploughs reduced draft force by up to 14% and 16% at 3.6 and 4 km/h respectively. As reported by Vermeulen et al. (1997) the soil adhesion to seed-bed preparation tools like furrowers can significantly affect germination rate. Since furrowers play an important role in tillage and seed planting, a reduction in tool friction and adhesion can affect the draft force and germination rate. Narrow tines, including chisel ploughs and those used as furrowers in seed planter machines are widely used in northern regions of Iran. Local farmers reported soil-tool adhesion as a main concern, which created difficulties in soil conditioning for tillage and seedbed preparation. It may be logical to carry out research on the practicality of using polymers as a surface coating for furrowers. The aim of this study is to use UHMW-PE, a polymer with low adhesion and friction characteristics as a surface coating on furrowers to reduce the required draft force.

2. Materials and methods

2.1. Ultra high molecular weight poly ethylene

Ultra high molecular weight polyethylene (UHMW-PE) plastic has been chosen to coat a furrower tine. To prepare the tine, a thick layer has been extracted from a UHMW-PE rod using machine works. Some of UHMW-PE properties are mentioned in Table 1.

Table 1
Mechanical properties of UHMW-PE.

[a]Properties	Value
specific weight, kg/lit	0.95
yield strength, MPa	17.6
elongation, %	5
compaction strength, Mpa	16.5
Rockwell hardness	R-38
water absorption, 1/8"	<0.01
dynamic friction against steel	0.14
[b]water contact angle at 20 °C, (ascending) °	94

[a] Reported by supplier.
[b] Tong et al. (1999).

2.2. Soil-Bin and the clay soil preparation

To carry out the draft force test, a locally designed and developed linear soil-bin at Sari Agricultural University was used. The soil-bin is 6 m in length, 2 m in width with a 5 horse power three phase motor, which is responsible for moving the shank holder up to 1 m/s. The speed was limited to 0.3 m/s. According to the soil texture triangle, the selected soil in the soil-bin was a clay soil. It was an Inceptisol soil according to USDA soil taxonomy. Atterberg limits (Atterberg, 1911) of the soil were measured according to ASTM D 4318 standard. The standard does not cover the soil sticky limit test. This limit was measured by recording the soil gravimetric moisture content when a steel spatula did not show adherence to soil while being drawn across the soil surface with a firm pressure (Baruah and Barthakur, 1997). Tests have been conducted in the soil mechanic laboratories of Sari University. Results of soil texture analysis and corresponding Atterberg limits are mentioned in Table 2. Gravimetric soil moisture contents were 4% and 18%. In order to homogenize the soil moisture contents, water was added to the soil while mixing it rapidly and a polyethylene sheet used to cover the soil surface to prevent evaporation and left for about 24 h to allow the moisture content to become homogenized.

A leveler attachment was connected to the soil-bin shank holder to grade the soil surface after each test. For compaction, a 25 kg roller was rolled over the graded soil after each test, three times for low compaction, and six times for high compaction. Soil moisture content was measured before and after compactions and found not to be significantly different. A handy penetrometer (Humboldt, H-4210A, U.S.A) was used to examine the uniformity of soil compaction in different spots of the soil-bin. Once the soil compaction was found to be uniform, soil dry bulk density before each test run was measured at depth of 15 cm and reported in Table 3.

The soil-bin was equipped with a load-cell (Kyowa, 500 kg, Japan) coupled to a data logger (Interface WTS-AM-1, USA). The load-cell measured the tensile force applied to the chain, which pulled the soil-bin's shank holder. The empty shank holder was pulled once to measure friction forces. Values obtained from this test were used to compute pure draft force.

Table 2
Soil texture analysis according to the grain size distribution and Atterberg moisture content limits.

Property	Parameter	Percentage, %
Soil Texture	Clay (<2 μm)	48.5
	Silt (2–63 μm)	18
	Sand (>63 μm)	33.5
Atterberg limits	Sticky limit	14
	Plastic limit	16
	Sticky point	42
	Liquid limit	44