Impact of land use types on soil moisture dynamics of loamy soils

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Abstract. In the last decades, drought has been a significant climate hazard in the Carpathian Basin. In this study, we investigated the soil moisture dynamics (SM) of three different land use types (pasture, ploughland, and orchard) in the Transdanubian Hills (SW Hungary). The soil moisture, matric potential and rainfall were measured between January 1, 2019 and February 28, 2023. Two monitoring stations were installed at each study site on the shoulder and at the toeslope positions. The study has revealed that the textural types of the study sites were silt loam, clay loam, and silt. The pasture had the most positive water balance, whereas the orchard had the most negative, especially in 2022 when trees were removed. The mean soil moisture values were 0.26, 0.21, and 0.21 for the pasture, ploughland and orchard for 10 cm, and 0.3, 0.22, and 0.22 for the pasture, ploughland and orchard for 30 cm, respectively. Moisture differences were relatively minor between the three sites, however, soil moisture dynamics were influenced by farming practices. Hence, site-specific mapping and analyses of factors responsible for efficient moisture retention are indispensable for the maximization of agricultural productivity and the optimization of the efficiency of ecosystem services. Our results could be used for the promotion of sustainable agricultural activities where loamy soils and subhumid continental climates prevail.

1 Introduction

Nowadays, climate change is one of the most important priorities for researchers, scientists, and policymakers. Impact of humans on ecosystem directly or indirectly, overuse of lands, agricultural intensification, and environmental pollutions are more noticeable than the past [1] One of the direct hydrological consequences of climate change is water stress soil moisture content (SMC) has a significant spatial variability and is controlled by several environmental factors, such as topography, land use/vegetation, climate change, and soil properties at different scales [2]. In the other hand, some meteorological factors like solar radiation, wind speed, and vapor deficit may also affect the rate of evaporation and transpiration (collectively called evapotranspiration) [3,4]. Due to the emission of greenhouse gases and deforestation, it is expected that the average temperature of the earth will increase by 1.5 degrees by 2050, whereas total rainfall, may decrease regionally. Increased temperature in the summer likely leads to higher evaporation and transpiration rates and the decline of soil moisture content [5].

Droughts impact the environment on a longer time scale than floods (often for years) but it can be controlled by integrated management as an important component of adapting to weather conditions [6,7].

Drought is one of the unavoidable natural hazards specially on Eastern and Southern Europe. Drought has diverse effects on human life, ecosystems, agricultural production, and tourism [8]. According to the Fourth and Fifth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC AR4 and AR5) expressed that in the 21st century, the increasing precipitation severity, floods, prolonged drought periods, high temperatures and heat waves will occur with the high probability in the near future. This pattern was demonstrated in Hungary in 2010 and 2011 with a back-to back recorded high and low annual precipitation totals. However, the conservation of water in the soil from the previous year in 2011 did not cause economic losses in cultivated crop yield [9,10]. Since the construction of massive structures such as dams is costly and harmful to the environment and ecosystem service, [11] the importance of flood control by natural processes has become evident. Consequently, water retention is a priority in floodplains. Among the main controlling factors of flood, the analysis of soil textural types, organic matter content, bulk density, slope, and vegetation have the greatest importance [9].

The key aim of the project is to provide data on moisture dynamics of silty and loamy soils and to find a sustainable land management practice under subhumid climate. The goal of this study is to show the influence of land use type and water retention on moisture dynamics from normal to dry seasons (2019-2022). According to our presumption, ploughlands should have a large evaporation loss and relatively low SMC. The

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contribution of this paper is to get data on the effect of three land use types on soil moisture dynamics.

2 Materials and methods

2.1 Study sites

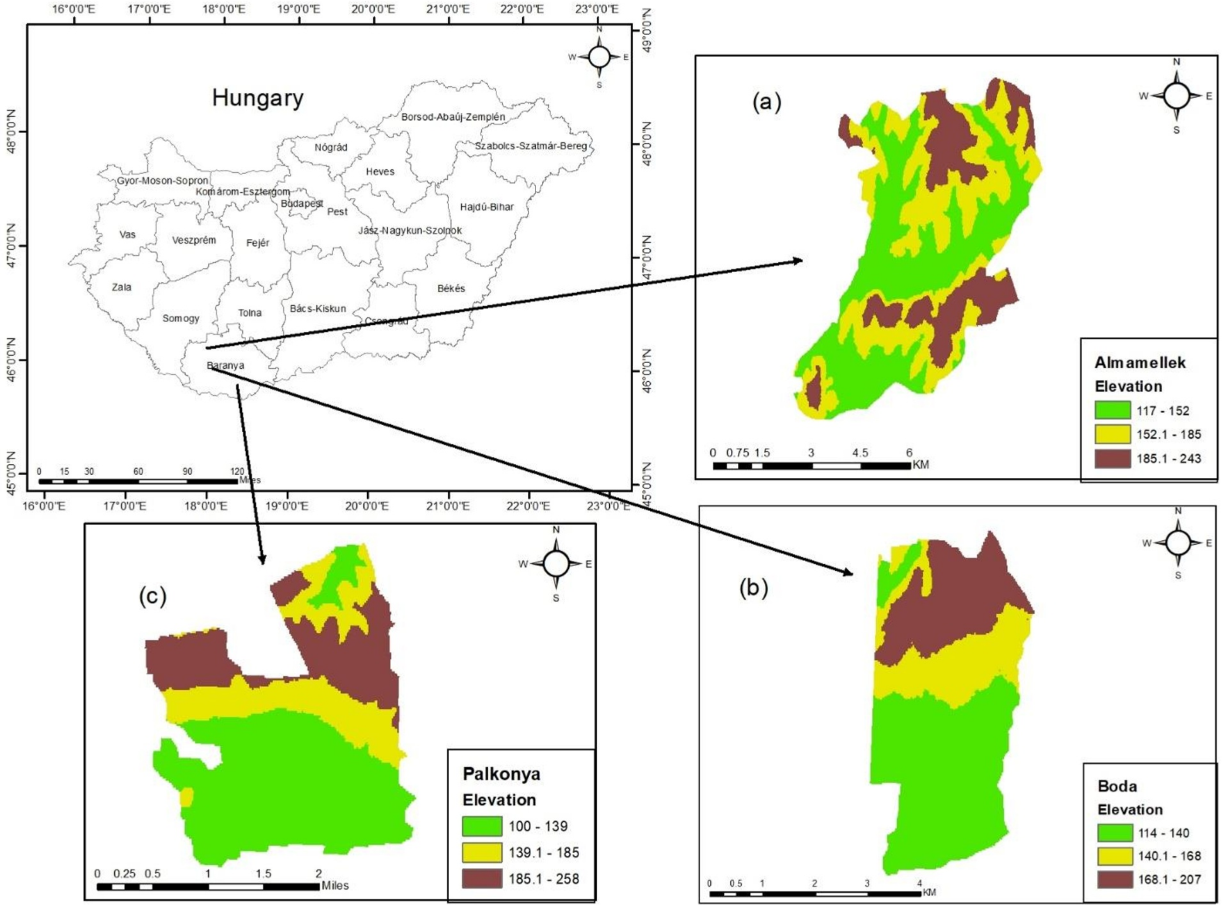

Fig. 1. Location of the study areas on the digital elevation model (DEM) generated from LiDAR survey. a: Almamellék (pasture), b: Boda (ploughland), c: Palkonya- Villánykövesd (orchard).

The three sites of interest are located in the Transdanubian Hills in SW Hungary in the vicinity of the city of Pécs: Palkonya (orchard), Almamellék (pasture), and Boda (ploughland) (Figure 1). All three sites are covered by loam and silt soils. Subhumid continental climate prevails at all sites.

2.1.1 Almamellék (Pasture)

This study area is located in the Zselic Hills, at an altitude between 130 m and 140 m. The mean slope is 5.92°, in the Almamellék area, and it reaches 9.7°, in the upper part of side site. According to the reports of Hungarian Agricultural Plot Registration Database [MePAR] shows medium to intensive water erosion. Meadows and grazing land are the types of land use in this location. The distance between the two monitoring stations is 167 m.

2.1.2 Boda (ploughland)

This zone under study is situated approximately 10 km to the west of Pécs, on the southwestern foothills of the Mecsek Mountains, sloping gently away from the Pécs basin half-basin, west of the village of Boda. The elevation between toeslope and shoulder site is 172 and 182 m, respectively. Majority of the land is cultivated with conventional tillage, growing sunflowers, soybeans, sugar beet, cereals, and rape seeds. The distance between the two monitoring stations is 190 m. A erosional valley and an erosional stream with a small grove in the lower part of the site have a profound effect on the moisture dynamics of the site.

2.1.3 Palkonya (orchard)

The third study area is on the northwest foreland of the Villány Hills, at the southern edge of the village of Palkonya. Cherry trees were grown here as a kind of land utilization. Like at the other two sites, parent material for the soil here is Pleistocene loess. The elevation of the lower and upper parts is 175 m and 182.7 m above sea level, respectively. The average slope is 8.98 percent. Grazing land is the land use type at this site. The distance between the two monitoring stations was 156 m.

2.2 Field monitoring

To monitor soil moisture content (SM) and matric potential TDR sensors and tensiometers (all manufactured by Meter Group Inc.) at two locations at each site at depths of 10 and 30 cm in December 2018.

The tipping-bucket rain gauge (ECRN-100, Meter Group, Pullman, WA, USA) was to measure rainfall totals and intensities at a resolution of 0.3 mm. Prior to being put into service, TDR sensors had been calibrated in a lab. EM-60 data loggers were used to record data in 15- minutes intervals.

2.3 Determination of soil texture

Soil samples were pretreated prior to grain size measurements by removing, organic matter (OM) and calcium carbonate (CaCO3) using H2O2 and 10% HCL, respectively. Grain size distribution was measured with static light scattering using a Malven Mastersizer 3000 particle size analyzer (Malvern Inc., Malvern, England, United Kingdom).

2.4 Calculation of Aridity index

Using data from the Hydrographic and Database Department of the Southern Transdanubian Water Directorate, aridity Indices were computed for the three study sites using mean monthly temperatures and monthly precipitation totals.

2.5 Assessment of field data

All statistical calculations were performed in MATLAB and MS Excel.

3 Results and discussion

Soil textural types of the three sites were dominantly silt loam. However, soils of the orchard site and the lower site of the ploughland had silt as a soil physical type.

Rainfall distribution markedly differed among the three sites in both studied years. (Figure 2). The highest monthly precipitation totals were recorded in May and June in 2019 and 2022, respectively. The highest total precipitation for the period of January to August was recorded at the pasture site both in 2019 and 2022.

The highest mean annual and the highest summer mean temperature were recorded in the orchard in 2019. (Table 1). The lowest temperatures (both the annual and summer means) were registered at the pasture site in both studied years. The mean annual temperature in 2019 for the three sites was (12.28°C) and increased to (12.42°C) in 2022. The lowest and highest temperatures in the summer of 2019 were observed in the pasture (21.91°C) and orchard (22.69°C), respectively. The same order of mean monthly temperatures in 2022 were again recorded at the pasture site (22.89°C) and orchard site (23.60°C). Although the difference of mean annual temperature was only 0.14°C between the two studied years, the difference was more pronounced between the mean temperature of the summers (0.98 °C).

Aridity indices were around 1 in 2019 for all land use types which translates to an almost equilibrium water balance. In contrast, evapotranspiration markedly exceeded annual precipitation totals in 2022 resulting in a very negative water balances, with AIs of 1.19, 1.19, 1.43 for the pasture, ploughland and orchard, respectively (Figure 3). The negative water balances were especially pronounced for the summer months, peaking out in July 2022 (9.68, 1.47, 5.29) for the pasture, ploughland and orchard, respectively, presenting the greatest water stress for local crops.

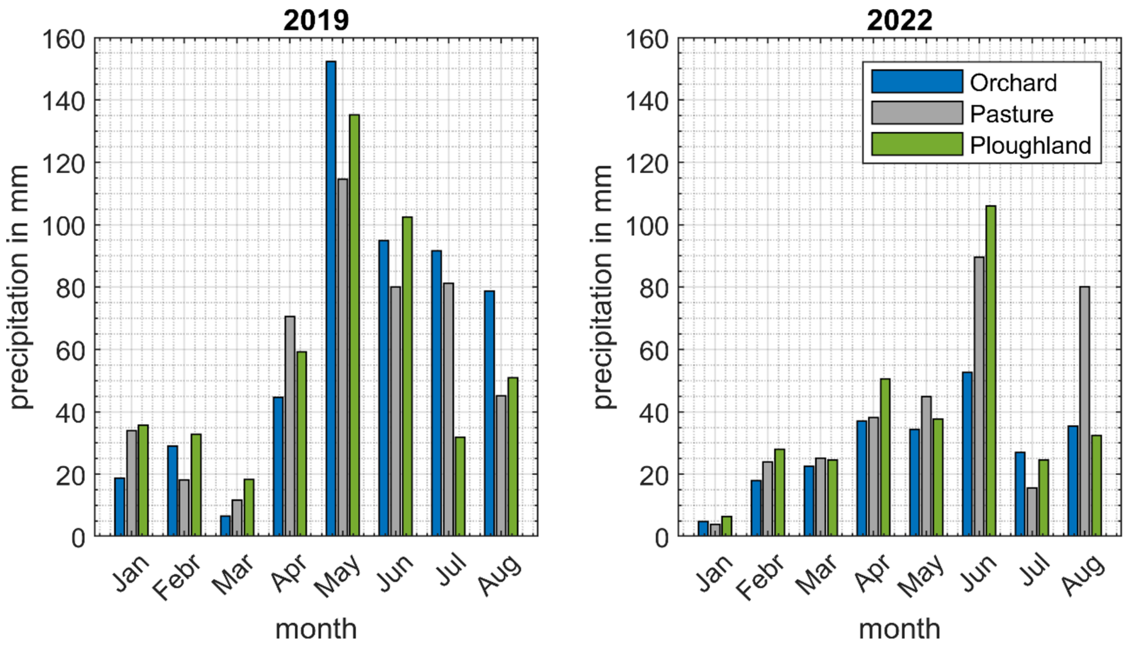

Fig. 2. Monthly precipitation totals from January to August in 2019 and 2022.

Table 1. Mean annual (January to December), summer (June to August) temperatures [°C] in 2019 and 2022.

	Annual		Summer	
	2019	2022	2019	2022
Ploughland	12.17	12.29	22.28	23.31
Orchard	12.66	12.81	22.69	23.60
Pasture	12.02	12.18	21.91	22.89
Average	*12.28*	*12.42*	*22.29*	*23.27*

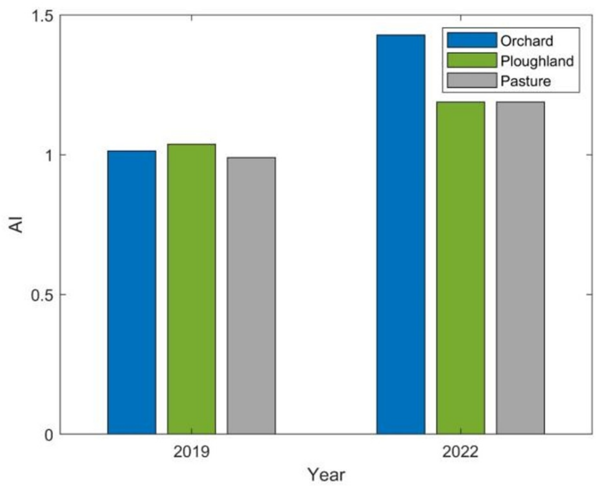

Fig. 3. Aridity indices for the summers of 2019 and 2022 of three land use types.

Mean soil moisture contents also reflected the differences of the water balances between the two studied years and summers. Mean annual (March-November) SMCs of the three studied sites were 0.662307 and 0.7424345 In 2019 and 2022, respectively (Table 2). Mean summer SMCs of 0.795355 and 0.682944 were measured in 2019 and 2022, respectively.

In accordance with the more negative water balances of 2022, SMCs were lower in 2022 compared to 2019 at all 3 sites at all depth and slope positions. The statistics of SM also showed a markedly differed fluctuation ranges between the three land use types. However, the latter changes were not as consistent as in the case of mean SMCs, as in some cases ranges increased, whilst in other cases decreased (Figures 4 and 5). Customarily, the natural pasture demonstrated the highest SMC while the ploughland had the lowest SMC both 2019 and 2022. Similarly to mean SMCs, the pasture demonstrated the highest water stress tolerance and the most uniform water dynamics between the three land use categories with a mean standard deviation of 0.6235 and 0.6935 in 2019 and 2022, respectively. The low fluctuation of the SMC in toeslope position at both depth is likely attributed to local pedological properties and the influence of a small grove in upstream direction (Figures 4a and 5a).

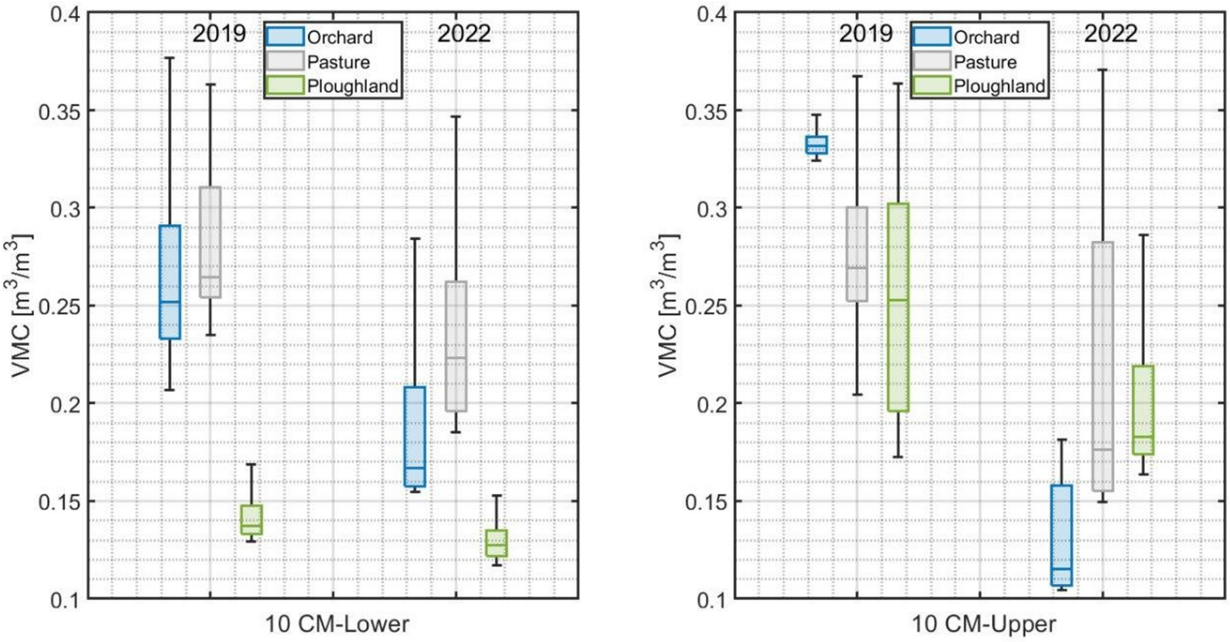

Fig 4. Mean soil moisture values in summer 2019 and 2022 for a depth of 10 cm in toeslope (left) and shoulder positions (right).

Table 2. Mean M-N and summer (shaded) SMCs for the three land use types in 2019 and 2022.

M-N	Mean 10cm		StDev 10cm		Mean 30cm		StDev 30cm	
Sites/Year	2019	2022	2019	2022	2019	2022	2019	2022
Ploughland	0.210	0.211	0.299	0.229	0.216	0.225	0.129	0.157
Orchard	0.008	0.244	0.130	0.275	0.285	0.216	0.118	0.297
Pasture	0.290	0.277	0.177	0.269	0.316	0.313	0.394	0.160
Mean	*0.508*	*0.732*	*0.606*	*0.773*	*0.816*	*0.753*	*0.641*	*0.614*
Summer								
Ploughland	0.199	0.166	0.079	0.05	0.211	0.185	0.048	0.022
Orchard	0.297	0.161	0.045	0.074	0.295	0.168	0.049	0.100
Pasture	0.276	0.222	0.069	0.111	0.312	0.274	0.049	0.074
Mean	*0.773*	*0.548*	*0.193*	*0.235*	*0.818*	*0.627*	*0.146*	*0.196*

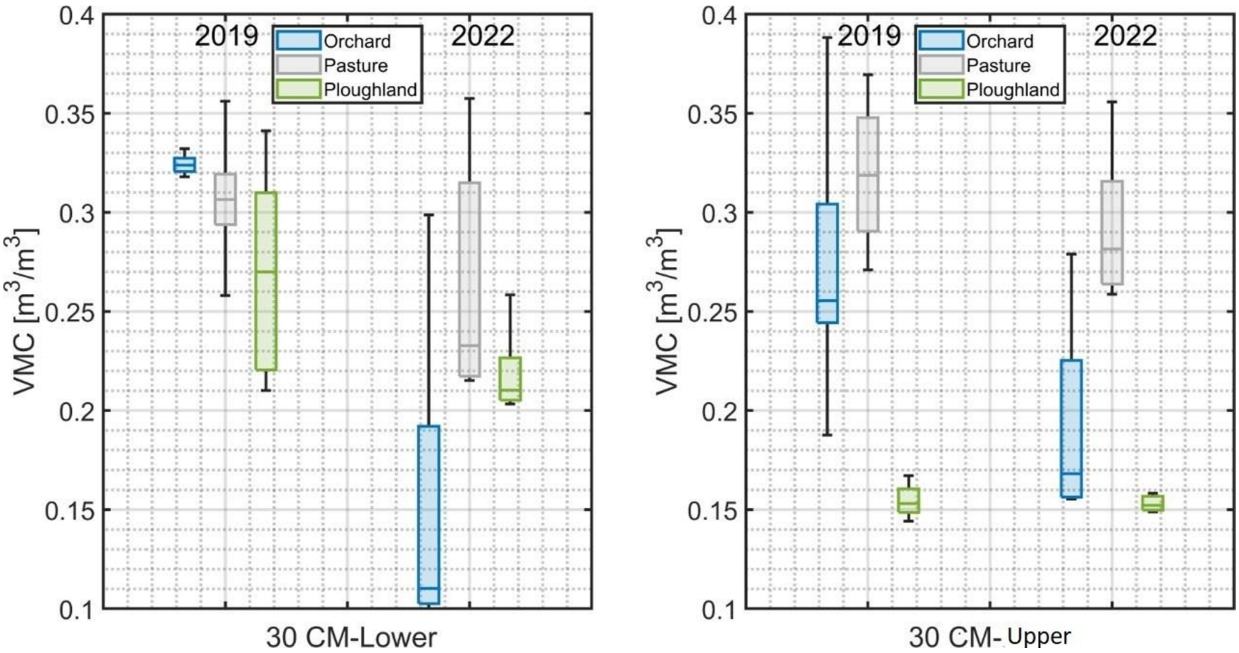

Fig. 5. Mean soil moisture values in summer 2019 and 2022 for a depth of 30 cm in toeslope (left) and shoulder positions (right).

Soil moisture content is controlled by multiple factors: soil hydraulic properties, soil textural types, slope, infiltration and surface runoff and climate change through altered water balances [10,12,13]. In the current study we analyzed the impact of three land use types (pasture, ploughland and orchard) on the moisture dynamics of silt loam and loam soils under the subhumid climate of the Transdanubian region of SW Hungary in the summers of 2019 and 2022.

In both studied summers the pasture site demonstrated the most optimal moisture conditions, i.e., the highest means SMC. This research also revealed an increased likelihood of drought conditions in the summers analyzed, both at the ploughland and the orchard site. In both studied summers the ploughland had the lowest mean SMC among the three studied sites. According to the presumption, the soybean canopy of the ploughland should have reduced evaporation loss by direct radiation from the soil. This low soil moisture of the ploughland soil is explained by (i) canopy interception and (ii) the high transpiration rate of soybean.

However, with the change of land use in 2022 in orchard site, the SMC decreased significantly compared to 2019. The marked change of SMC in the orchard soil was caused by the removal of cherry trees from above the sensors. Therefore, an increasing evaporation loss by direct radiation and a negative water balance were observed at this site from early 2022 on.

4 Conclusions

The impact of three land use types (ploughland, pasture, and orchard) on local water balance and soil moisture dynamics was analyzed in the current study. The fluctuations of SM were the highest at the ploughland site and on average this site showed the lowest soil moisture content. Although the ploughland site was covered with soybeans between April and early October, which limited evaporation loess due to direct radiation, this site had the most negative water balance among the three studies land use types.

Pasture demonstrated the highest SM and the most stable behavior among the three sites. The result of the present study may be useful for implementing sustainable agriculture cropping systems, especially under subhumid climates and on loamy soils. However, drought may have a long effect on soil quality, human health, and the hydrologic cycle. Therefore, understanding the long-term processes of negative water balances may is important to reduce side effects and prevent consequential losses.

References

1. D. Shi, H. Tan, W. Rao, Z. Liu, H. I Elenga, VZJ **19**, 1 (2020)
2. X. Guo, Q. Fu, Y. Hang, H. Lu, F. Gao, J. Si, Sustainability **12**, 9 (2020)
3. S. I. Seneviratne, T. Corti, E. L. Davin, M. Hirschi, E. B. Jaeger, I. Lehner, B. Orlowsky, A. Teuling, J. Earth Sci. Rev. **99** (2010)
4. M. Tang, W. Li, X. Gao, P. Wu, H. Li, Q. Ling, C. Zhang, PeerJ **10** (2022)
5. Á. Horel, T. Zsigmond, C. Farkas, G. Gelybó, E. Tóth, A.Kern, Z. Bakacsi, Sustainability **14**, 7 (2022)
6. M. Ferk, R. Ciglič, B. Komac D. Loczy, Acta Geogr. **60,** 1(2020)
7. A. Grobicki, F. MacLeod, F. Pischke, IOS4 ***17*** (2015)
8. K. Fiala, V. Blanka, Z. Ladányi, P. Szilassi, B. Benyhe, D. Dolinaj, I. Pálfai, J. Environ. Geogr. **7** (2014)
9. G. Nagy, D. Lóczy, S. Czigány, E. Pirkhoffer, S. Á. Fábián, R. Ciglič, M. Ferk, HGB **69**, 3 (2020)
10. S. Czigány, N. Sarkadi, D. Lóczy, A. Cséplő, R.Balogh, S. Á. Fábián, R. Ciglič, , M. Ferk, , G. Pirisi, M. Imre, G. Nagy, E. Pirkhoffer, Sustainability **15**, 6 (2023)
11. J. Stürck, A. Poortinga, P.H. Verburg, Ecol. Indic **38** (2014)
12. B. Fu, J. Wang, L. Chen, Y. Qui, Catena. **54** (2003)
13. Á. Horel, E. Tóth, G. Gelybó, I. Kása, Z. Bakacsi, C. Farkas, Open Geosci. **7**, 1 (2015)