SUBSTANTIATION OF TILLAGE METHODS AIMED AT RATIONAL USAGE OF WATER RESOURCES

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Abstract. In the article the results of theoretical substantiation and field trials of various tillage methods aimed at increasing the efficiency of water distribution in the soil use during potato growing are presented. The substantiation of rational tillage methodswas made taking into account the physical phenomenon of thermoelectrokinesis. This phenomenon is valid for any capillary anisothermal systems including the root spreading horizon. Cultivator for deep soil loosening leaves in the treated zone huge numerous capillary channels and large pores. It leads to decreases of the intensity of heating of the treated soil layers due to their less thermal conductivity. Measurements of soil temperature, moisture content and level of rainfall throughout the growing period of potatoes have shown that decreasing of the intensity of soil heating leads to the stabilization of the temperature on the depth 15 cm and 17 % increasing of the total water content in the root spreading zone on the depth till 90 cm. The use of methods of deep soil loosening in technologies of potato growing makes it possible to use water resources more rationally thanks to reducing the water losses due to overheating the top soil layers. Deep loosening also helps avoid wet spots in the potato field due to good water infiltration to the lower layer via big pores in the treated soil.

Keywords: thermoelectrokinesis, soil wetness, soil temperature, tillage system.

Introduction

The soil is the Earth friable layer, which consists of mineral and organic elements with numerous pores, which are formed as a result of tillage, root remains, insect and worm passages, etc. The internal space of these pores is filled with air and water, which provide the necessary conditions for root spreading during crop growing [1; 2].

In the nature, narrow soil pores are capillary channels, in which the length and width are much greater than the distance between the walls. In addition, the soil has certain properties of thermal conductivity, i.e. a possibility to transfer thermal energy from warm layers to sites with a lower temperature. Thus, the root-spreading zone of the soil is an anisothermic capillary system filled with a soil solution.

The surface of soil pores, like any solid body, has a negative electrical charge. Positive ions of soil solution will be attracted to the surface of the capillary, and anions will be repelled from it [3]. At the periphery of the water film inside of the soil pores there is a mobile layer of anions. The electric field of the capillary walls decreases while increasing the thickness of the water film [4]. Capillary walls with lower temperature have lower electrical potential. This means that cold capillary walls attract a water film of greater thickness to them and a smaller amount of ions are presents in the mobile layer inside the capillary compared to the part having a higher wall temperature. Inside the capillary channel an electrical potential difference between warm and cold zones occurs. Under electrical potential difference, the anions from the zone of high concentration will begin to move into the zone with a smaller content. Moving along the capillary from the zone with warm to the zone having a lower wall temperature, the anions of the soil solution entrain the molecules of water, Fig. 1. Thus, due to the equalization of the electrical potential inside the capillary with different wall temperatures, the water pump starts to operate, transferring moisture from the warm zone to the cold site [5]. This physical phenomenon of water transfer within the capillary anisothermal system is called thermoelectrokinesis [6].

An obligatory condition for moving of the soil solution within the capillaries under the action of the thermoelectrokinesis phenomenon is the temperature difference between its various sections. It should be taken into account that the greater the temperature difference between the warm and cold zone, leads to higher intensity of water movement within the capillary.

Thus, by using knowledge about the main regularities of the movement of soil water under the influence of the temperature difference will help create the most favorable conditions for the plant growing by optimizing the soil wetness in the root spreading area. For this, it is necessary to:

- ensure the accumulation of significant water reserves in the deep layers of the soil horizon;
- create a deep and wide network of capillary channels in the root spreading zone in the soil;
- create and maintain fine structured soil in the root spreading zone during the whole growing season of the crops;
- create on the soil surface a thermo insulated layer to reduce the temperature difference between the upper and lower soil horizons.

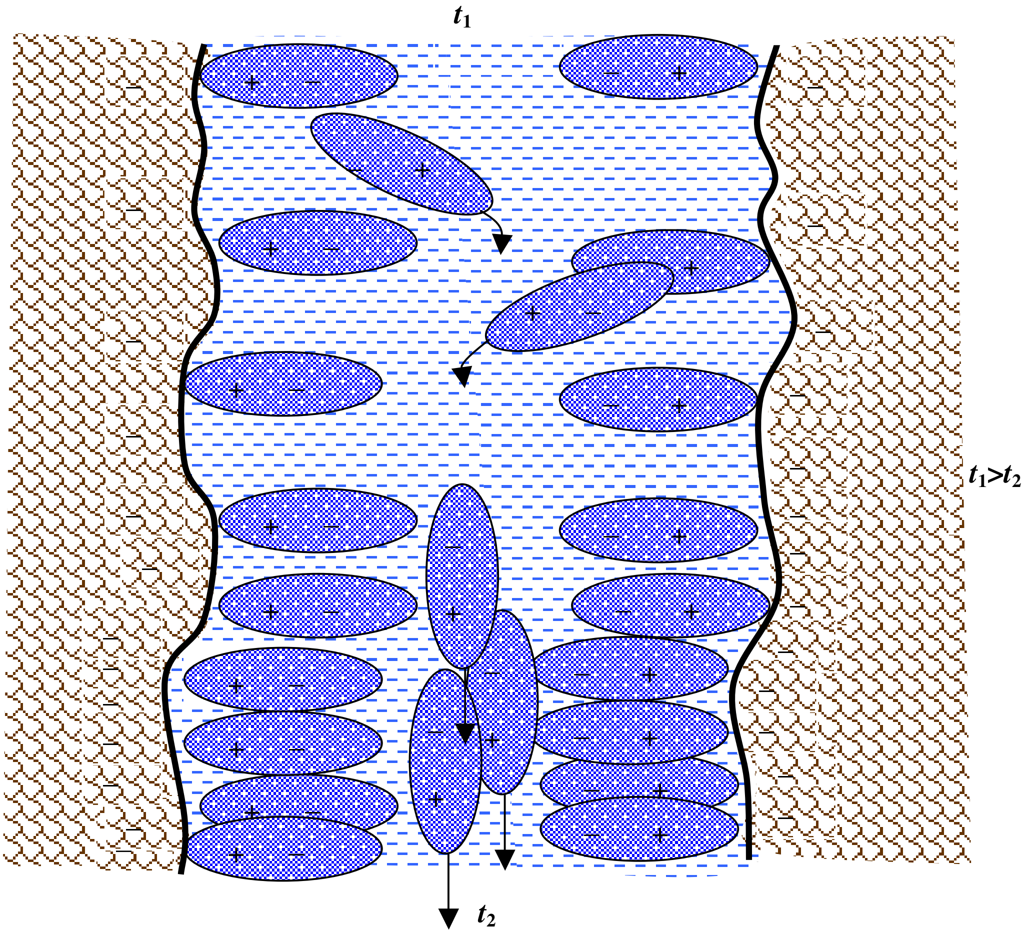

Fig. 1. **Scheme of movement of soil water within capillary channel under influence of thermoelectrokinesis phenomenon**

Materials and methods

For testing the effect of the tillage method on the soil wetness, two types of cultivators were researched, which are used for ridge forming during potato growing. One of them – rotary cultivator, performed soil crushing in the inter row space by knives and formed tight ridges with a smooth surface Fig. 2 [7; 8]. The high density of the ridges was achieved due to the close adherence of small soil particles to each other and air pushed out under the action of the ridge-forming plate. Another cultivator, using ripper tines for deep loosening of the soil, also carried out inter row cultivation of potatoes, but at the same time received ridges with a coarser surface and friable soil structure inside them, Fig. 3 [9]. The ridges, after this cultivator passes, have an uneven surface and a loose structure due to the fact that they consisted of larger soil elements, between which there are huge numerous pores with air [10; 11].

For registration of the rainfall level, air temperature, air humidity, soil temperature and wetness in various layers up to a depth of 90 cm, an autonomous measuring complex was used, Fig. 4. The special soil probe *D*was immersed in the soil to a depth of 90 cm. All data were fixed every 15 minutes and kept on the internal memory. Daily collected information was sent to the server for collecting data via GSM modem *A* in automatic mode. A rechargeable battery and a solar panel B ensured complete autonomy of the operation of the measuring complex.

Fig. 2. **Rotary ridge former cultivator**

Fig. 3. **Ridge former cultivator with ripper tines**

Field trials were conducted from 28.06.16 until 05.08.16. In this period as rule the highest air temperature and water deficiency take place. Water in this period is a limit factor for formation and most active growth of new tubers [12].

Fig. 4. **Measuring complex for recording of rainfall level of precipitation, temperature and water regime of soil state:** *A* – modem; *B* – solar battery; *C* – pluviometer; *D* – probe with humidity and temperature sensors

Results and discussion

During field trial over the entire observation period with 1-hour increments information was obtained about the dynamics of the rainfall level, air temperature, soil temperature and wetness in different layers till a depth of 90 cm. All the data obtained were mathematically processed and after that an estimate was obtained of their statistical characteristics and the range of their changes during the trial period. Based on the statistical data graphs of the weather conditions (air temperature and rainfall level) and the issued soil parameters (soil temperature and wetness) in different horizons were obtained.

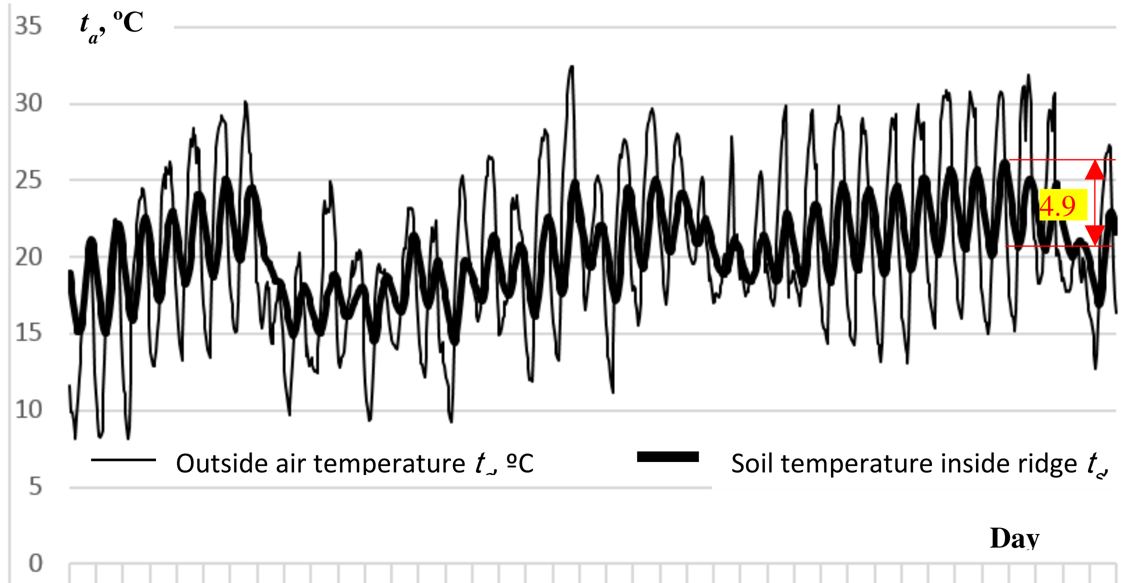

Fig. 5. **Graphs of daily change of outside air temperature and soil temperature inside ridge after pass of rotary ridge former cultivator**

Fig. 5 shows the dynamics of the change in the air temperature ta and soil temperature ts inside the ridge after using the rotary ridge former cultivator, and in Fig. 6 – the same indices, but only after the pass of the ridge former cultivator with ripper tines.The soil temperature was measured at a depth of 15 cm – in the zone of formation of the main part of the new potato tubers. After using ripper tines on the inter row cultivators in the soil there is presence of huge numerous air pores in the top layer, which is composed of larger particles. It means that the change in the soil temperature is less dependent on the outside air temperature.

In the table the results of statistical calculation of the data that were shown in Fig. 5 and 6 are presented – the mathematical expectations of random processes of: outside air temperature $m(t_a)$, daily air temperature difference $m(\Delta t_a)$, soil temperature inside the ridge $m(t_s)$ and daily soil temperature difference inside the ridge $m(\Delta t_s)$.

Table 1

Results of statistical processing of the data of outside air temperature and soil temperature inside the ridge after application of various types of cultivators

Type of ridge former cultivator	**Outside air temperature $m(t_a)$, ºC**	**Daily air temp. diff. $m(\Delta t_a)$, ºC**	**Soil temp. inside ridge $m(t_s)$, ºC**	**Daily soil temp.diff. inside ridge $m(\Delta t_s)$, ºC**
Rotary	20.4	12.84	20.3	4.93
With ripper tines			19.8	3.68

Analysis of the statistical data of the process changing the soil temperature after passing of various types of cultivators has shown that the presence of air filled pores inside the treated layer leads to less warming of the soil and to reducing of the daily temperature fluctuation inside the ridges.Into the ridge with a dense soil structure, its temperature at a depth of 15 cm differs little from the temperature of the outside air, while the temperature of friable soil with rough structure has an average value of 0.5 ºC less during the whole trial period. The average value of the temperature fluctuation inside the ridges with rough soil structure is less 1.25 ºC, if compared with the soil temperature in the ridges consistent of small particles. The decrease in the average value of the soil temperature and daily temperature fluctuations in the zone of tuber formation provides a more favorable and stable temperature regime for potatoes [13; 14].

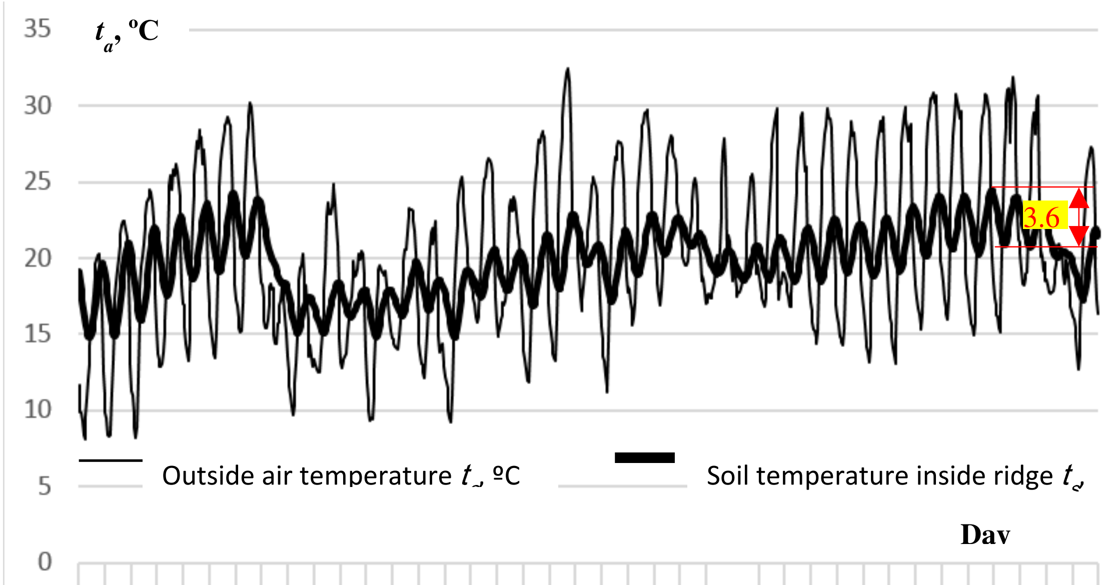

Fig. 6. **Graphs of daily change of outside air temperature and soil temperature inside ridge after pass of ridge former cultivator with ripper tines**

Earlier it was mentioned that the soil wetness largely depends on the temperature of the current soil horizon. This affects the water supply of the root system of growing crops.

Figures 7 and 8 show the level of rainfall and the variation of the soil wetness during the trial period in different soil horizons after using on the potato field a rotary cultivator and a cultivator with ripper tines, respectively.

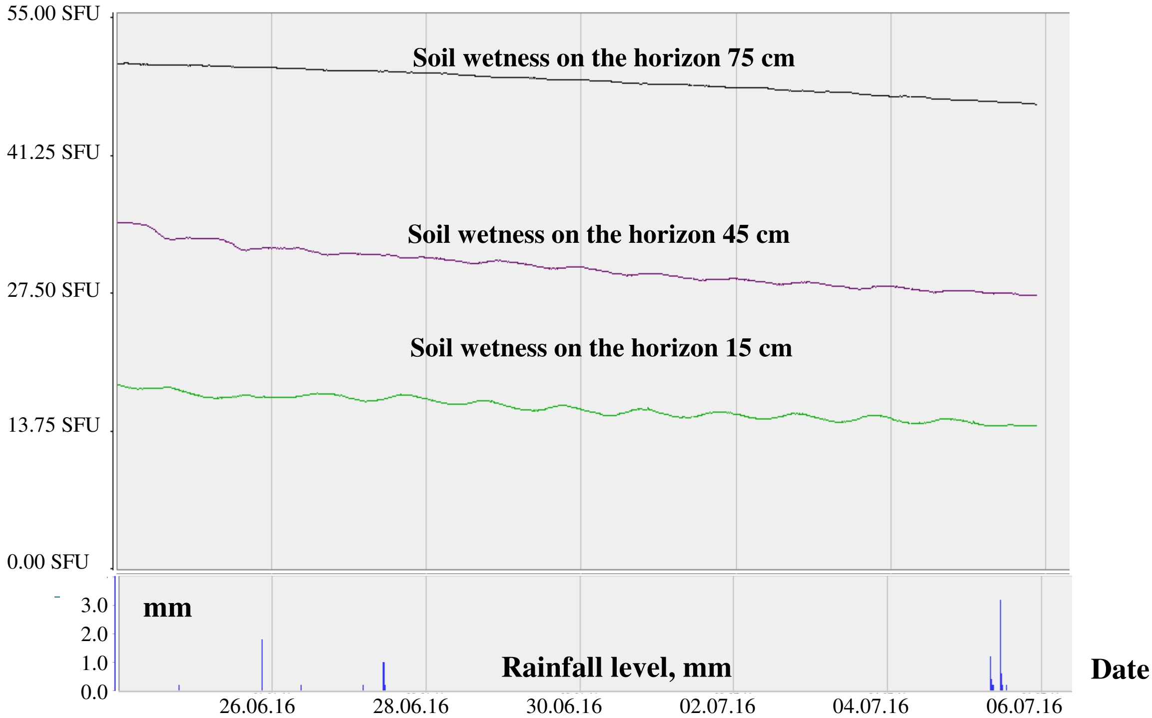

Fig. 7. **Rainfall level and variation of soil wetness in soil horizons after pass of rotary ridge former cultivator**

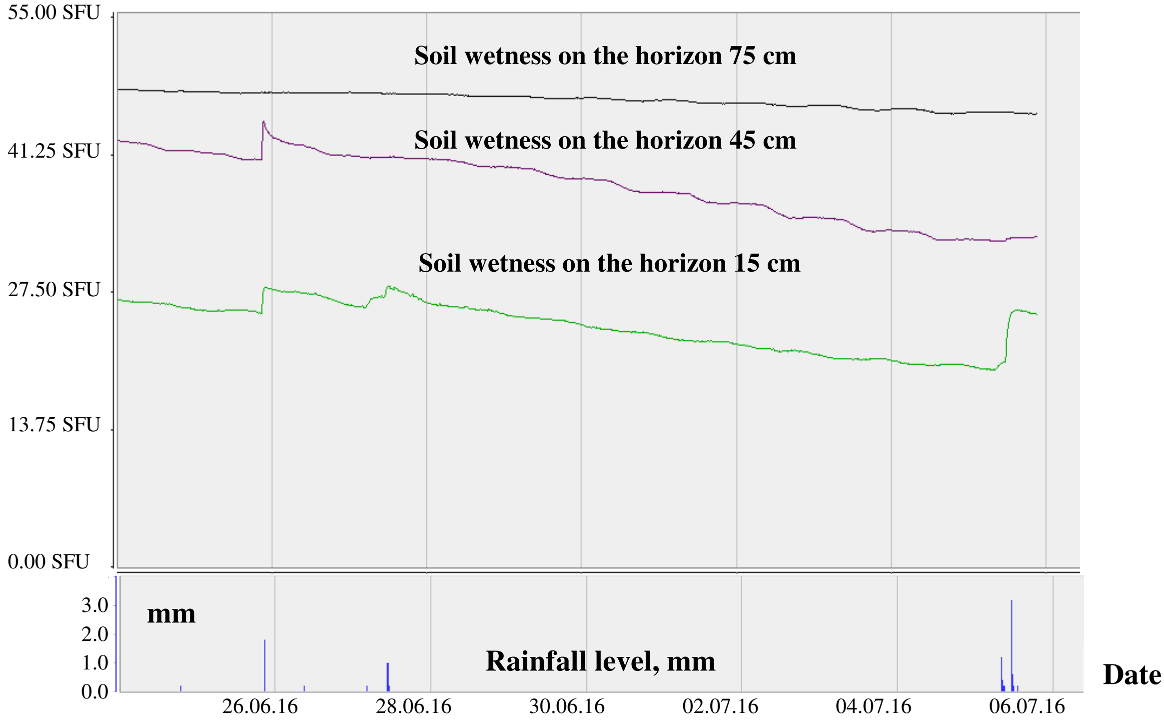

Fig. 8. **Rainfall level and variation of soil wetness in soil horizons after pass of ridge former cultivator with ripper tines**

Fig. 9 and 10 show the dynamics of the changes in water reserves (WR) during the trial period in the potato root spreading zone at a depth of 90 cm after using of a rotary cultivator and a cultivator with ripper tines, respectively.

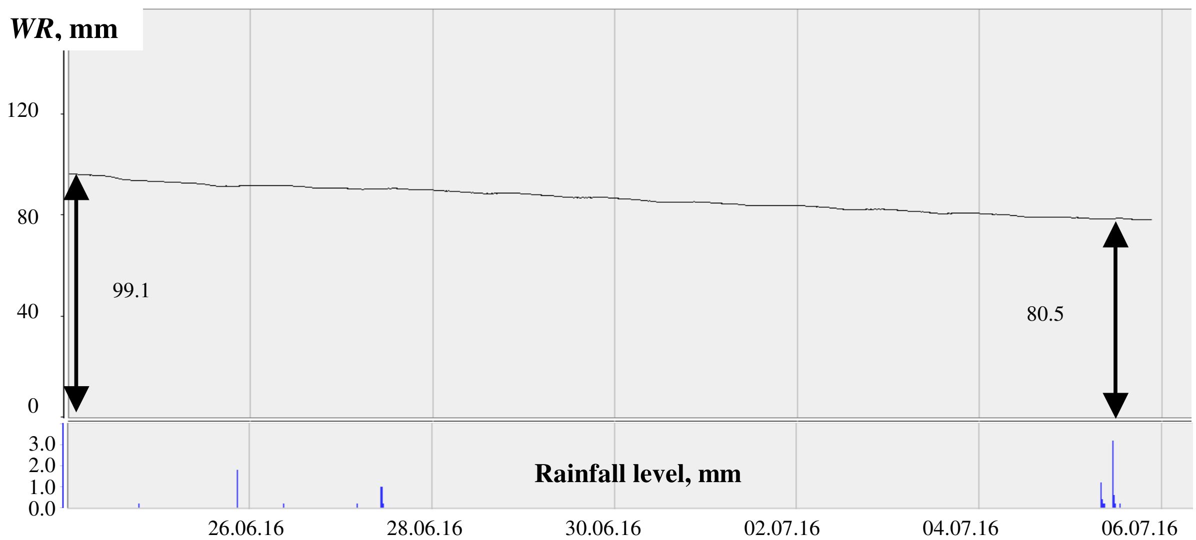

Fig. 9. **Rainfall level and dynamic of changes in water reserves at depth of up to 90 cm after pass of rotary ridge former cultivator**

Based on the analyses of the processes of the water content in the soil shown in Fig. 7-10, it is obvious that the denser soil structure, created by a rotary cultivator and compacted by the ridge former plate, is more depended on the outside air temperatures. A higher temperature in the top soil horizon provides to a more intensive outflow of water into the underlying horizons with a lower temperature. Therefore, potatoes treated by the rotary cultivator suffer a water deficit in comparison with potatoes treated by the cultivator equipped with ripper tines that form the ridge with huge quantity of air pores between more or less rough soil elements.

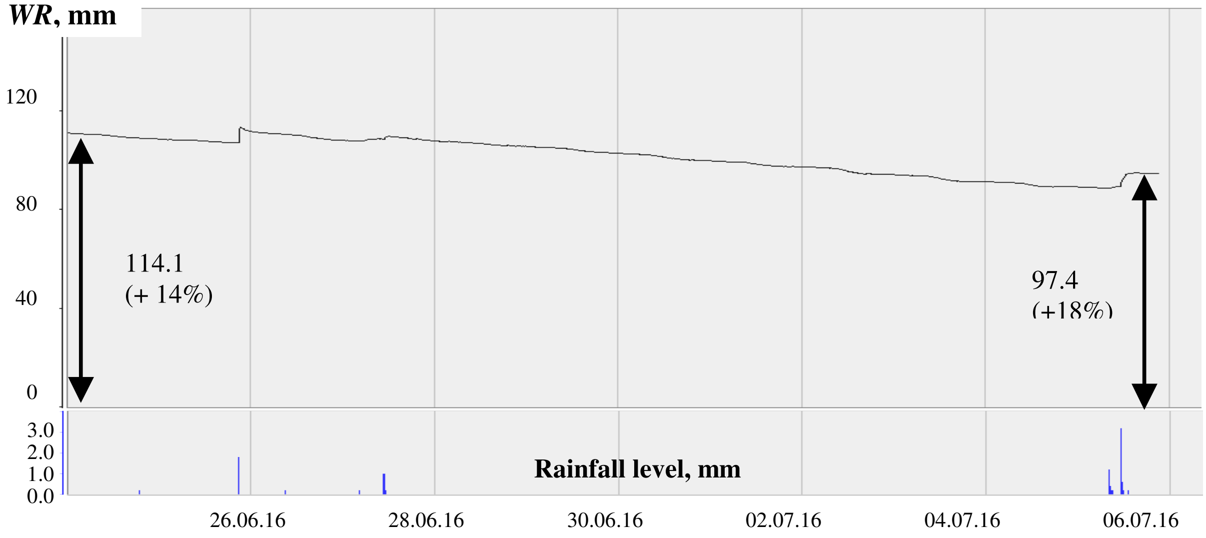

Fig. 10. **Rainfall level and dynamic of changes in water reserves at depth of up to 90 cm after application of ridge former cultivator with ripper tines**

Total water reserves on the depth of 90 cm after using the cultivator with ripper tines are at 17 % higher than the water reserves on the same depth after the pass of the rotary cultivator. It should be noted that large air pores absorb excess moisture during rainfall as evidenced by a sharp increase of the soil wetness in the upper soil horizons at a depth of 15 and 45 cm some time after the rainfall onset. Tightly laid small soil aggregates restrain the penetration of water through the treated zone into the lower horizon of the soil. This leads to a disturbance of the ecological balance due to the runoff of water with the soil elements on the slopes and formation of over-wet spots in the low sites of the landscape [15].

Conclusions

1. Field trials have confirmed the regularities of moisture movement within the soil under the effect of the phenomenon of thermoelectrokinesis.
2. The formation of a friable layer on the top soil horizon with the presence of a significant number of air pores reduces the heating / cooling of the soil under the influence of outside air temperature and provides a more stable temperature regime in the root-spreading zone. It leads to obtaining more smooth and comfortable condition for potato growing during all vegetation period.
3. A coarse structure of the top soil layer and good spreading network of capillary inside the soil provide complete absorption of rainfall and a uniform distribution of water in the root-spreading zone. Rough soil structure in combination with a stable temperature regime has increased the total water reserve in the 90 cm deep area by 17 %, if compared with a more denser top soil horizon consistent of small soil elements formed after the pass of the rotary cultivator.

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