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Research Paper

Soil Water Regime Spatial Heterogeneity Under Alfalfa Growing in The Forest-Steppe Zone of Ukraine

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Abstract. The article considers the issue of spatial heterogeneity of the soil water regime in agricultural fields in the forest-steppe zone of Ukraine. The studies were conducted under the conditions of growing perennial herbs, directly alfalfa varieties "Sinyukha". The redistribution of moisture over the microrelief elements in spring during snowmelt and the flooding of microdepressions with thawed water was shown, the duration of which was 10-15 days in the years of observation. The moisture reserves in the 0-100 cm layer amounted to 108-126% on the slopes compared to control, and increased on the bottoms (after filtration and evaporation of melt water) -to 137-148%. The harvest of green mass of alfalfa at the bottom was completely absent, and on their slopes it was 116-93% compared to control, depending on weather conditions. In the work, field and laboratory research methods and a system of UAV-ERS methods, as well as determination of vegetation indices, were used.

Keywords: *Soil, Spatial heterogeneity, Micro-depression, Water regime, Photosynthesis, Drones, alfalfa,*

Introduction

The phenomenon of mosaic soil cover is inherent in the Left Bank and Right Bank of Ukraine, with each region having its own characteristics depending on the historically established lithological processes of the territory. A common feature of the relief of playland territories is the presence of numerous micro-lowlands (micro-depressions). Their origin in the Right-Bank Forest-Steppe is most often associated with suffusion processes**.**

Investigations of the spatial heterogeneity of typical chernozem productivity on the right-bank Forest-Steppe because of the soils water regime features on flat plains with pronounced microrelief were carried out by us in 2008-2017, mainly under cereal crops, especially under winter wheat (Starodubtsev & Bogdanets, 2015; Starodubtsev *et al*., 2013; Starodubtsev *et al*., 2016; Starodubtsev & Bogdanets 2015; Starodubtsev *et al*., 2009; Starodubtsev *et al*., 2015; Starodubtsev 2017; Starodubtsev *et al*., 2018; Vlasenko & Starodubtsev 2020). The results of these studies showed that the redistribution of moisture of atmospheric precipitation over the soil surface during snowmelt in spring and, to a lesser extent, heavy rainfall in summer significantly affects the state and productivity of wheat, especially in years with a lot of snow and frozen soil before snowmelt. A detailed account of the winter wheat crop in 2017 on different morphological elements of microdepressions showed that crop losses at the bottom of microdepressions with a depth of up to 50-100 cm were 65-70%, and on the slopes of the depressions - 20-30% (Starodubtsev & Bogdanets, 2015; Starodubtsev *et al*., 2013; Starodubtsev *et al*., 2016; Starodubtsev & Bogdanets, 2015) On the whole, in the studied fields of the NULES of Ukraine at research farm in the Kiev region, the loss of winter wheat yields due to the peculiarities of the water regime of the soils of different elements of the microrelief amounted to approximately 15-25%.

Such significant crop losses made it relevant to assess the effect of the water regime of microdepressions on other crops, in particular on alfalfa, cultivated on the same field for several years and having a different resistance to flooding and over moistening of soils.

Objects and Methods

The basis of study is preliminary soil research work of Prof. V.M. Starodubtsev, which took place since 2008 in the Right-Bank Forest-Steppe soil province on typical chernozem. During 2016-2019, detailed studies are conducted on a field of 32.5 hectares, and review studies - on production fields of 400 hectares. Soil sections and drills up to 200 cm are dug on the plain, as well as on the bottom and

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slopes of microdepressions with various depths. For the first time in our studies, the heterogeneity of the soil cover is considered as an essential property which affects the soil cover water regime. The studies covered 3 crops: winter wheat of the «Merlena» cultivar (in the vegetation period 2016-2017), spring barley of the «Britney» cultivar (2018) and alfalfa of the «Sinyukha» cultivar (2017-2019).

Sowing alfalfa of the «Sinyukha» variety was completed in September 2017 with good soil moisture in October (Figure 1), therefore, good plant sprouts were obtained. Observations of the crops development were carried out systematically using Sentinel-2 satellite images, and soil moisture in the flat areas and in microdepressions was determined seasonally by soil sampling to a depth of 100 cm. The green mass of alfalfa was determined by mowing plots 1x1 m in 4 replicates at different relief elements, taking into account the timing of mowing plants on all field. It is important to note that the observation period was characterized by significant changes in weather conditions (Figure 1). Observation of the vegetation state under conditions of the soil spatial heterogeneity was carried out on key micro-depressions C-1 and C-5.

Results and Discussion

The structure of the soil covers at studied field of the research farm «Velikosnitinske» (Figure 1) indicates the dominance of meadow chernozem soils (26.69%) and typical chernozem (24.88%), and only 20,97% occupy titular modal chernozem shown on the standard soil map of this farm. As for the basic characteristics of the soils water regime of this field, in micro-depressions up to 1 m deep and in a large meso-depression in the southeastern part of the field with the same depth, the water regime is flushing, in which leaching of carbonates and other soil products to a depth of 4-5 m or more, that is, to a depth of groundwater, take place.

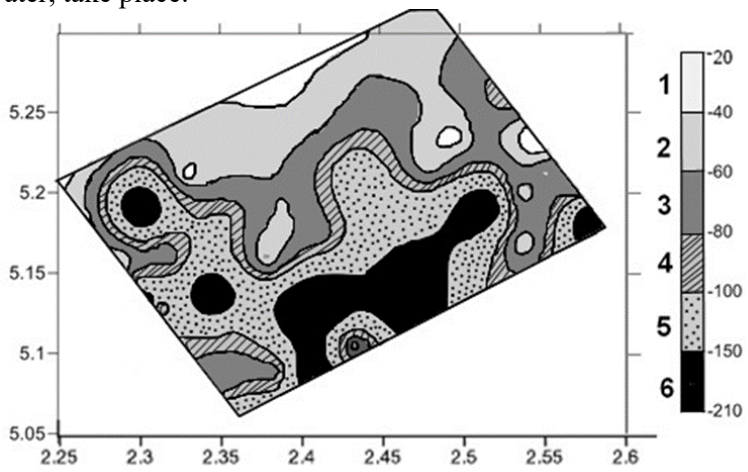

Figure 1. Part of the experimental field soil map: 1 – chernozem typical with high carbonate horizon - (20-40 cm); 2 – chernozem typical (modal or reference) - (40-60 cm); 3 – chernozem typical with more deep carbonate horizon - (60-80 cm); 4 – leached chernozem - (80-100 cm); 5 – meadow-chernozem soil - (100-200 cm); 6 – meadow-chernozem and chernozem-meadow soils on noncarbonate loess - (deeper than 200), **(**Starodubtsev & Bogdanets 2015)

In microdepressions with a depth of approximately 0.5 m, the water regime of the soils is periodic-leaching, carbonates are washed out of the soil profile to a depth of 1-2 m, sometimes even deeper. And only in micro-depressions of less than 0.3 m and in nano-depressions, that created by tillage, the water regime is unwashed out, except for wet years, when it becomes periodically flushing (Starodubtsev *et al*., 2013)

Depending on the weather characteristics of the transitional winter-spring period, the entire depressions in agro-industrial fields is filled with water, or waterlogged (depending on their depth), creating a network of cells with specific agroecological conditions. Visually, such areas are in the form of concentric circles, much darker in color compared to the background control areas. That is why the water regime is considered as the main process in studying soil cover heterogeneity, studies of its dynamics were carried out seasonally during the research period. The pictures clearly show the difference in the state of the experimental field in different wetting years (2018, 2019). The results of

the precipitation and temperature data analysis during the growing season made it possible to record periods of lack of moisture and temperature peaks and alfalfa productivity.

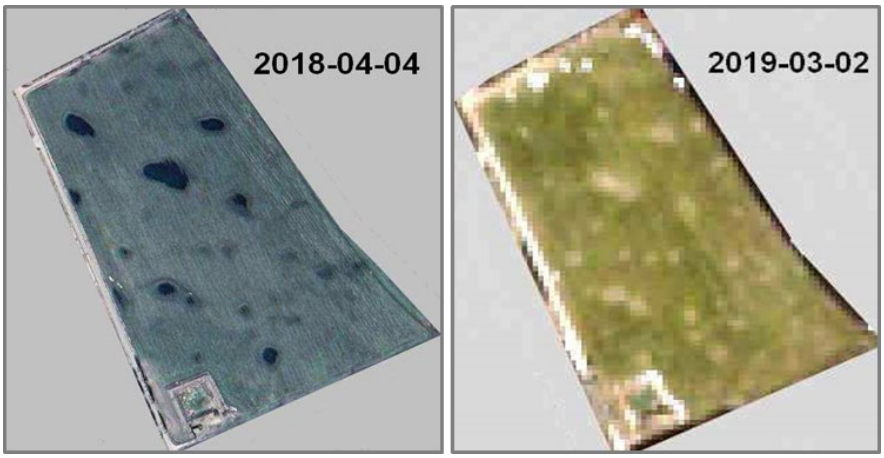

Figure 2. Flooding of microdepressions with alfalfa in the spring of 2018 (left) and the absence of flooding in spring 2019 (right) in Sentinel-2 satellite images.

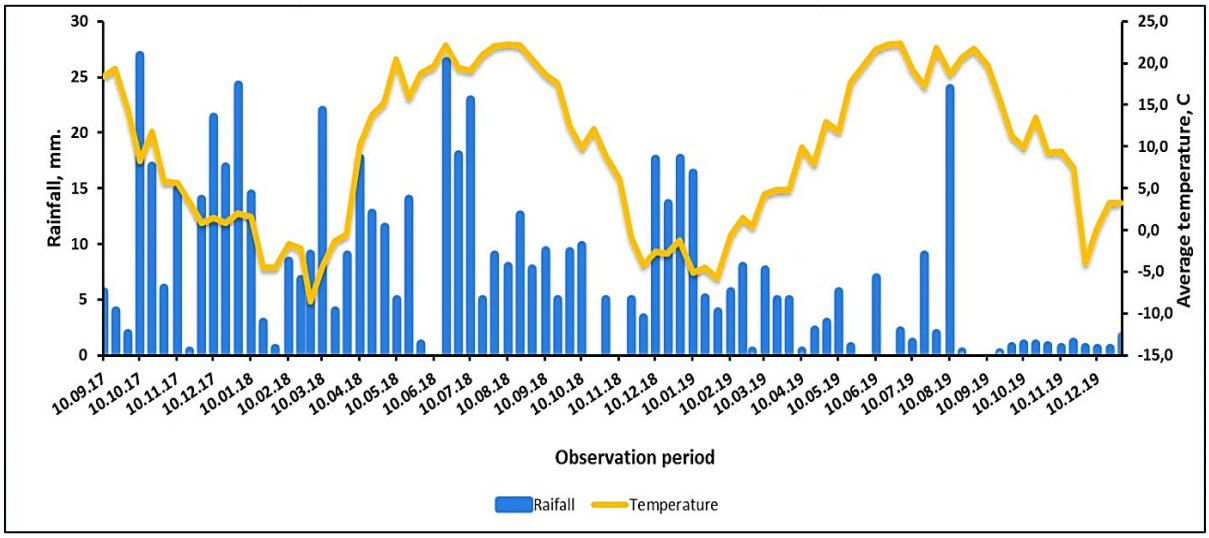

Figure 3. Weather conditions for the growing period of alfalfa in 2017-2019

In 2018 the spring began in early April, that is, a month later than in the previous year, and was characterized by rapid increase in temperature and fast snow melting. The flooding of microdepressions with alfalfa was observed within 10-15 days, which is well shown in the Sentinel-2 satellite image (Figure 2).

Assessment of moisture reserves in the soil layer 0-100 cm 3 weeks after the beginning of snow melting and, accordingly 1 week after evaporation from the surface of the water and absorption into the soil, showed that there was a significant redistribution of moisture among the morphological elements of depressions (Figure 3).

At the bottom of pothole (microdepression), the moisture reserves were about 3600 m^3 / ha, on the slopes they were 1000 m^3 / ha less, and on the plain - 1200 m^3 / ha less. At the same time, alfalfa plants at the microdepression bottom died, and on the slopes and on the plain they developed satisfactorily. During hot and dry May and June, the moisture reserves on the plain sharply decreased (by almost 1000 m^3 / ha), and on the slopes and lowering bottom - by 600-700 m^3 / ha. Under these conditions, alfalfa plants developed better on the slopes of the depressions than on the control, and weeds began to appear at the bottom. As a result, by the second harvest of alfalfa for green fodder, there was no harvest at the bottom of the depression, on the slopes the freshly cut green mass averaged 115 metric centner / ha, and in the control 99 metric centner / ha. Only the July rains (Figure 3) improved the state of vegetation.

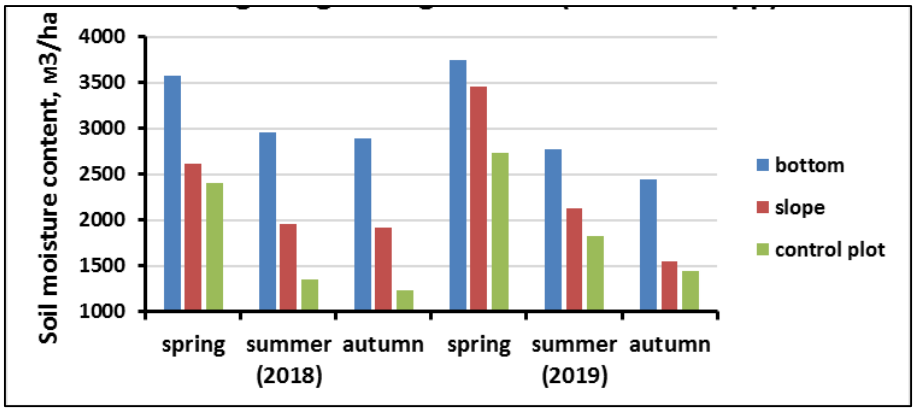

Figure 4. Dynamics of moisture reserves in the soil of the bottom, slope of the pothole (microdepressions) and on the plain (control) in 2018-2019.

The water regime of the soils of the experimental field changed significantly in 2019. After a warm winter, snowmelt began in early March with unfrozen soil and a gradual increase in temperature. Moisture on the plain and slopes was absorbed into the soil, and at the bottom of the depressions, snow accumulated over the 2019 winter still remained (Figure 2).

Figure 5. Physiological state of plants within the C-1 pothole, 19.06.2018 (from left to right, T1- bottom, T2 - slope, T3 - plain)

As a result, although there was no flooding of depressions, the moisture reserves in all morphological elements were large (Figure 4, 2019), which contributed to the good development of alfalfa. However, at the bottom of the depressions, alfalfa was completely replaced by weeds.

The condition of the vegetation cover is as follows: the bottom is alfalfa (cover 5-7%), the rest are weeds, the slope is cover 100%, height 55-60 cm; the plain - coating - 95%, height - up to 45 cm. During this period, the temperature regime was at the level of 21 ºC, and the amount of precipitation was approximately 25 mm. Already the first mowing of alfalfa amounted to approximately equal amounts on the plain and on the slopes of the lowering (42-45 t / ha of freshly cut green mass), and the weeds dominated in the lowering (Figure 5).

To illustrate the seasonal dynamics of alfalfa development in 2019, we present the traditional indicator of the vegetation index (NDVI) according to https://eos.com (Figure 6) and the results of the statistical processing of the results of its determination taking into account 4 cuttings of green mass during the growing season.

NDVI values for plants range from 0 to 1. In the middle of the season, the NDVI index can be used to determine how plants develop on the field. If the index values are medium and high (0.5-0.85), then, most likely, the agroecological state is within normal limits. If the index is low - it seems that something is missing from the plot, for example, moisture or nutrients.

Figure 6. Alfalfa vegetation index dynamics, 2019

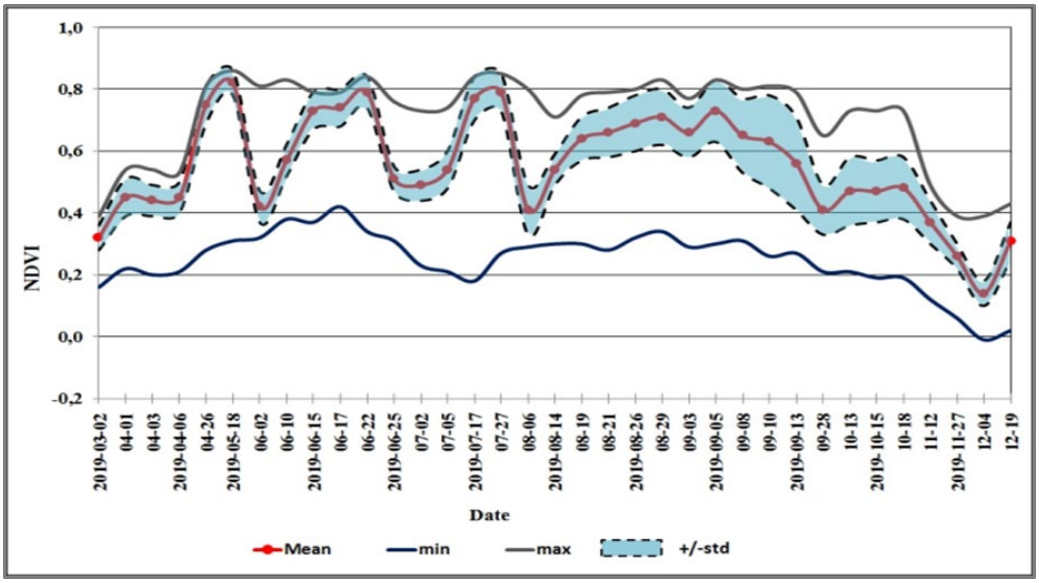

Figure 7. Annual dynamics of the vegetation index, taking into account 4 mowing of alfalfa (statistical analysis)

According to the NDVI index, recommendations are being formed for the differential application of nitrogen fertilizers. Based on the results of statistical processing (Figure 7), it is possible to identify

zones of high, medium and low vegetation for calculating the rate of fertilizers. Presumably, if the vegetation index in the plot is high, then the dose of fertilizers should be reduced by 10-30% of the average norm, if average, then increase - maximum by 20-25% of the average norm, if low, then first of all through field studies it is necessary to determine the cause of the poor state of the plants.

Conclusion

The results of the study indicate a high degree of heterogeneity of the soil cover of the Right-Bank Forest-Steppe and a peculiar water regime of soils on flat areas, in micro-depressions and even in nano-depressions. Based on our previous studies (Starodubtsev 2017; Starodubtsev *et al*., 2018; Vlasenko & Starodubtsev 2020) and the information provided in this article, we believe that spatial heterogeneity of the soil cover is an integral characteristic of its formation and functioning in the plain Forest-Steppe of Right-Bank Ukraine.

It is important to take into account the heterogeneity of the soil cover and the water regime of soils when conducting long-term (stationary) scientific research and when introducing precision farming systems. A two-year period of studying the features of the water regime and soil productivity during alfalfa cultivation showed that a significant redistribution of soil moisture occurs along the relief elements in the fields with microdepression. In spring, the moisture reserves in the meter-long layer on the bottom are 137-148% compared with the control, and on the slopes it is 108-126%, and the fluctuations in the values depend on the weather conditions of the year.

The yield of alfalfa green mass changes less significantly and ranges from 116 to 93% compared with the control. Spring flooding with thawed snow for more than 10 days leads to the complete death of alfalfa plants on the bottoms and its replacement by weed vegetation. That is, alfalfa, according to our two-year observations, is less resistant to flooding with thawed snow compared to winter wheat (Vlasenko & Starodubtsev, 2020)

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