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GENERAL CONSIDERATIONS CONCERNING THE EFFECTS OF ELECTRO-OSMOSIS ON DECREASING THE FORCES AND THE ENERGY NEEDED FOR TILLING THE SOIL

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ABSTRACT

Electro-osmosis principle consists in the application of a direct current voltage for an anode-cathode system introduced into soil. The effect of this system consists of the mobilization of water particles from the soil and their transport, in a very short time, from the anode to cathode. The soil water transported from the anode to cathode, on the tool-soil contact surface, in consequence, will produce a lubrication of the active surface and thereby a considerable reduction of the friction forces and implicitly of the energy necessary to move the tool through the soil.

INTRODUCTION

Electro-osmosis principle consists in the application of a direct current voltage for an anode-cathode system introduced into soil. The effect of this system consists of the mobilization of water particles from the soil and their transport, in a very short time, from the anode to cathode (Larson D.L., et al., 1992). For tillage machines, the anode can be the soil for a disc-knife and the cathode - the working part (plough-body, ridge-plough, cultivator arrows, coulters, etc.).

It is known that a basic component of the force resistant to the travel of working parts through the soil is the frictional force that arises on the tool-soil contact surface (Martina L., et al. 2019).

The soil water transported from the anode to cathode, on the tool-soil contact surface, in consequence, will produce a lubrication of the active surface and thereby a considerable reduction of the friction forces and implicitly of the energy necessary to move the tool through the soil.

The energy required for tillage is a considerable part of the total energy consumed for plant cultivation. When soil tillage is performed by pulling or pushing tillage tools, a significant part of the tillage energy is consumed to overcome the frictional forces on the contact surfaces between the tool and the soil (Vlăduţ V., 1998). The active surface of the tillage tool can be chosen appropriately in order to minimize friction or mechanical energy required for tillage.

Enamel coatings do not have a durability corresponding to the working parts and the lubrication must ensure the environmental conditions (Jianming Ling, 2021). Also, the reduction of frictional forces varies with the soil conditions and with the working and operating parameters of the machine.

These conditions are restrictive enough for the application of electro-osmosis to be specialized to some extent. Almost all studies focused on reducing the resistance force, but an indirect factor to consider is the reduction of traction requirements. Even when the resistance force can be reduced only by increasing the total power required for traction it can make electro-osmosis practical and economical (Dano Jr. P.L., 1961).

Reducing the traction requirements can reduce the cost of the necessary equipment, electro-osmosis having a maximum effect at high humidity, where the traction capacity is diminished (Martina L., et al. 2019).

More information is needed before electro-osmosis can be applied intensively with high efficiency. The energy required to overcome the resistance to move the tools in the soil is a considerable part of the energy used in plant production process. When the soil is tilled by mechanical pushing or pulling, the soil tillage tool requires a large amount of energy to overcome the frictional resistances at the pass of the tillage tool (Mohammed M., 2018).

The shape of the tool and its active surface can be chosen to minimize friction and thus the energy required for tillage. Using other methods to reduce friction, such as the principle of vibrating tools, coatings, and lubrications, was limited by their shortcomings (Larson D.L., Clyma H.E., 1995). For example, the energy required to produce tool vibrations may be higher than the energy required for tillage, the coatings may be insufficiently durable, and lubrication must be harmless to the environment.

In addition, the reduction of relative friction forces varies with the soil conditions and the machines used to perform the tillage. Thus, the actual costs of its application are uncertain (Lingwei Zheng, et al, 2019).

MATERIAL AND METHOD

Soil tillage tests to quantify the forces required to move and reduce energy obtained by electro-osmosis were performed in a soil canal 1.2 m wide and 0.5 m deep, the test section having 10 m length, with the walls provided with rails that serve as a support for the trolley on which the tillage tools are placed.

The trolley is controlled by an actuation system consisting of an electric motor and a gearbox that allows to ensure three operating modes.

Fig.1. Test stand for highlighting the effect of electro-osmosis on the reduction of traction force in soil tillage tests

The stand consists of:

- an electric motor with a speed of 950 rpm;
- a gearbox and a clutch that allows to obtain three working speeds;
- a hydraulically actuated brake;
- a 4-wheel trolley that rests on the rails fixed laterally to the walls of the canal. The trolley is equipped with an articulated mechanism for adjusting the vertical position, the adjustment of the horizontal position being done manually;
- tillage tools: a cultivator arrow and a disc knife that rests on a bar attached to the trolley, on which is also mounted the tensometric bridge.

The shape of the tool and its active surface can be chosen to minimize friction and thus the energy required for tillage.

In addition, the reduction in relative friction forces varies with the soil conditions and the machines used to perform the tillage. Thus, the actual costs of its application are uncertain.

The **main elements** that are part of the equipment for producing the electro-osmosis effect are:

- Metal frame;
- Tillage tool;
- Disc knife;
- Tillage knives;
- Disc support;
- Knife support;
- Insulations;
- Power source;
- Voltage inverter (switching source: 0÷80 V/1A);
- Electrical circuit for tensometric measurement.

The **metal frame** is made of OL 42 and represents the metal support on which the soil tillage tool (knife) and the disc knife are mounted, between which the electrical circuit for tensometric measurement will be mounted.

For laboratory measurements, the measuring or recording instrument and the voltage amplifier may be mounted on an adjacent desk, provided that the length of the test section in which the tests are carried out does not exceed 10 m.

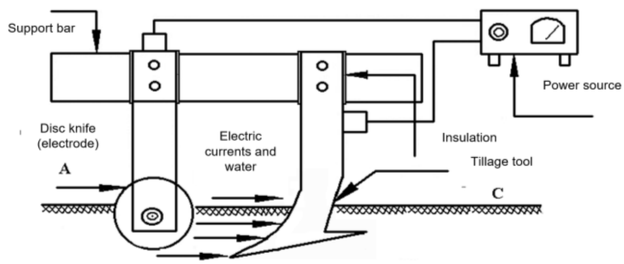

Fig.2. Schematic representation of the equipment used in soil tillage tests with electro-osmosis

The processing tool (cathode) is a 206 mm wide cultivator arrow, selected as a tool for performing tillage tests.

Cultivator arrows are frequently used in soil tillage having a sufficient friction surface to give a component large enough of the total resistance force, but small enough to be used effectively in limiting the test space.

Nevertheless, the arrows serve as a cathode, a positive voltage being connected to the arrow support to attract water for lubrication to the surface of the arrow. The support is electrically insulated from the cultivator frame by a dense layer of electrical-insulating material.

The disc knife (anode) is a disc used in SD-3.6 seeders with a diameter of 350 mm that is mounted in front of the soil tillage tool, having the role of creating an electric field between the tillage tool (cathode) and the disc knife (anode). For tests, either a disc knife mounted on the centre of the longitudinal axis of the frame or two discs mounted symmetrically to the longitudinal axis of the frame are used.

The fixed knife has the same role as the disc knife, the mounting being done in the same way with respect to the longitudinal axis of the frame, the only difference being that these knives are mounted rigidly to the frame and the resistance to the passage through the soil is higher.

Disc supports, knife supports are used for mounting and fixing the knives on the metal frame used as a support.

The role of testolite, PVC or rubber insulations is to insulate the active parts of the equipment (processing chisel and disc knives) from the metal frame in order to obtain the electric field between the anode (disc knife) and cathode (processing chisel) through the soil and the water within.

The power supply consists of a 12V and 150A battery and is used to provide the voltage needed to make the electric field.

Voltage inverter (switching source: 0÷80 V/1A) is supplied from a battery with voltages between 10.5÷14.5 V delivering any programmable voltage in the range 0÷80 V at a current of maximum 1 A.

Output voltage and current measurement circuit. This circuit allows the measurement of the voltage at the output of the source in the range 0÷80 V and the current generated in the range 0÷800 mH divided into 3 subdomains 0÷8 mA, 0÷80 mA and 0÷800 mA.

Main technical characteristics:

- Input voltage 10.5÷14.5 VDC;
- Output voltage 0÷80 VDC;
- Output current 0÷1 A;
- Maximum output power 80 W;
- Output voltage stabilization factor min. 500;
- Total yield approx. 85%.

RESULTS AND DISCUSSIONS

The reduction of the resistance force varied, the tillage tests being performed in two different soils: one *sandy* and another *loamy-sandy* (medium soil), with a clay content of over 16%.

For each type of soil, the tests were performed at two different moistures: 8% and 12%, respectively at two different working speeds: 2.15 km/h, respectively 3.42 km/h, the applied voltages being between: 0 and 40V.

As in the case of sandy soil the reduction of the resistance force was insignificant, only the data from the loamy-sandy soil were taken into account.

For the beginning, the tests for determining the variation of resistance were performed, without applying an electrical voltage for the two moistures: 8% and 12%, three tests for each speed and moisture.

For the moisture of 8%, a test was performed with the tensometric bridge connected to an oscillograph, thus recording the variation of the resistance force over time without applying a supply voltage.

This variation of the resistance force was compared with a pre-determined standard force of 950 N. Thus it was possible to determine exactly the value of the resistance force and its variation.

Before each test, the soil surface was levelled and compacted to obtain a soil density as close as possible to that of the field. Likewise, in order to obtain a uniform moisture along the entire length of the canal, the soil was watered and then water was let to evaporate for a while until the soil reached the desired moisture.

The tillage tests were performed at a depth of 15 mm, the voltage applied from a direct current source mounted on a frame, varying between 0 and 40V. Each of the tillage tools was insulated reported to the frame so as not to destroy the tensometric bridge.

To determine the water potential through the soil, the following must be taken into account: soil moisture, resistance to penetration, density and electrical resistivity.

Following these tests, with the effect of electro-osmosis, a maximum reduction of 10.1% of the soil resistance to tillage was obtained, using a knife as an anode, a travel speed of 2.15 km/h, a moisture of 8% and a 40V voltage.

At the same moisture, using the knife as anode but moving at a speed of 3.42 km/h, a maximum reduction of resistance of 12.3% was obtained, at 40V supply voltage.

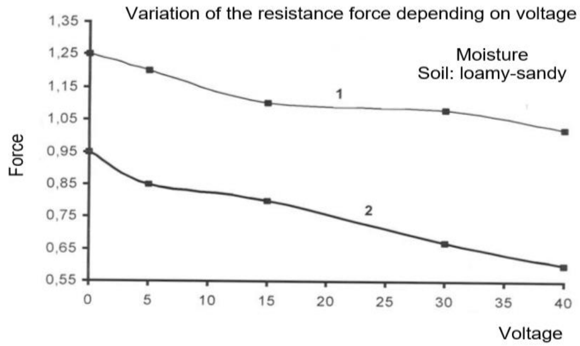

Fig.3. Variation of the resistance force depending on voltage
1 – travel speed of 2.15 km/h; 2 – travel speed of 3.42 km/h

For tests in which the soil moisture was 12%, using a single knife as an anode, the travel speed of the tool through the soil being 2.15 km/h, the maximum reduction of the traction force required for soil tillage was 13.9%, at a supply voltage of 40V.

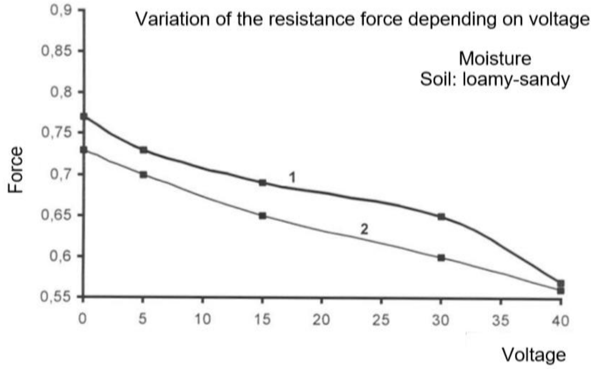

Fig.4. Variation of the resistance force depending on voltage
1 – travel speed of 2.15 km/h; 2 – travel speed of 3.42 km/h

In the case of tests in which the travel speed was 3.42 km/h, the soil moisture of 12%, using a knife as an anode and a supply voltage of 40 V, a maximum reduction of the traction force of 18.89% was obtained.

CONCLUSIONS

Thus the following conclusions can be drawn:

- the greatest reduction of the traction force was obtained at higher soil processing speeds, but this speed was limited. It has also been observed that this reduction depends on the soil structure, so that in the case of soils with high clay content the effect of reducing the resistance of the tool to soil tillage decreases progressively with increasing speed;
- the reduction of the traction force is directly proportional to the increase of the supply voltage reaching a maximum at 40V. This effect can also be observed in the case of soils with high clay content but to a much lesser extent due to the soil structure and high density that do not allow the movement of water from anode to cathode;
- the reduction of the traction force is greater when using a knife as an anode than in the case when two knives were used;
- the resistance encountered by the soil tillage tool decreases proportionally with the soil moisture (the effect of electro-osmosis is more accentuated the higher the amount of water in the soil).

In conclusion, the efficiency of the electro-osmosis process increases proportionally with the increase of moisture, of the travel speed of the tool through the soil and with the increase of the supply voltage and is inversely proportional to the soil density, the number of knives and the degree of soil uniformity.

Therefore, it is observed that using electro-osmosis in the soil tillage process, great reductions of the traction force are obtained during processing, thus implicitly saving energy and reducing the cost per unit of processed surface.

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