

# COMPARISON OF SOIL MOISTURE INDICES AND FIELD MEASUREMENTS IN HILLY AGRICULTURAL LANDS OF SW HUNGARY

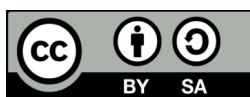
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## Abstract

The retention of surface runoff and the preservation of soil moisture are among the most important water-related ecosystem services. In addition to field monitoring, advanced remote sensing techniques have been devised to reveal soil moisture dynamics on agricultural land. In our study we compare two soil moisture indices, TWI and SAVI, in three agricultural areas with different land use types. The SAVI has been found suitable to point out spatial variation on the moisture conditions of the vadose zone.

**Keywords:** water stress, soil moisture dynamics, remote sensing, volumetric soil water content ( $\theta_v$ ), tension, Topographic Wetness Index (TWI), Soil Adjusted Vegetation Index (SAVI)

## 1. Introduction

Soil moisture content is an environmental property which is highly appreciated under the conditions of global climate change. In the Carpathian Basin climate change will primarily involve marked aridification trends (Meyer et al. 2017). On agricultural land water availability, in close interaction with other properties like soil structure, aeration, nutrient supply, soil reaction and microbial activity, is vital for crop cultivation (Rodríguez-Ituber & Poparto 2007, Várallyay 2015). In agriculture soil moisture can be preserved through optimized arable and grazing land management, minimal tillage or organic farming (Várallyay 2016; Eurlax Document 52017AE1814 2017). In the

landscape, different combination of land uses result in different soil moisture, hydrology, and other characteristics (see Ciglič and Nagy 2019 for some examples). Land use also influence ecosystem services (Riberio, Šmid Hribar 2019). The spatial pattern of soil moisture content depends on the land use mosaic, the quality of land cover, topography (slope inclination and exposure), the severity of soil erosion, texture and hydraulic conductivity of soil (Várallyay 2003, Pásztor et al. 2016).

Several approaches have been proposed for the estimation of soil moisture dynamics (Rodríguez-Ituber & Poparto 2007, Brocca et al. 2017). The common problem of field measurements, remote sensing detection and numerical modelling is the masking

effect of vegetation and land use which reduces spatial variation. Analyzing NDVI values, Nicolai-Shaw et al. (2017) found that at the peak of drought spells great anomalies of precipitation, temperature and evapotranspiration are observed, while the vegetation index values often show considerable delays. This time lag is probably due to the lack of information on soil moisture in the deeper root zone which is not properly detected by remote sensing. Thus, the water available for plants is generally underestimated. Variation in grasslands is usually greater than for forests. This may be related to the capability of trees to access moisture at greater depths and to store water under dry conditions. Yang et al. (2015) studied seven hillslopes on the Longtan catchment (Henan province, China) and found a positive correlation between the Topographic Wetness Index (TWI) and near-surface (0–1 m) soil moisture content and an inverse correlation with soil moisture at

depths below 2 m. In the deep layers biomass correlated negatively with soil moisture. Soil moisture stored in shallow horizons is obviously more dependent on topography. Gou et al. (2020) observed in the chernozem soils of Heilongjiang province of NE-China that land use type was more influential on soil moisture pattern in the deeper horizons than in the shallow horizons, while, in an opposite way, the impact of topography was less discernible in the deeper than in the surface horizons. Therefore, it is claimed that land use and topography jointly control soil moisture distribution at various depths.

The objective of our research was to compare the Soil Adjusted Vegetation Index (SAVI) and the Topographic Wetness Index (TWI) values with the measured soil moisture content change in three agricultural areas with different land use classes. This is a novel investigation in as much as no similar study has been made in the Transdanubian Hills.

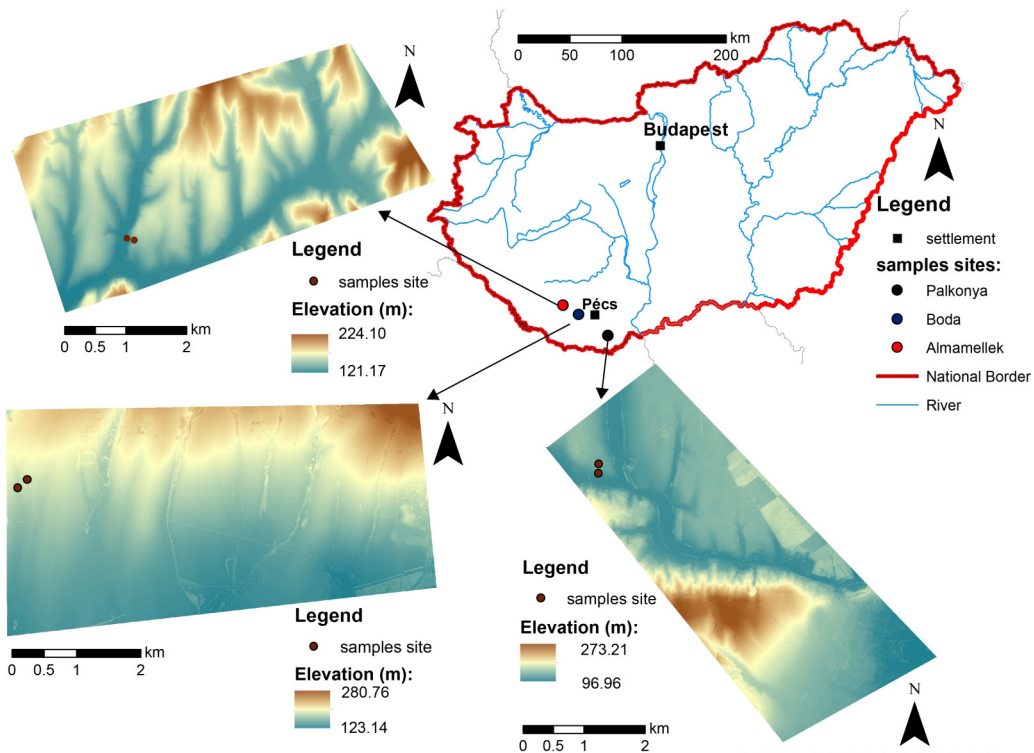


Fig. 1. Locations of study areas in SW Hungary

## 2. Methods

$$TWI = \ln(a/\tan \beta) \quad (\text{eq. 1})$$

### Location of study sites

For the investigation three study areas had been selected in the Transdanubian Hills: at the villages of Boda, Palkonya and Almamellék (Fig. 1). It is a region of semihumid continental climate modified by the climatic type of the year (whether continental, Atlantic or Mediterranean) and the orographic effect. Although in most years precipitation shows an increasing gradient towards the west, in 2019, when field measurements were made, rainfall totals showed a rather mosaic pattern with annual precipitations of 630, 770 and 830 mm in Boda, Almamellék and Palkonya, respectively. In all study areas slightly eroded brown forest soils (e.g., WRB: Endocalcic Luvisol) with clay illuviation and formed on loess parent material are typical (Szalai 2008). Soil depth typically ranges from 70 cm to 250 cm (Hervai et al. 2017). Average slope angle for the Boda and Almamellék areas is 4.24%, while for Palkonya it is 8.98%. Although all of the areas are agricultural lands, land use is different: arable farming at Boda, cherry orchard at Palkonya and grazing land at Almamellék.

### Monitoring system

To monitor moisture dynamics in the study areas over the growing season, at the top and bottom of slopes Teros 12 volumetric soil moisture sensors and Teros 21 tensiometers were placed at 10 and 30 cm depths in the topsoil. At the upper sites of measurement Decagon ECRN-100 tipping bucket rainfall gauges were installed to detect and quantify rainfall events.

### Calculating Topographic Wetness Index

The Topographic Wetness Index (TWI) is used to estimate the distribution of moisture in an area based solely on topographic conditions (Beven & Kirkby 1979). The TWI can be calculated from the Digital Elevation Model (DEM) using the following equation:

where  $a$  is upslope catchment area above the studied pixel ( $\text{m}^2$ ),  $\beta$  is slope inclination in degrees. TWI is a dimensionless number, ranging from 0 to 30. The SAGA GIS software was employed in its calculation.

### Remote sensing estimation of plant vegetation index

The various satellite systems scan the surface below with different number and width of bands. The detected signals inform about the state and changes (direction of ongoing processes) of the ground surface (Xue & Su 2017; Ladányi & Kovács 2010). The NDVI index relies on reflectance in the red (R) spectral band absorbed by chlorophyll molecules (at 580–680 nm wavelengths) and in the near infrared (NIR) band, where reflectance by plant cell structures is strong (at 725–1100 nm wavelengths) (Tucker 1979; Jackson et al. 1983; Justice et al. 1984). The NDVI is calculated from the following equation:

$$NDVI = \frac{NIR-R}{NIR+R} \quad (\text{eq. 2})$$

where R is the spectral reflectance of red visible light, NIR is the spectral reflectance of near infrared radiation. NDVI is dimensionless and ranges from -1.0 to +1.0. Typically, vegetation shows values between 0.1 and 0.7, the higher index values indicating higher photosynthetic activity and healthier plants.

The Soil Adjusted Vegetation Index (SAVI) is a modified version of the NDVI, which also accounts for the deviations deriving from soil brightness and colour (Huete 1989).

$$SAVI = \frac{(NIR-R)(1+L)}{(NIR+R+L)} \quad (\text{eq. 3})$$

The value of L ranges from 0 to 1. In practice the value of L is adjusted to environmental conditions. If vegetation cover is dense, it is close to 1, which shows that the soil background does not affect the photosynthetic activity of the vegetation.

However, this ideal situation rather rarely occurs in natural environment. Therefore, the SAVI index can only be applied if the foliage and vegetation cover are high (Major et al. 1990, Kaufman & Tanré 1992). Under most climatic and pedologic conditions the value of L is around 0.5: in this case the value of SAVI is close to 0 and is equal to the value of the NDVI (eq. 3 reduces to eq. 2). In general, however, an inverse relationship exists between the SAVI and the NDVI. Similarly, in most cases, the value of L is inversely proportional with the amount of vegetation to optimally adjust the soil influence.

For our investigation we used open-access ESA Sentinel-2 images with less than 10% cloud cover for the period between March 1, 2019 and June 31, 2020. The SAVI index was calculated using ArcGIS 10.4. software.

**Statistical analysis**

Results were evaluated through Spearman rank correlation:

$$r_s = 1 - \frac{\sum d_i^2}{n(n^2-1)} \quad (\text{eq. 4})$$

where n is the number of observed cases, d is the difference between two ranks of observations. Correlation values are

between -1 and 1, showing the intensity of the relationship between the two variables. Correlations between measured soil moisture content, tension and SAVI index values were analysed for the period from March 1, 2019 to May 31, 2020.

**3. Results**

The data from our monitoring system for the study period show that the measurement sites at the top slopes were wetter in all the three areas (Nagy et al. 2020). This finding contradicts the prediction from TWI, i.e. that soil moisture is higher at the base of slope. The TWI distribution indicates that the position of landscape elements on the slope influences moisture dynamics downslope (Fig. 2).

The analysis of SAVI values showed, independent of study period, that at Palkonya and Boda the top measurement sites had at least by 0.042 higher soil moisture than the bottom ones (Fig. 2). While at Almamellék the top site had a higher SAVI value in spring, in summer the bottom site had a higher SAVI index.

On the arable land of Boda the measured soil moisture showed a negative correlation

Table 1. Correlation between measured volumetric water contents ( $\theta_v$ ) and matric potential ( $\Psi_m$ ) and the SAVI at the Boda study site

	Top monitoring site				Bottom monitoring site			
	10 cm		30 cm		10 cm		30 cm	
	$\theta_v$	$\Psi_m$	$\theta_v$	$\Psi_m$	$\theta_v$	$\Psi_m$	$\theta_v$	$\Psi_m$
2019	<b>-0.750</b>	-0.571	-0.677	-0.563	<b>-0.942</b>	-0.778	-0.697	-0.061
2019-2020*	-0.087	<b>0.127</b>	0.088	0.077	0.281	0.656	<b>0.816</b>	0.720

\*predicted

Table 2. Correlation between measured volumetric water contents ( $\theta_v$ ) and matric potential ( $\Psi_m$ ) and the SAVI at Palkonya study site

	Top monitoring site				Bottom monitoring site			
	10 cm		30 cm		10 cm		30 cm	
	$\theta_v$	$\Psi_m$	$\theta_v$	$\Psi_m$	$\theta_v$	$\Psi_m$	$\theta_v$	$\Psi_m$
2019	<b>0.597</b>	0.259	0.696	0.525	<b>0.513</b>	0.201	0.486	0.417
2019-2020	-0.574	<b>-0.472</b>	-0.579	-0.318	-0.679	-0.317	<b>-0.632</b>	-0.306

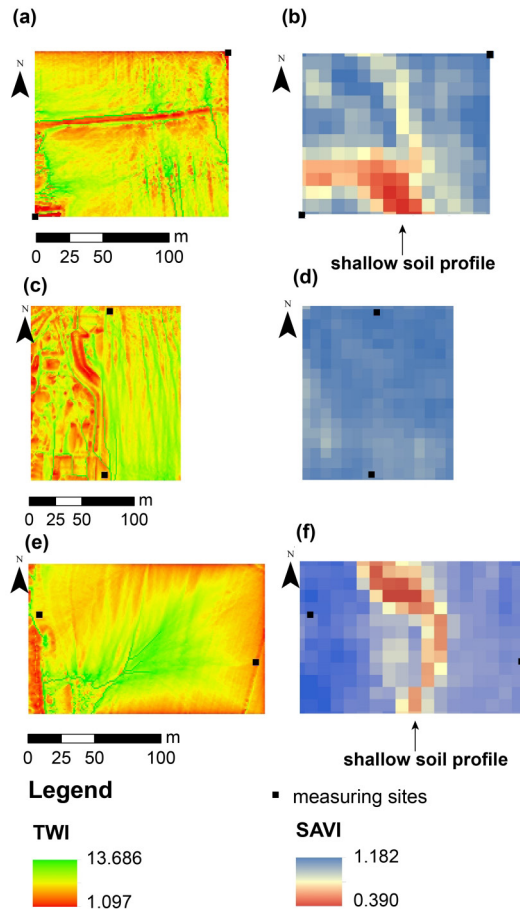


Fig. 2. TWI and SAVI indexes at the study sites. (a), TWI of Boda; (b) SAVI of Boda; (c), TWI of Palkonya; (d), SAVI of Palkonya; (e), TWI of Almamellék; (f), SAVI of Almamellék

with SAVI at both soil depths and for both positions of measurement sites in 2019. The correlation between volumetric water content ( $\theta_v$ ) and SAVI was  $r = -0.697$  for 2019. There is an inverse relationship between the two variables (Table 1), while tension was not linked to SAVI ( $r = -0.061$  at slope bottom and at 30 cm). Over the 2019–2020 measurement period there was strong correlation at the bottom site at 30 cm depth.

While the correlations between SAVI and  $\theta_v$  and between SAVI and tension are positive for Palkonya and for 2019, for the entire study period in 2019–2020 it is negative (Table 2). The strongest correlation was found between  $\theta_v$  and SAVI at 30 cm depth ( $r = 0.696$ ), while the weakest between tension and SAVI at

the bottom site at 10 cm depth ( $r = 0.201$ ) for 2019. Regarding the whole period, the strongest correlation was found between  $\theta_v$  and tension at the slope bottom site and at 10 cm depth ( $r = -0.679$ ) and the weakest also at the bottom site at 30 cm ( $r = -0.306$ ).

For the grazing land site of Almamellék no period with unambiguous positive correlation could be identified (Table 3). In the 2019 period at 30 cm depth of the upper measurement site a strong negative correlation was observed between SAVI and  $\theta_v$  ( $r = -0.899$ ) and a medium strong correlation at 30 cm depth of the lower measurement site between tension and SAVI ( $r = 0.729$ ). In the entire 2019–2020 period there was a very weak correlation between

Table 3. Correlation between measured volumetric water contents ( $\theta_v$ ) and matric potential ( $\Psi_m$ ) and the SAVI at the Almamellék study site

	Top monitoring site				Bottom monitoring site			
	10 cm		30 cm		10 cm		30 cm	
	$\theta_v$	$\Psi_m$	$\theta_v$	$\Psi_m$	$\theta_v$	$\Psi_m$	$\theta_v$	$\Psi_m$
2019	<b>-0.452</b>	-0.329	-0.899	-0.881	<b>0.467</b>	0.651	0.628	0.729
2019-2020	0.181	<b>-0.025</b>	0.291	0.125	0.136	0.174	<b>0.321</b>	0.149

SAVI and  $\theta_v$  for both measurement sites at 30 cm soil depth ( $r > 0.290$ ).

The correlations with SAVI were the strongest where the rhizosphere was more developed, like in the case of the cherry orchard in Palkonya. The SAVI best correlated with  $\theta_v$  at all three study sites.

When the phenological stages are considered, in spring, and especially in March, the soil is wet, but it is not reflected in the vegetation as it is not yet developed. April was (and is usually) particularly dry period of the year, hence soil moisture negatively correlated with the SAVI. In summer the deeper root zone was wet and the vegetation was green, but at a depth of 30 cm the correlation with the SAVI was positive.

#### 4. Discussion and conclusions

Our results support the view that vegetation and land use have a masking effect (Rodríguez-Ituber & Poparto 2007; Brocca et al. 2017) and apparently moderate differences in the actual distribution of soil moisture, particularly in the case of the SAVI for the Palkonya orchard. However, this observation is contradicted by findings in the arable and grassland areas, where the influence of shallow soil and outcropping loess is manifested in SAVI values (Fig. 2). This points to the origin of the masking effect in root development: the deeper roots find available water, the least it is reflected in SAVI values. This assumption supports the experience by Nicolai-Shaw et al. (2017) that the changes are often reflected in the vegetation indices with delay. They also warn that remotely sensed root-zone moisture data

are specific to plants. Partly in accordance, and partly opposed to Yang et al. (2015), we found positive correlation between the SAVI and the actual moisture contents at a depth of 10 cm, but inverse correlation at a depth of 30 cm.

According to Yang et al. (2015) the TWI positively correlated with near-surface soil moisture content (at 0–1 m). Our results only revealed positive correlation between TWI and  $\theta_v$  for the depth of 30 cm. This can probably be explained with the water retention capacity of anthropogenic landscape microelements (hedgerows, tree rows) and the infiltration induced by such elements (Syrbe – Grunewald 2017). Our results are in harmony with the claim by Guo et al. (2020) that land use class has a greater impact on the deeper root zone than on the surface layer. In areas where the vegetation had deeper reaching roots, we found higher SAVI values (above 1.102). Their other assumption that the impact of topography on the deeper layer was weaker than on the surface layer could also be confirmed. This phenomenon was particularly conspicuous where the soil was shallower and the SAVI value was less than 0.405.

According to our results the following conclusions have been drawn:

i. Temporarily a relationship between SAVI and soil moisture content can be observed and their correlation depends on the period of observation (the actual weather conditions of the growing season and the phenological phase).

ii. The SAVI is suitable to point out spatial variation of moisture conditions of the vadose zone. It is also capable to supply data

for precision farming algorithms on moisture dynamics, moisture conservation and water supplying capacities of the individual agricultural fields provided the same crop is grown on them in subsequent seasons.

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