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RESEARCH ARTICLE

# Ecologic and economic estimation of land productivity spatial heterogeneity in forest-steppe zone

V.M. Starodubtsev[1*] R.M. Basarab[1]

**Abstract:** The perspectives of the Sentinel-2 satellite imagery use for the ecological and economic assessment of land productivity spatial heterogeneity in territories with microrelief are analyzed. The duration of microdepressions ("potholes") flooding with melting waters on the winter wheat fields and the resulting decrease in yield have been established. A quantitative determination of the index of heterogeneity of land productivity and its application for the adjustment of the value of agricultural land in the sale and purchase transactions are proposed.

**Keywords:** land productivity, spatial heterogeneity, microdepression, satellite image

## 1 Introduction

The ecologic and economic assessment of land productivity spatial heterogeneity attracts scientific and practical interest. It became especially aggravated with the introduction of the so-called "precision farming" into practice, which requires new approaches to knowledge of soils and agricultural technologies for successful competitive farming. And in modern Ukraine, accurate knowledge of the soil cover, expressed quantitatively, is also necessary taking into account the needs of a market economy. After all, the problem of buying and selling the most valuable natural resource of Ukraine land is already overdue.

Previous environmental studies of the spatial heterogeneity problems of the soil cover and land productivity in the Forest-Steppe of Ukraine mainly examined differences in soil lithology, their particle size distribution, organic matter content, agrochemical properties and other features.[1,3] But in fact, here on the flat plains, the soils of microdepressions are formed under the impact of overwetting (and even short-term flooding) with atmospheric precipitation, primarily with meltwater in spring. The distinctive processes in soils of such depressions are, first of all, leaching of carbonates and other products of soil formation, as well as gleying. Agrochemicals and industrial pollutants penetrate with filtered water to a considerable depth (in our case - to groundwater at a depth of 4-5 m) as well.[1,2] And with descending streams of moisture, particles of the solid phase of the soil are also transferred, as a result of which these microdepressions exist for centuries, despite the annual influx of water erosion products into them and even for planning works (leveling the field surface). For the practice of agriculture, the most important consequence of the microdepressions existence in the relief and the spatial heterogeneity of the soil cover caused by them is the heterogeneity of such lands productivity that we study, which affects their value.

## 2 Materials and methods

The object of research is the formation of land productivity spatial heterogeneity due to the specific water regime of soils in fields with microdepressions in the area of typical chernozem (black soils) of the Right-Bank Forest-Steppe of Ukraine. Experiments were conducted in 2017-2018 in research facilities of NUBiP of Ukraine in the Kiev region. Methodically, they represent the final stage of longer-term studies, including ground-based studies of soil cover on fields with microdepressions (2008-2015), monitoring of the crops condition and soil productivity in 2016-2017, using unmanned aerial vehicles (UAVs), remote sensing of winter wheat sowings with Sentinel 2A and 2B satellites.

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* **Correspondence to**: V.M. Starodubtsev, National University of Life and Environmental Sciences of Ukraine, Kiev, Ukraine; Email: Starodubtsev@voliacable.com
[1] National University of Life and Environmental Sciences of Ukraine, Kiev, Ukraine

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## 3 Results

The critical period for assessing the spatial heterogeneity of the water regime and soil productivity are the first weeks after melting of the snow cover and filling the relief microdepressions with water[1–4] . Therefore, we analyzed images of Sentinel for the period after April 2, 2018, when intensive snow melting began in the fields. The first available image for April 8, 2018 (Figures 1), that is, 6 days after snowmelt, clearly showed the filling with thawed water of deep (50-100 cm) and medium (30-50 cm) relief depressions in a field with winter wheat. And the small depressions (20-30 cm), filled with melt water, turned out to be hardly noticeable due to the general moisture saturation of the surface layer of the soil. The image contrast increased dramatically in the image for April 18, 2018 (Figures 1, in the middle), that is, 16 days after snow melt, when the soil began to dry in even areas of the field.

The deep depressions at that time were filled with water, in the middle depressions the melt water was still on their bottoms, and the shallow ones differed in greater soil moisture compared to even areas. Subsequently, water was consumed for evaporation from the surface, filtration deep into the soil, and for transpiration by preserved wheat plants. After 3 weeks with no rains, melt water was observed only at the bottom of the deepest depressions, and after 4 weeks (Fig. 1, below) it was no longer on the soil surface[1–4] . But in the deep depressions, the wheat plants were already dead or were severely depressed.

Observations in the previous (2017) year on a field with winter wheat also confirmed that melt water remains on the surface of soils in shallow relief depressions for approximately 1 week, in medium (2 weeks), and in deep ones (3 weeks), maximum (4 weeks). This is well illustrated by images[1,3] made by a quadrocopter (UAV) on the second day after intense snowmelt (Figures 2) and after 3 weeks (Figures 3).

To assess the impact of microdepressions flooding with meltwater on the state of winter wheat plants in April 2018, the NDVI index was also determined, showing the spatial distribution of plant mass in the field. In the deepest depressions during prolonged flooding, the plant mass decreased to 5–30% in comparison with even areas. And in the remaining parts of the field, the inhibition of wheat shoots weakened with a decrease in the depth and duration of flooding. Later on, during the growing season, the development of wheat plants was partially restored, but the plants on the bottom and slopes of the depressions ripened more slowly and the grain remained immature for harvesting.

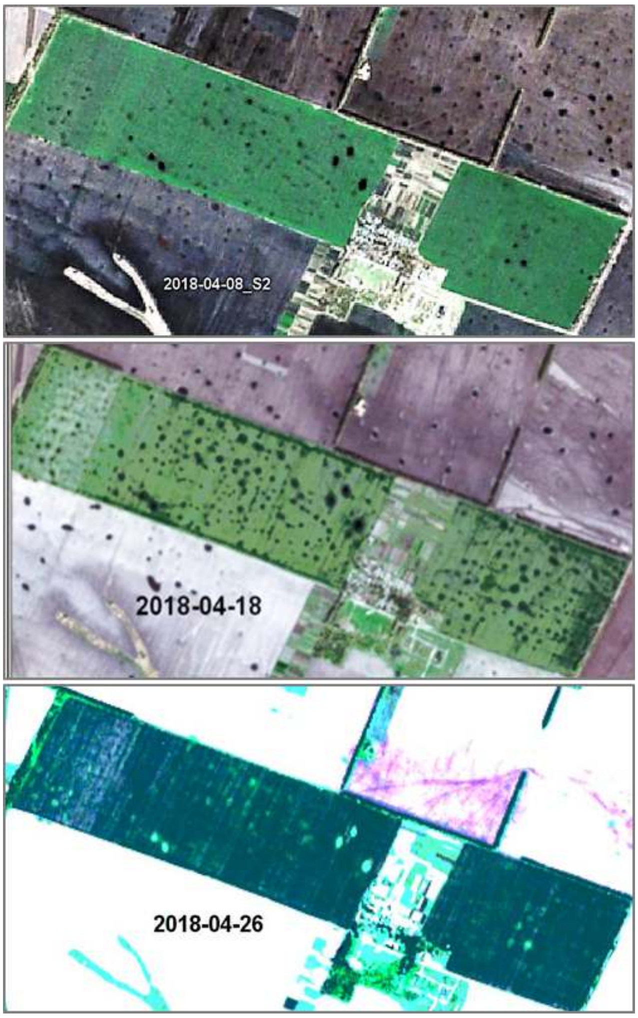


**Figure 1.** Sentinel-2 images of the experimental field for April 8 (above), April 18 (in the middle) and April 26, 2018 (below)

**Figure 2.** Flooding of microdepressions with melt water on a field with shoots of winter wheat on April 2, 2017

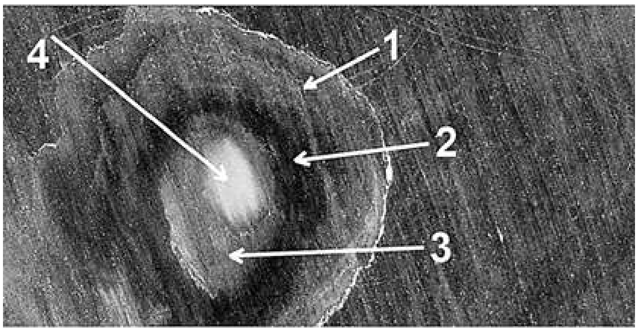


**Figure 3.** The effect of the duration in the winter wheat flooding by meltwater in the microdepression: 1. weak depression after 1 week of flooding; 2. moderate depression after 2 weeks; 3. severe depression after 3 weeks of flooding; 4. water at the bottom of the depression

In order to assess the real losses of the winter wheat crop in micro-depressions of the relief, the crop was counted using the meter method in 4-8 replications. In our previous study,[4] in deep depressions (50-100 cm), the crop averaged 33% of the yield in flat areas of the field (control), in medium depressions (30-50 cm) with 71%, and in shallow (20 -30 cm) with 84%. In general, the "shortage" (decrease) of the crop in the fields with microdepression was (Figures 4)

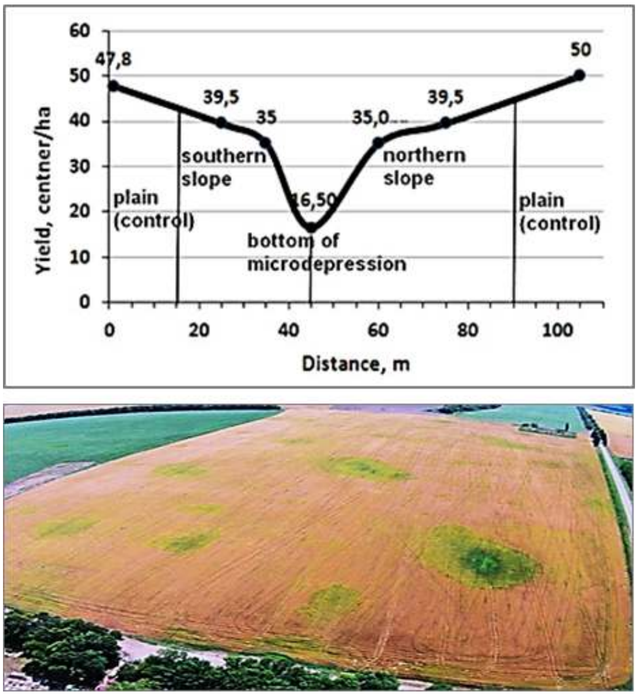


**Figure 4.** Wheat crop in microdepression and general view of the field before harvesting

Taking into account the obtained results the necessity and possibility of determining and mapping areas of microdepressions with different depths in the fields of the Right-Bank Forest-Steppe with chernozem soils became very important. For this purpose, it was proposed to analyze Sentinel-2 satellite images of the fields with winter wheat crops no later than 2 weeks after the start of intensive snowmelt. Such an analysis (Figures 5) made it possible to determine the areas of microdepressions of different depths in the field under study.

On the area of 180 hectares, deep depressions (50-100 cm) occupy 19.2 hectares or 10.7%, medium (30-50 cm) with 31.8 hectares or 17.7%, and shallow (20-30 cm) with 44.2 hectares or 24.6%.

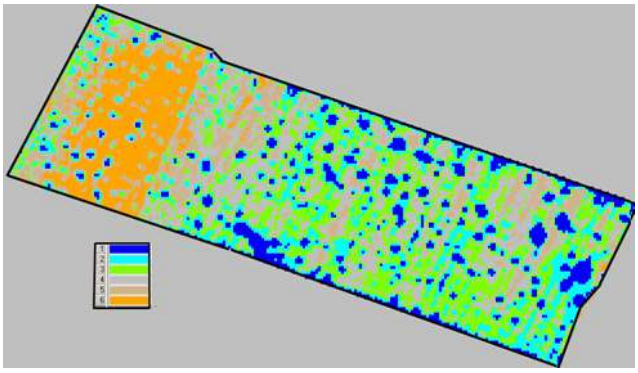

**Figure 5.** Classification of the relief microdepressions on the field under study with the ERDAS imagine program: 1. deep depressions (50-100 cm); 2. medium (30-50 cm); 3. shallow (20-30 cm); 4-6. relatively flat sections

The data obtained allow us to calculate the proposed **"field heterogeneity index"** according to the microrelief conditions (Equation 1):

$$\mathbf{I_{hf}} = \frac{\mathbf{S_{md}}}{\mathbf{S_f}} \tag{1}$$

where: $\mathbf{I}_{hf}$: index of field heterogeneity; $\mathbf{S}_{md}$: micro depressions area; $\mathbf{S}_f$: total field area.

In this area, the field heterogeneity index was 0.53, that is, 53% of the area is occupied by microdepressions with different depths, and only 47% is occupied by a flat area where there is no spring flooding with melt water and a corresponding decrease in winter wheat yields. We consider it expedient to draw up maps of field heterogeneity, reflecting spatial heterogeneity of land productivity in the area of growing winter wheat. And taking into account the results of our studies of microdepressions' soil[1] in fields with a predominance of typical chernozem, we propose to calculate the "**soil cover heterogeneity index**" according to the formula (Equation 2):

$$\mathbf{Ihs} = \frac{\mathbf{Sps}}{\mathbf{Sts}} \tag{2}$$

where: **Ihs**: index of the soil cover heterogeneity; **Sps** - area of the prevailing soil; **Sts** - total field area.

Naturally, as empirical data are accumulated, the calculation of both indicators will be further improved, taking into account the share "weight" of the components included in **Smd** and **Sts**.

The results obtained also make it possible to calculate the real soil productivity of flat land plots in fields with pronounced microrelief, when production data are available on gross grain yield and average yield. In such cases, it is recommended to do the calculation using Equation 3:

$$\text{Yf} = \frac{Yp \times (S1 \times \text{K1} + \text{S2} \times \text{K2} + \text{S3} \times \text{K3} + \text{K4} \times \text{S4})}{(S1 + S2 + S3 + S4)} \tag{3}$$

where: **Yf**: actual average yield**Yp**: yield of flat areas; **S1, S2, S3, S4**: areas of flat plots, shallow, medium and deep depressions; **K1, K2, K3, K4**: yield reduction ratios: (K1 = 1.00; K2 = 0.84; K3 = 0.71; K4 = 0.33).

In the field under study, where winter wheat was grown in 2018 using the bacterial fertilizer Extrakon, which was developed and introduced by Professor Patyka NV, the average yield was 71 centners per hectare. The calculation by the proposed equation allows us to determine that the real yield on flat plots was 84.1 centners per hectare, that is, 13.1 centners per hectare more. And in shallow micro-depressions of the relief, it was 70.6 centners per hectare, in medium (59.7 centners per hectare, and in the deep ones (only 27.7 centners per hectare). Consequently, due to the peculiarities of the water regime of the soil, micro-depressions in this field alone collected 236 tons of wheat less than would be potentially possible in accordance with the effective fertility of chernozem soils. In general, for farms of Right-Bank Ukraine, this factor is very significant and should be taken into account when determining the price of land, depending on the quantitative assessment of the microdepressions of the relief presence on specific fields. And in the mapping of the lands of this region in accordance with the index of spatial heterogeneity of their productivity, the authors are ready to assist farms on a contractual basis.

## 4 Conclusions

(1) Satellite images of Sentinel-2a and 2b are promising for assessing the spatial heterogeneity of land productivity with well-marked microrelief.

(2) The optimal time for these satellites to probe the surface of fields with winter wheat sowing is 2 weeks after the onset of intense snowmelt and flooding of microdepressions with melt water.

(3) Joint ground-based, airborne (UAV) studies and remote sensing determined the average duration of flooding with melt water in micro-depressions with winter wheat crops, depending on their depth: shallow depressions (20-30 cm) flooded on average for 1 week, medium (30- 50 cm) with 2 weeks, deep (50-100 cm) with 3 weeks.

(4) The coefficients of the winter wheat yield decreasing in micro-depressions were determined empirically, taking into account their depth and duration of flooding. The yield total decrease in fields with micro-depressions is estimated at 1.3 t/ha.

(5) The index of spatial heterogeneity of field productivity (Ihf) is proposed for a quantitative assessment of such heterogeneity according to the equation **Ihf = Smd/Sf,** where **Smd** is the area of microdepressions, **Sf** is the total area of the field.

(6) To assess the complexity of the soil cover of fields with microdepressions, a calculation of the "soil heterogeneity index" **(Ihs)** was proposed at a certain taxonomic level of soil classification: **Ihs = Sps/Sts**, where **Sps** is the area of prevailing soil, **Sts** is the total area of the field.

(7) A method is proposed for estimating wheat yield in micro-depressions with different depths according to the average yield determined from the gross grain harvest and empirical coefficients of yield reduction in them (Equation 3).

(8) It is recommended to use the "productivity spatial heterogeneity index of the field" to adjust the price of agricultural land for the sale and purchase. To do this, it is advisable to carry out mapping of the flat areas of the Forest-Steppe of Ukraine according to this indicator.

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