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OBSERVATION OF CONSEQUENCES OF SEWAGE SLUDGE DISPOSAL BY VEGETATION MONITORING OF CULTIVATED ARABLE LAND

F. KOVÁCS – ZS. LADÁNYI – M. HEGEDŰS

Department of Physical Geography and Geoinformatics, University of Szeged

Abstract: To observe the effects of sewage sludge disposal on fields used for crop production, we planned a multi-year, high-resolution data collection. Considering plant growth, more detailed weekly (high) time resolution and high spatial resolution were also necessary. Sentinel-2 multispectral imaging satellites provide finer resolution and optical data with a 3-to-5-day revisiting period. The vegetation indices applied can be used to evaluate the photosynthetic activity of the plants. There are some detectable differences between the areas affected by the placement of sewage sludge and those that are not affected. The advantage of sewage sludge placement is that nutrient replenishment eliminated biomass production differences between the monitored quadrates containing similar plants.

Keywords: *sewage sludge, biomass production, Sentinel-2, spectral index*

1. INTRODUCTION

Crop production and agricultural management have a strong impact on the rate of charging of the soil. The humus content in the A horizon of Chernozem soils in the Great Hungarian Plain may have been 1.5–2 times as higher at the time of the beginning of farming (cca. 10,000 years before) than as the current 2–4%. A significant proportion of soils on arable land are exposed to severe pressures, possibly showing signs of chemical and physical degradation, one of the main reasons for which is intensive agriculture [1]. The yield of cultivated crops will be affected in the near future by the increasingly extreme weather caused by climate change [2]. Thus, preserving and improving soil fertility is of common interest.

There is still a lack of a coherent strategy in the European Union regarding sewage sludge use in agriculture. There are several approaches to sewage sludge treatment, and many of them have targeted agricultural use [3, 4]. The agricultural use of sewage sludge is one means of nutrient supply. Valuable components can be recycled into the soils: organic matter, nitrogen, phosphorus and other plant nutrients [5]. The amount of sewage sludge is increasing with the progress of sewage disposal and treatment programs, and the safe use of this amount is also a problem, which is regulated in Hungary by Government Regulation 50/2001. (IV. 3.) and the Decree 36/2006. (V. 18.). Due to the extra nutrients in the sludge free of toxic substances, the development of the plants becomes more balanced, yield can increase and crop quality also improves. However, changes in the quality and quantity of organic matter in soils are slow, and soil improvement can be a long process [6].

To observe the effects of sewage sludge disposal on fields used for crop production, we planned a multi-year, high-resolution data collection. Considering plant growth, we aimed to achieve a more detailed weekly time resolution as well as high spatial resolution. The evaluation of the impact of the regular sewage sludge disposal on agricultural land based on biomass production was carried out for each land parcel based on the data and methods of multispectral remote sensing for the period of 2016, 2017, 2018 [7, 8].

Our further research aimed at more detailed, longer-term and higher time resolution impact assessment on different agricultural land parcels in a sample area of south-eastern Hungary. Using the SENTINEL-2 satellite images, the highest temporal and spatial resolution were applied for data collection. Our preliminary assumption suggests that crops under sewage sludge field application develop more dynamically. The process is, of course, complex, as land use changes and meteorological / climatological parameters influencing plant development also have to be considered.

2. DATA AND METHODS

The study area is located in the lowland interfluve area between the Körös River and Maros River, in the territory of Újkígyós settlement *(Figure 1)*.

Figure 1
The location of the soil quadrates (1t–10t) in the study area and the land cover changes in the period 2016–2019

The area, formed by fluvial and eolian processes, belongs to the Körös River Catchment. The static groundwater level was measured at 2 m below the surface. It has an extent of 5.6 hectares where 2.5 m^3/ha/year of treated municipal sewage has been applied regularly in autumn since 2013 on Chernozem and meadow Chernozem soils. Soil sampling was carried out in quadrats of 50 × 50 m^2 in the area, where 1t–4t were continuously treated areas. Quadrats 6t-7t are partly control areas, sewage sludge was deposited here only in 2018, while 9t-10t were control areas not treated with sewage sludge *(Table 1)*. The land coverage of the 1t–4t quadrats always differed from the 6t-7t and 9t-10t quadrats between 2017–2019. The biomass production of the 1t–4t quadrats can be distinguished from the others during the monitoring, and the values of 6t-7t and 9t-10t can be compared with each other depending on the time of sewage sludge placement.

Table 1

Crops produced in the quadrates and the sewage sludge placements

quadrats /year	**2016**	**2017**	**2018**	**2019**	**sewage sludge placement**
1t	maize	oil radish	winter wheat	colza	2017 autumn
2t	maize	oil radish	winter wheat	colza	2017 autumn
3t	maize	oil radish	winter wheat	colza	2017 autumn
4t	maize	oil radish	winter wheat	colza	2017 autumn
6t	colza	maize	maize	winter wheat	2018 autumn
7t	colza	maize	maize	winter wheat	2018 autumn
9t	sunflower	maize	maize	winter wheat	–
10t	sunflower	maize	maize	winter wheat	–

In addition to the scientific, agricultural applications of satellite remote sensing – eg. drought monitoring [9, 10] – new users are already increasing the number of drone applications based on business and agricultural economics. The high spatial resolution required by detailed land parcel-based surveys assumes the use of aerial imagery or very high-resolution satellite imagery, but their use is very expensive if we intend to comply with the very high time resolution required by the monitoring.

Free downloadable remote sensing data such as from LANDSAT is also applicable [11], but cannot alone supply good temporal resolution, which hardly allows plot scale evaluation of crop development in Hungary. The Sentinel-2 multispectral instrument (MSI) with refined spatial resolution allows for improved and accurate monitoring of the effect of sewage sludge with the presence of red-edge bands, which are not present in freely available multispectral sensors and whichwidens the spectral windows, for instance the heavy metal stress discrimination at broader scales [12] Sentinel-2 multispectral imaging satellites provide finer resolution and optical data with a 3-to-5-day revisiting period *(Table 2).* In the first period in 2016, only the Sentinel-2A satellite was in orbit and just the Level 1C (L1C) data product was available for download. In 2017, 2018, nd 2019 data from Sentinel-2A and -2B, at Level 2A (L2A, Bottom-of-Atmosphere (BoA) reflectance values) also became accessible. In the Sentinel-2 granule system, the study area is fully covered by one 100 × 100 km tile: 34TDS.

Only cloud-free images with atmospheric correction were evaluated (altogether 81 images). All available images in the vegetation period were used, which meant numerous images, mainly in 2018. Despite the high time resolution, we did not have data for July 2016 or May 2019 due to cloud coverage. We also used images from March to replace the fewer spring images.

Table 2

Sentinel-2 multispectral image parameters and database

Satellite / Sensor	**Multispectral imagery**	**Applied spectral bands central wavelengths**	**Spatial resolution**
Sentinel-2A / 2B	20 images / 2016 14 images / 2017 29 images / 2018 18 images / 2019	B2: 492.4 / 492.1 nm B4: 664.6 / 664.9 nm B8: 832.8 / 832.9 nm	10 m

The main application of multispectral remote sensing is the efficient observation of vegetation. Satellite images provide a cost-effective way of assessing the spatial and temporal patterns of biomass productivity by extracting vegetation indices. The NDVI and EVI vegetation indices applied can be used to evaluate the photosynthetic activity of the plants and the changes in biomass mass [13] (Equations 1, 2).

$$\mathrm{NDVI} = \frac{\mathrm{NIR-Red}}{\mathrm{NIR+Red}} \tag{1}$$

$$\mathrm{EVI} = \mathrm{G} * \frac{\mathrm{NIR-Red}}{\mathrm{NIR+C_1*Red+C_2*Blue+L}} \tag{2}$$

where NIR indicates the near infrared band, Red indicates the visible red band, Blue indicates visible blue band, L = 1, C_1= 6, C_2 = 7.5, and G = 2.5.

At a resolution of 10 m, there were few pixels in the area of sample quadrats (approximately 25 pixels/quadrat), which is why possible defective pixels may be more distorted. Insufficiently detailed time data density can make it difficult to compare results from different years.

The studied years had different weather conditions *(Figure 2)*. The investigated years show different distribution of precipitation. During the growing season, the average rainfall is approximately 340 mm and the average temperature is 17.3 °C. 2019 was very extreme, as in May there was twice the amount of precipitation compared to the general average, however, in March, there was hardly any precipitation. Higher precipitation values were in June of 2016 and in March of 2018. 2017 was the driest year and 2018 was the warmest year.

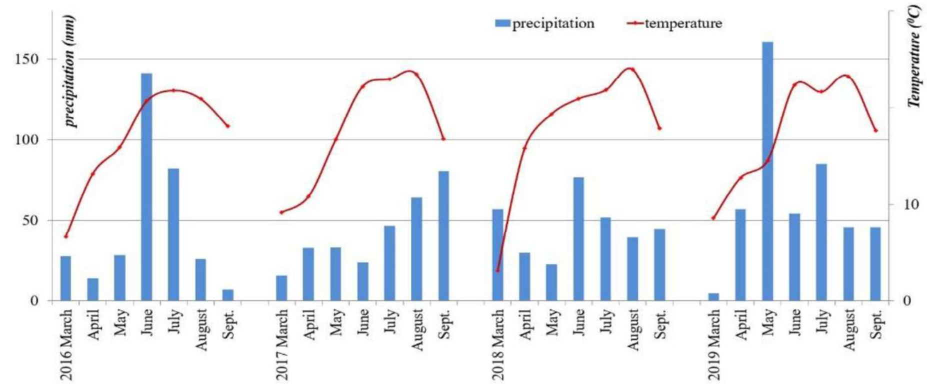

Figure 2

Temperature and precipitation for the study area (Békéscsaba station) between 2016–2019

3. RESULTS AND DISCUSSION

The differences in the vegetation development of the plant types and in the land cover can be clearly seen in the vegetation index values derived from the images (*Figures 3* and *4*). Land use changes can also be detected (see *Figure. 1* and *Table 1*). The 1t–4t quadrats were always characterized by similar land use: they were covered by oil radish in 2017 and by winter wheat from 2018. Quadrats 6t-7t and 9t-10t also had similar land use, except for 2016; maize in 2017 and 2018 and winter wheat in 2019. According to the EVI/NDVI values, in 2016 the majority of the area was characterized by crop production showing a peak biomass production in May-June (e.g. winter wheat, oil radish). The cereals started to develop as early as spring and were harvested by July; this can be seen in green curve in 2018 in Fig. 3. In 2017-18, half of the sample area (1t–4t) remained similar, but the other half changed to other production, when the EVI/NDVI maximum production was in July-August (e.g. maize). The corn later started to develop and was harvested in August; it can be seen in the green curve in 2018 in Fig. 3. The biomass production on all areas peaked by June in 2019, but two types of crops were recognized in quadrats 1t–4t and 6t-7t, 9t-10t. NDVI values were higher and more easily saturated on the rich vegetation area, but the increase in biomass production was well assessed with them. In several years, plant types could be better distinguished in the NDVI data set (e.g. 2016), but the EVI as an enhanced index reduced the impact of soil and atmosphere. The study confirms that there is no single best index, rather it is worth using them together in the evaluation; for instance the difference between EVI and NDVI values of the 6t-7t areas in 2016 and 2017 were spectacular.

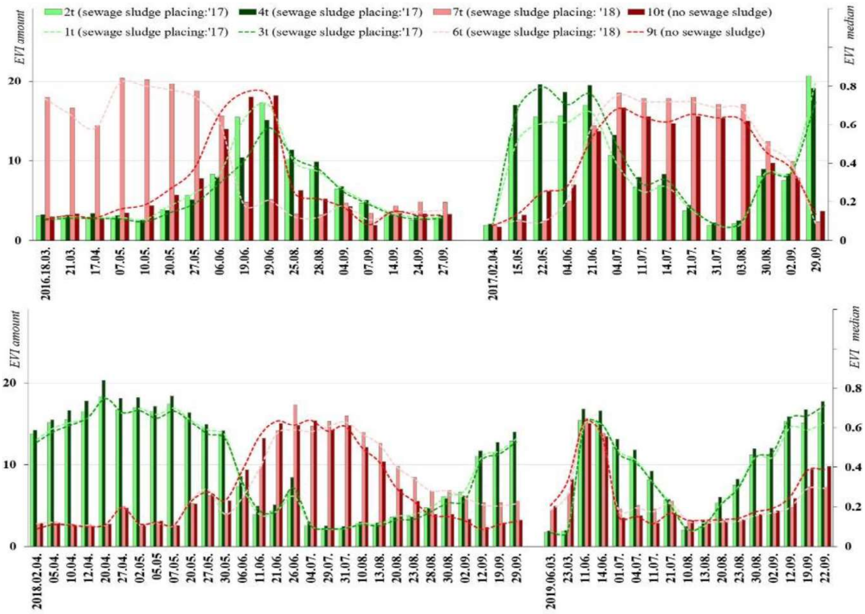

Figure 3

EVI values for all quadrat areas between 2016–2019
(dotted line is based on EVI median values, columns are EVI amount values)

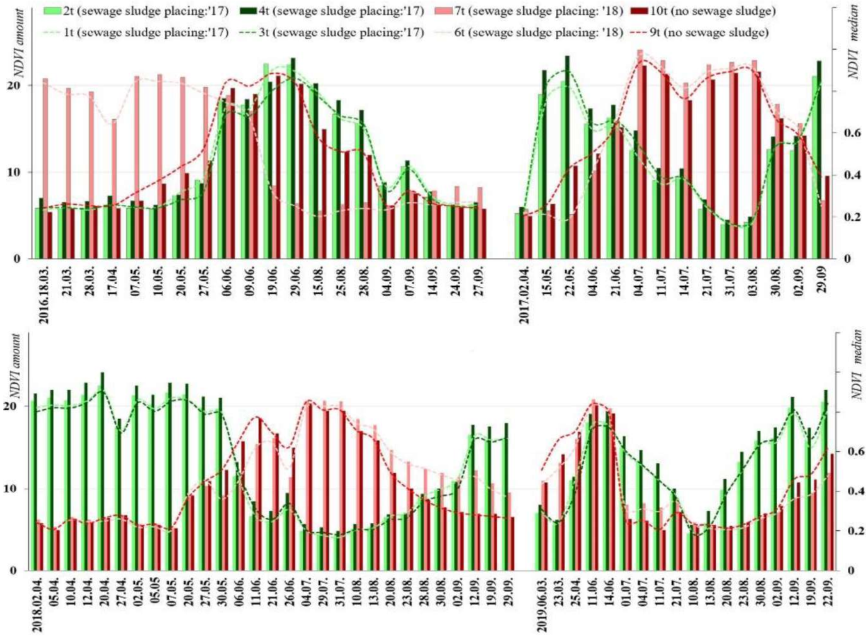

Figure 4

NDVI values for all quadrat areas between 2016–2019
(dotted line is based on NDVI median values, columns are NDVI amount values)

The effect of the 2017 placements is suggested by the NDVI values in 2018 in the 1t–4t quadrats, but this effect was contradicted by the high EVI values in 2016 in the 6t-7t quadrats. The profiles of the curves/columns after the placement of 2017 in the areas of 1t–4t became remarkably the same, which was not typical before. The advantage of sewage sludge placement was that it eliminated the differences in biomass production between quadrats containing similar crops by replenishing nutrients on monthly average images (*Figure 5* and *Figure 6*). The same can be observed in 2019 for quadrats 6t-7t, where there was sewage sludge placement in 2018.

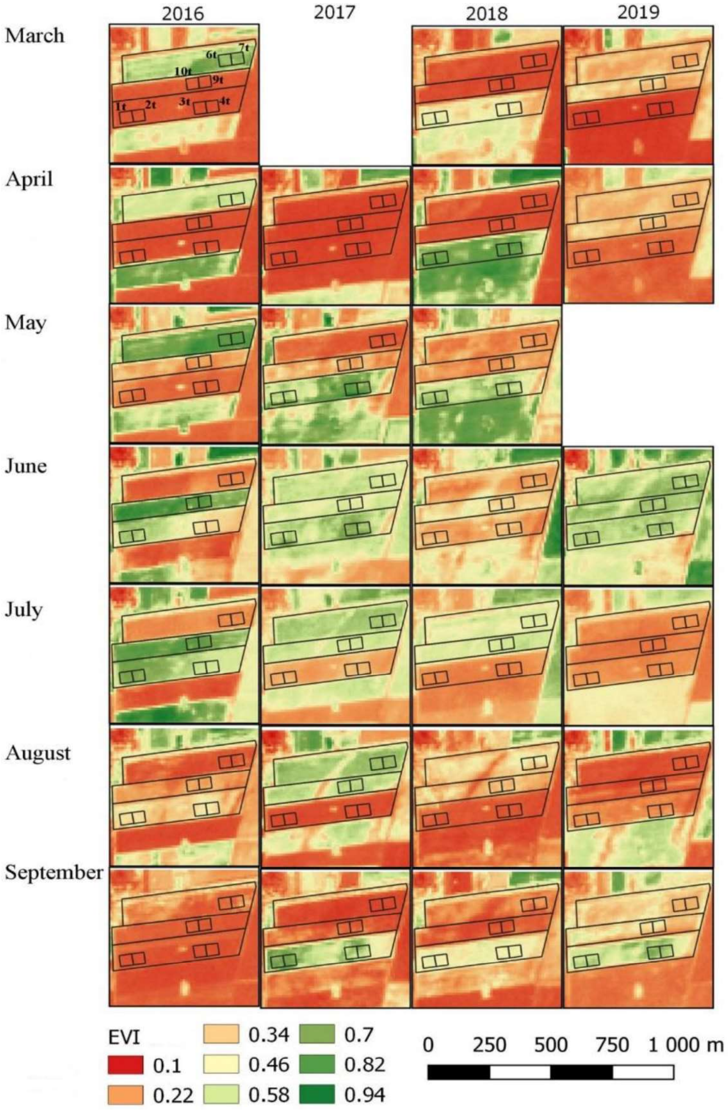

Figure 5
Vegetation production evaluated by EVI, 2016–2019

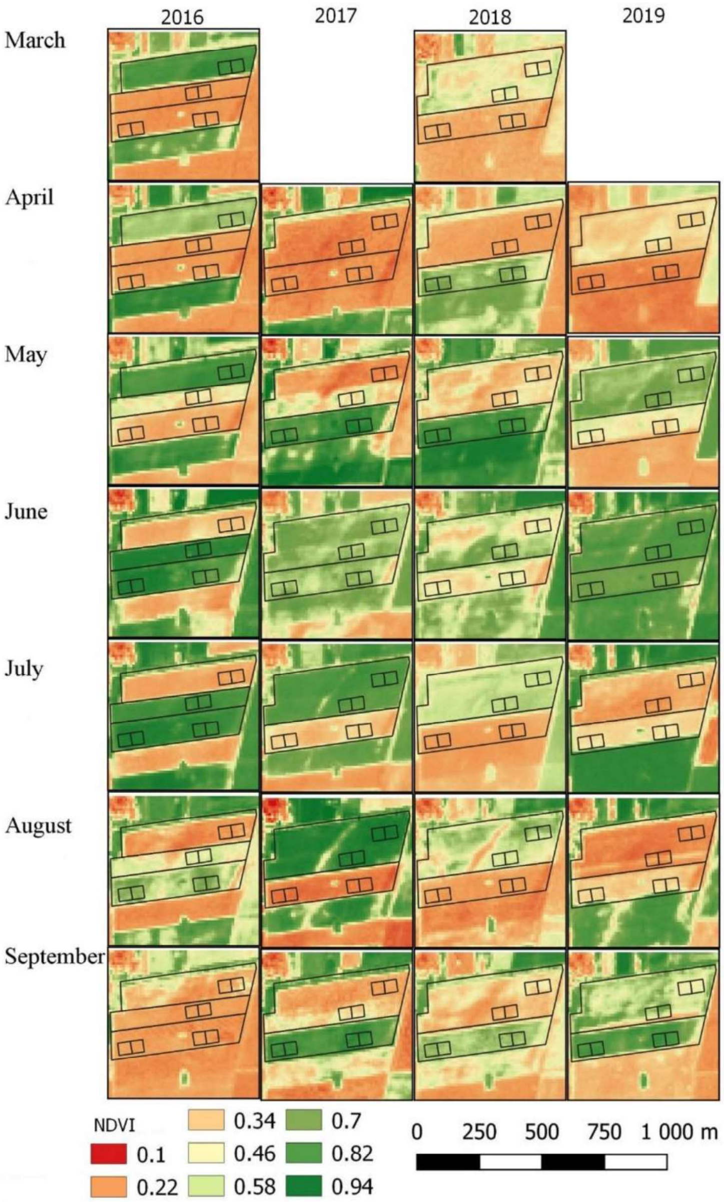

Figure 6
Vegetation production evaluated by NDVI, 2016–2019

When looking only in terms of peak values of biomass production on the 1t–4t quadrates, considering the placement in 2017 and changes in the crops produced, the data of the previous year were higher between 2016 and 2017. Assuming the same crop production between 2018–2019, the yield of 2019 showed values of 1.2–2.6 times, which also exceeded the production in 2017 recorded at the same time; here biomass production increased after the field application of sewage sludge. This is reinforced by the fact that the index values for 2017 started with higher values than in the previous year, at higher temperatures and nearly equal precipitation values; excess nutrients from placement may also have played a role in the difference.

In the different biomass production periods of 6t-7t quadrats we experienced the richest vegetation in 2016–2017 years, up to 1.4 times more than in 2018. Between 2016 and 2019, the August-September period was comparable; here the actual values were somewhat higher, with a difference of up to 1.5 times. The impact of sewage sludge application is therefore noticeable, but we will need the data from 2020 to further verify this. Contrary to our expectations, the index values were higher in the 9t-10t control quadrats where there was no sludge placement than for the 6t-7t quadrats, where land use was similar.

In particular, the arid summers of 2017 and 2018 showed the location of the ancient alluvial geomorphological forms; the geographical factors influencing even the small area are indirectly outlined on the basis of the different soil conditions of the forms. They also cause a significant difference in yield within a land parcel (*Figures 5* and *6*).

4. CONCLUSION

Our goal was to monitor the impact of sewage sludge disposal on the vegetation development of arable land crops. Both the NDVI and EVI indices performed well for this purpose, as expected. There are some detectable differences between the areas with placement of sewage sludge and those that without it. If there is a rainfall event the plants affected by the placement of sewage sludge will benefit more from it next time period; in the case of an extreme situation due to a lack of rainfall plants suffer a smaller decrease in biomass production than the untreated areas. The advantage of sewage sludge placement is that nutrient replenishment eliminated biomass production differences between the monitored quadrates containing similar plants.

To detect significant differences, we continue data collection; 36 LANDSAT OLI images will be also included in the observation. Due to the differences in the crops produced, in addition to the four studied years, 2020 will also be monitored.

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