The effect of the Danube diversion on the soil moisture conditions in Csallóköz and Szigetköz

Gábor Koltai[1], Zsolt Giczi[1], Viliam Nagy[2], Gábor Illés[3], Kálmán Rajkai[4,*]

[1]Agricultural and Food Sciences Faculty, Széchenyi István University, Mosonmagyaróvár, Hungary
[2]Ustav Hydrology, Slovak Academy of Sciences, Bratislava, Slovakia
[3]Forest Research Institute, University of Sopron, Sárvár, Hungary
[4]Institute for Soil Sciences, Agricultural Research Centre, Budapest, Hungary

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Summary

Following the commissioning of the Gabčíkovo (Bős) hydroelectric power plant in 1992, a monitoring program was launched to assess the agricultural and forestry consequences of the diversion of the Danube into a newly built derivation channel in the Žitný ostrov (Csallóköz) and Szigetköz areas. Prior to the Danube diversion, groundwater played a significant role in the water supply of plants, therefore it is of primary importance to monitor the changes in groundwater levels and soil moisture. Correlation between the groundwater depth and soil moisture time series taken at four measurement points of Szigetköz (T-03, T-04, T-09, T-16) between 1995 and 2012 was analysed. Average and extreme water levels (quartiles 1 and 4) were examined for the 18-year time series, in which 2nd and 3rd quartiles of the groundwater levels were treated together as characteristic water level. It was found that groundwater significantly correlated with soil moisture storage below the rooting zone of field crops.

Keywords: groundwater level, soil moisture probe, soil moisture storage, quartile analysis

A Duna-elterelés hatása a Csallóköz és a Szigetköz talajnedvesség-viszonyaira

Koltai Gábor[1], Giczi Zsolt[1], Viliam Nagy[2], Illés Gábor[3], Rajkai Kálmán[4,*]

[1]Széchenyi Egyetem, Mezőgazdasági és Élelmiszertudományi Kar, Mosonmagyaróvár, Magyarország
[2]Szlovák Tudományos Akadémia Hidrológiai Intézete, Bratislava, Szlovákia
[3]Soproni Egyetem, Erdészeti Kutató Intézet, Sárvár, Magyarország
[4]Agrártudományi Kutatóközpont, Talajtani Intézet, Budapest, Magyarország

Összefoglalás

A Gabčíkovo (Bős) vízerőművet 1992-ben helyezték üzembe. A dunacsúnyi duzzasztó vize a bősi erőművön átfolyva a Szlovákiában épített vízlevezető csatornából 40 km után tért vissza a korábbi Duna főmederbe. A régi Duna főmederbe emiatt az elterelt szakaszon a korábbi vízmennyiség ötöde került. Minthogy mind a szlovákiai, mind a magyarországi mezőgazdasági és erdőterületek vízellátásában a talajvíz és a dunai árhullámok jelentős szerepet játszottak, 1995-től a Duna-elterelés hatásának felmérésére talajvízszint és talajnedvesség monitoring program indult a Csallóközben és a Szigetközben. A szlovák megfigyelések publikált anyagainak megállapításait és a Szigetközből két szántóföld, egy kaszálórét és egy nyárfaültetvény 1995 és 2012 közötti mérési adatait dolgoztuk fel. A talajvízmélység és a 10 cm-es talajrétegek mért térfogatszázalékos (v.%) nedvességtartalmából számított talajvízkészletek közötti korrelációt számítottuk. A 18 éves idősoron külön vizsgáltuk a jellemző, illetve a szélsőséges vízszintek (1. és 4. kvartilisek) hatását. A jellemző vízszintek hatásának vizsgálatához a talajvízszint értékek 2. és 3. kvartilisét egyben kezeltük. Megállapítottuk, hogy szignifikáns, ill. közel szignifikáns összefüggés csupán az átlagosnál a talajfelszínhez közelebbi (Q1) talajvízmélység esetén volt kimutatható mind a mély (T-03), mind a sekély talajrétegű (T-09) szántóföld 210–300 cm-es, illetve 120–140 cm-es talajszintjében. Vagyis a szántóföldi kultúrák számára az átlagos talajvízmélység nem jelentett vízpótlást. A régi Duna főmederhez közeli kaszálóréten (T-04) a talajvízmélység helyett a dunaremetei

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medervízszint adatok és a talajnedvességkészlet között még a 140 cm-es mélységben található kavicsos alapkőzet fölötti 20 cm-es talajrétegben sem volt jelentős kapcsolat. A mély talajrétegű (300 cm) erdészeti mérőhely (T-16) talajvízmélység és talajnedvességkészlet korrelációja csupán a 210–300 cm-es talajréteg esetében volt közel szignifikáns. A nyárültetvények fejlődéséhez szükséges éves 700–900 mm vízigény biztosítására emiatt a régi Duna főmederbe engedett többletvízre lenne szükség. A szántóföldi kultúrák terméshozama is elsősorban az adott év csapadékmennyisége és eloszlása szerint alakul. Amennyiben az időjárási feltételek kedvezőtlenek, megoldásként öntözni szükséges.

Beszámoltunk továbbá arról, hogy két éve négy mérőhely üzemel, ami a naponta óránként mért 6 órás átlag talajnedvesség-adatokat gyűjti. A folyamatos talajnedvesség-adatgyűjtés célja az időjárás, a növényi vízfelhasználás és a talajvízből történő nedvesítés nyomon követése és a talajvízforgalom-modell leírásának a kontrollja. A közeljövő feladata az évente 12-14 alkalommal az ezeken a mérőhelyeken is gyűjtött kapacitívszondás és a folyamatos nedvességmérési eredmények megfeleltetése, minthogy a bemutatott közel azonos példa mellett több helyen és mélységben időben párhuzamos módon változik ugyan a kétféle érték, azonban akár több, mint 5 v.% különbséggel.

Kulcsszavak: talajvízszint, talajnedvesség-szonda, talajnedvesség-készlet, kvartilis analízis

Introduction

In April 1995, the Government of the Republic of Hungary and the Government of the Slovak Republic agreed on technical measures to increase the water flow into the original Danube riverbed and into the Mosoni-Danube. In October 1992, in connection with the commissioning of the Gabčíkovo (Bős) hydroelectric power plant, the water flowing from the Čunovo dam to the power plant was diverted for 40 km into a newly built derivation channel in Slovakia. From the derivation channel, the water of the Danube was diverted back to the main riverbed at the village of Szap. The Bős-Nagymaros dam system also had a significant impact on arable farming, primarily by lowering groundwater levels and limiting irrigation opportunities. By diverting the Danube, the direction of groundwater leakage changed, where previously the river fed the groundwater in the gravel layer, there it became its tap *(Lámer 2010)*.

Slovakia and Hungary have launched a monitoring program in both the Žitný ostrov (Csallóköz) and Szigetköz areas to monitor the ecological changes caused by the Danube diversion. The Monitoring Program prepared summaries and annual reports on the environmental condition of Žitný ostrov (Csallóköz) *(Web_1),* and Szigetköz and the results of monitoring *(Web_2)*.

Due to the decrease of the groundwater level in the upper Žitný ostrov (Csallóköz) and Szigetköz areas, the changes in the soil water supply from the groundwater and its effects on agricultural production and soil moisture conditions were assessed. The amount of moisture that can be taken up from the soil by field crops was estimated and its correlation with the amount of yield was examined *(Nagy et al. 2007)*. It was found that in both areas the yield almost exclusively depends on the rainfall conditions because the possibility of using groundwater as a water source is only temporary.

In the present work, we summarize the observations that started in 1995 following the seasonal changes in soil moisture in the Szigetköz area. The amount of water retained and stored in the soil, the role of water supply are decisive in the development of crop yields, as it was found in the field measuring sites of three settlements of Szigetköz for the years 2003 and 2005 *(Koltai et al. 2008)*. Moisture that infiltrates the soil from precipitation and enters the soil from the groundwater by capillary rise is stored and flows according to the water-holding and water-carrying capacity of the soil. As the amount and distribution of annual precipitation is a function of the weather, the effect of climate change predicted for 2010 and 2050 on the changes in plant available soil moisture amount was studied at two measuring sites in the Szigetköz area *(Koltai et al. 2013)*. Considering the plant water demand of alfalfa, grass, wheat and maize fields during vegetation period the available soil moisture amount was determined from the measured soil moisture profiles. Besides, the ground water depth for required capillary moisture supply was also calculated and compared to the reported measured ground water depth in the Žitný ostrov (Csallóköz) and Szigetköz areas *(Koltai et al. 2012)*. The assessment of the ecological and agricultural effects of soil moisture content can be performed by regular measurements, as declared by the Szigetköz Monitoring Program after the Danube diversion *(Web_2)*.

When designing the location sites of soil moisture measurements, the historical antecedents of the formation of the Szigetköz water system were also considered. After leaving the mountains, the fall of the river decreased, and its alluvium was deposited. Reefs formed, which were blurred and re-deposited again. The vegetation that settled on the reefs turned them into islands. The islands cut the riverbed into branches and steered it in different directions. The settlements followed the migration of the Danube branches from island to island, to places free of flooding. According to the survey of the Bratislava Economic Association in 1866, even in the middle of the 19th century, the river swept 2,000 acres (>800 hectares) of coastal soil in 10 years *(Göcsei 1979)*.

The floods of the Danube deposited alluvium in varying thicknesses on the previously deposited gravel layers. In Szigetköz, the material of soil formation is almost entirely river sediments and alluvium. Sediments are characterized by high lime content as well as high vertical and horizontal variability, stratification and spotting. This spatial inhomogeneity has great importance not only for the conditions of agricultural lands, but also in the case of forests *(Illés–Szabados 2008)*. According to the time of soil formation and the increasing depth of groundwater, humus casting, meadow and terrace chernozem soils occur to the greatest extent *(Várallyay 1992)*.

The changes in groundwater level in Szigetköz and their agricultural impact are typically distinct where (1): the Danube flows in a suspended bed on a high-thickness gravel cone, where (2): both the groundwater level and the soil or cover layer are decisive, and where (3): the stratification of the soil cover layer with different particle compositions, or the stratification of sand interlayers create a cover layer with an independent water balance, not depending on groundwater *(Major 1992)*.

In the Szigetköz Monitoring program, the consequences of the decrease in groundwater level due to the diversion of the Danube are presented with 18-year measurement results at measuring sites having different subsoil and topsoil, as well as some possible use of the recently launched continuous moisture measurements.

Materials and Methods

Two measurement sites (T-03 and T-09) were selected to show changes in soil moisture storage in a deep and a shallow soil cover arable land. A lawn having a shallow soil cover (T-04), and a deep soil cover poplar plantation (T-16) were also selected for the study between 1995 and 2012. The measurement sites were chosen because changes in groundwater level and the moisture storage of the deeper soil layers are more sensitive to the flow of the diverted Danube section in the floodplain areas than in areas further away from the main riverbed.

In Szigetköz a BR-150 (SMM-001) capacitive probe *(Andrén–Rajkai–Kätterer 1991)* was used for soil moisture measurements. Thin-walled plastic pipes were installed at the measuring sites near the groundwater measuring well from the soil surface to the bottom of the cover layer. With the capacitive moisture measuring probe, soil moisture measurements were carried out at the selected four monitoring points at a measuring depth of 140 or 300 cm, i.e. above the continuous layer of gravel or sand depending on the stratification of the site. The geographical locations of the four measurement sites are shown in *Figure 1*.

The BR-150 displays the moisture content by volume % (v.%) of a 10 cm soil layer. Soil moisture measurements were made at the measuring sites 12–14 times a year from April to October. Furthermore, in 2018, Campbell CS616 soil moisture measuring probes and data loggers were installed at the T-03, T-09, T-16 measuring sites, which measured six-hour soil moisture averages continuously, i.e. on an hourly basis, on the two arable fields and the poplar plantation. The probes installed in the soil were used to measure the average moisture content of 30 cm soil layers. From the measurements, the capillary rise of water and the wetting effect of rainwater infiltration can be determined with greater reliability than from the multi-weekly moisture data. However, for technical reasons, continuous soil moisture data only appear reliable from the end of September 2020.

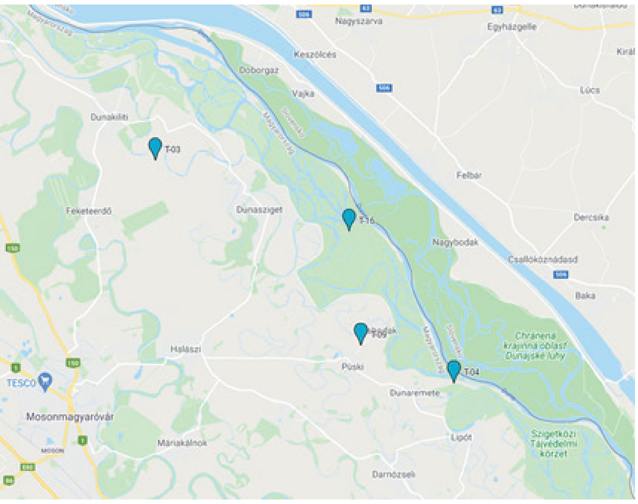

Figure 1 | Measuring sites T-03, T04, T-09 and T-16 in Szigetköz

At the four-soil moisture measuring monitoring sites *(Figure 1)*, the correlations between soil moisture storage and water level in the groundwater level observation well near the measuring site were examined between 1995 and 2012. At the T-04 Dunaremete measuring point, due to its proximity to the old main riverbed of the Danube, the water level data of the main river was used.

Soil and surface water level data were provided by the North-Transdanubian Water Directorate. To determine the groundwater level, the water level of the preceding seven days was considered for each moisture measurement. This was necessary because the rise and fall of groundwater was different in the observation well and in the soil due to the piezometric water level. The moisture content of the soil is more significantly influenced by the change of water level in the time frame of the previous few days than by the groundwater level on the day of the measurement. Groundwater levels for the seven days were averaged if they differed by <10 cm day^{-1}. At a water level deviation of >10 cm day^{-1}, water levels were averaged from the day after the sudden change of groundwater level. Water level data were recorded at each site every 3 days. To estimate the water level change, the data set was supplemented with linear interpolation up to a 3-day gap. Days with rapid water level rise were excluded from further analysis, and when the groundwater approached the soil surface at 1 m or when the water level change was >50 cm day^{-1}. The effect of a rapid decrease in groundwater level >10 cm day^{-1} and <50 cm day^{-1} was neglected.

Soil moisture data were assigned to averages calculated from water level data. Daily water level data in ascending order were divided into quartiles. The 2nd and 3rd quartiles, which were treated together, were considered the characteristic groundwater level, and the 1st and 4th quartiles were considered to be extreme water levels. Soil moisture storage (mm) was calculated for the soil layers as the sum of 10 cm moisture data (v.%). The above evaluation methodology was used by Koltai et al. (2019). To detect the groundwater effect, the correlation between the three water level groups (Q_1, Q_{2-3}, and Q_4) and the average moisture storage of the soil layers was determined at the four measurement sites.

The daily average of the 6-hour averages of the hourly moisture measurement of the Campbell CS616 probes from the end of September 2020 was used for soil layers detected by the probes. To compare the moisture values of the BR-150 and of the Campbell CS616 probes, the 10 cm moisture values of BR-150 were averaged over the 30 cm probe length of CS616.

Results and Discussion

Relationship between groundwater level and soil moisture storage between 1995 and 2012

The total number and distribution of groundwater quartiles between 1995 and 2012 at the selected four measurement sites are shown in *Table 1*.

T-03

The measuring point T-03 was located about 4 km from the old Danube riverbed, on the right bank of the Zátonyi Danube branch, on the border of the village of Dunakiliti. The sand content of the humus alluvial soil gradually increases downwards from the depth of 180 cm. The measuring point was located in an arable land adjacent to the groundwater measuring well. Soil moisture measurements were made to a depth of 300 cm. The effect of groundwater level on soil moisture storage is shown in *Table 2* and *Figures 2* and *3*.

Table 1 Number of groundwater level data of measuring sites and quartile distribution (Q_1, Q_{2-3}, Q_4) of groundwater levels

	T-03 Dunakiliti		T-04 Dunaremete		T-09 Püski		T-16 Dunasziget	
	Case number	Wd. (1)	Case number	Wl. (2)	Case number	Wd. (1)	Case number	Wd. (1)
	pcs	cm	pcs	cm	pcs	cm	pcs	cm
All data	219	366	236	97	186	279	208	317
1st quartile (Q_1)	55	331	59	168	46	233	52	267
2nd–3rd quartiles (Q_{2-3})	109	360	118	91	94	273	104	314
4th quartile (Q_4)	55	411	59	39	46	340	52	372

Wd. (1): mean ground water depth; Wl. (2): main riverbed water level

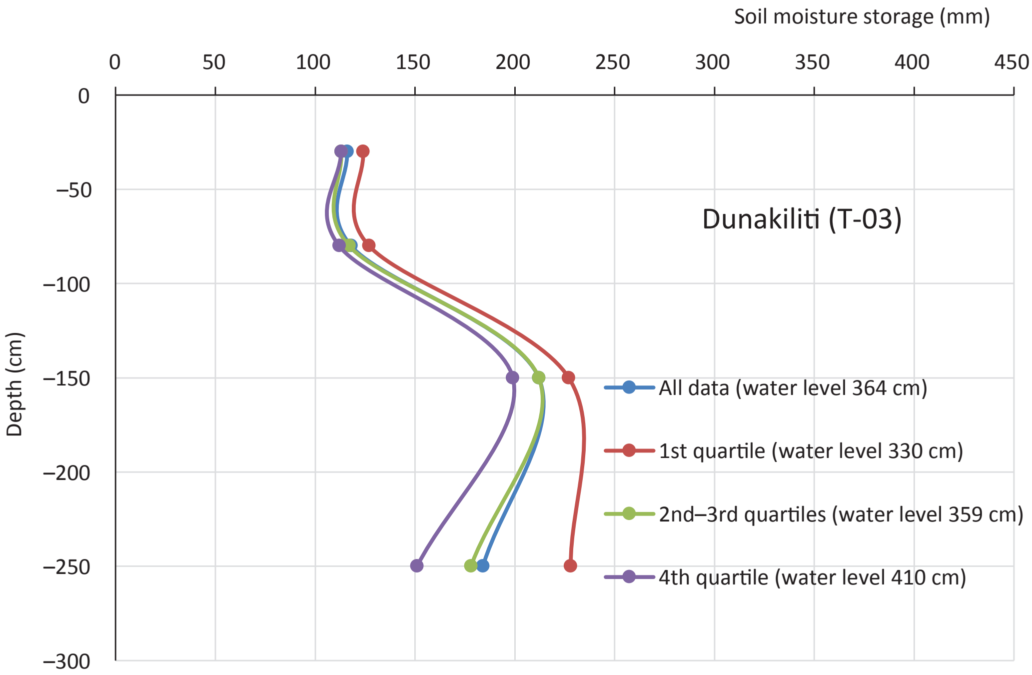

Figure 2 Soil moisture storage profiles measured with BR-150 device for the quartiles of daily groundwater depths at T-03 measuring point between 1995 and 2012

Table 2 | Effect of groundwater level on soil moisture storage in the Dunakiliti arable land

	Ground water level (cm)	Soil moisture storage (mm)			
Case number: 229		10–50 cm	10–100 cm	110–200 cm	210–300 cm
Minimum	298	86	180	170	118
Maximum	461	173	321	280	300
Mean	365	116	234	212	184
Standard deviation	32	18	31	23	37
Correl. coeff.	–	–0.168	–0.278	–0.411	–0.723

Table 3 | Effect of groundwater level on the moisture storage of soil layers in Dunaremete

	Ground water level (cm)	Soil moisture storage (mm)			
Case number: 242		10–50 cm	10–140 cm	10–100 cm	110–140 cm
Minimum	7	82	193	155	38
Maximum	463	218	575	399	184
Mean	97	140	359	265	95
Standard deviation	62	30	80	52	31
Correl. coeff.	–	0.195	0.297	0.248	0.357

The highest groundwater level (Q_1) for measuring site T-03 was below the depth of 300 cm *(Table 1)*. However, the Q_1 groundwater effect was significant only for the moisture content of the 210–300 cm soil layer ($R^2 = 0.5228$). The correlation between the groundwater depth and the soil moisture content in *Table 2* was always negative. It can be seen in *Figure 3* that this was due to the relationship between the groundwater level close to the ground surface and the higher soil water storage.

Figure 2 shows that at a soil depth of about 180 cm, all three (Q_1–Q_4) ground water level quartiles had the lowest average soil moisture storage over the 18-year period between 1995 and 2012. This means that the moisture content of the 0–180 cm soil layer was not regulated by groundwater but by precipitation and irrigation.

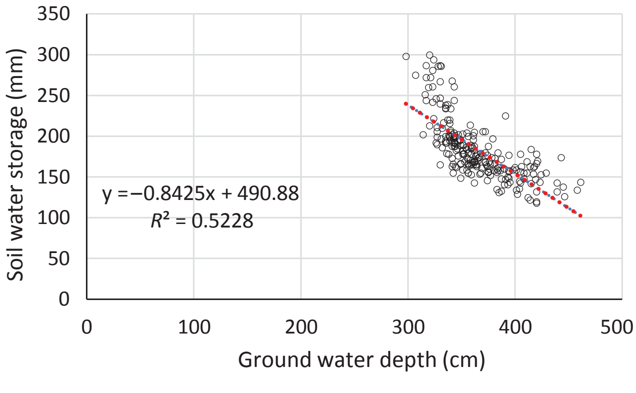

Figure 3 | Relationship between the highest (Q1) groundwater level and the moisture storage of the 210–300 cm soil layer at the T-03 Dunakiliti measuring point

T-04

At measuring point T-04, near the Dunaremete old Danube riverbed water level meter site, the groundwater level was usually located in the gravel bed at a depth of 140 cm below the soil surface. The depth of soil moisture measurement was therefore 140 cm. Prior to the Danube diversion, groundwater had a dominant effect in wetting the shallow topsoil. The groundwater level at this measuring point followed the water level of the old Danube main riverbed. The soil moisture data measured at this site were combined with the water level data of the main riverbed water meter. The effect of water level on the moisture storage of each layer of the soil profile is shown in *Table 3.*

The deepest groundwater level was indicated by the average water level of the lowest main riverbed (Q_4 = 39 cm) *(Table 1)*. Because groundwater depth and main riverbed water level have the opposite signs, the correlation between main riverbed water level and soil moisture storage is positive *(Table 3)*. The above-average soil water storages (265–399 mm) were caused by the wetting effect of the water level rise of the Danube floods at the T-04 measuring site. However, due to the rare flood waves, the increase in groundwater level and the consequent increase in soil moisture content and storage did not show a significant relationship *(Table 3)*.

T-09

The measuring point is located in an arable land on the border of the village of Püski, two kilometres from the Danube. Below a humus-rich alluvial soil, there is a layer of sandy gravel at a depth of 145 cm. The measurement depth of soil moisture was therefore at 140 cm. The ef-

Table 4 | Effect of groundwater level on soil moisture storage in the Püski arable land

	Ground water level (cm)	Soil moisture storage (mm)			
Case number: 203		10–50 cm	10–100 cm	110–140 cm	10–140 cm
Minimum	137	90	174	48	223
Maximum	439	217	414	165	575
Mean	276	149	292	118	410
Standard deviation	47	26	47	26	70
Correl. coeff.	–	–0.380	–0.503	–0.662	–0.577

fect of groundwater level on soil moisture storage is shown in *Table 4*.

The quartile mean groundwater level of the near-surface groundwater was 233 cm *(Table 2)*. The mean moisture storage of the 0–100 soil layer was about 70% of the maximum one. The ground water effect on the water storage of the 10–100 cm soil layer was not significant ($R^2 = 0.2528$). This means that between 1995 and 2012, there was no significant effect of groundwater on the changes in soil moisture storage in the fertile layer of this arable land. Even ground water effect on the 110–140 cm soil layer just above the gravelly parent material was only close to significant ($R^2 = 0.4382$) in that time period.

T-16

The measuring site was a planted poplar forest in the Danube floodplain area on the outskirts of Dunasziget. The thick topsoil is a carbonated and humus alluvial soil. The clay loam top layers gradually become sandy downwards. The depth of soil moisture measurement was 300 cm. The sandy gravel subsoil appears at 345 cm. Larger flood waves caused even surface flooding. At that time, due to the impassability of the road leading to it, the measuring point was not accessible. The effect of groundwater level on soil moisture storage is shown in *Table 5* and *Figure 4*.

The mean water level (Q_1) closest to the soil surface was 267 cm *(Table 2)*. The groundwater effect on the average moisture storage of the 210–300 cm soil layer was almost significant ($R^2 = 0.4699$) in the 1995–2012 study period. This result is also shown by the moisture storage profiles shown in *Figure 4*. Thus, in Dunasziget, the development of the poplar plantation was affected by the groundwater to a varying extent but promoted its development at the soil depth of approximately 180 cm and above. Poplar stands in the vicinity of Dunasziget showed balanced growing trends between 1995 and

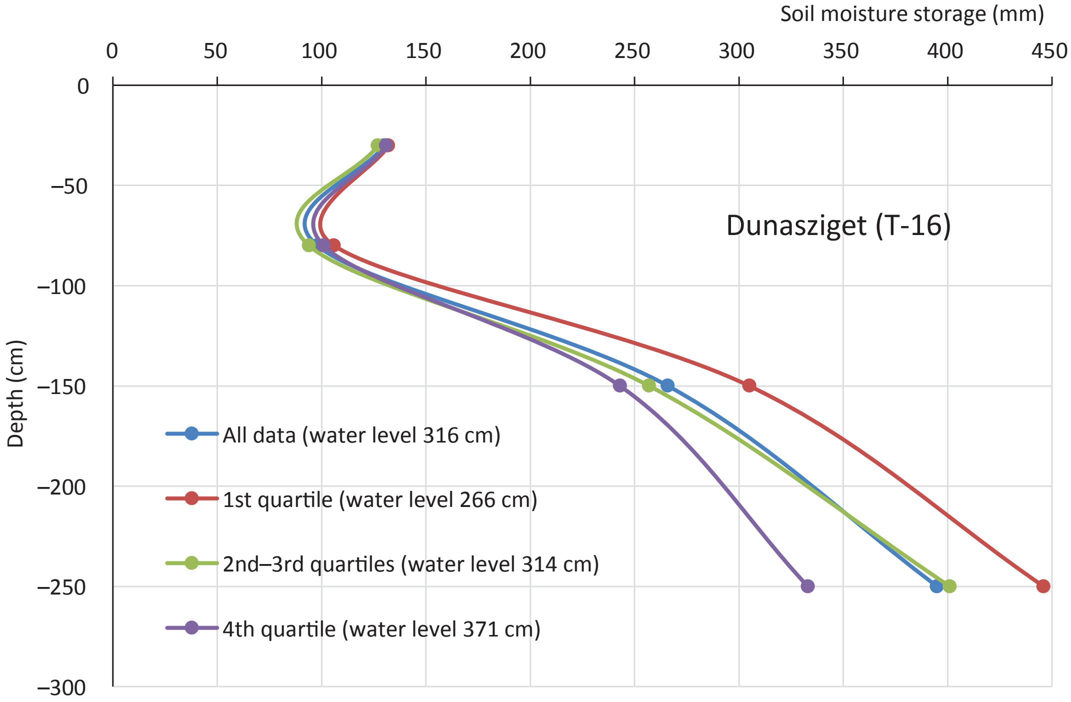

Figure 4 | Soil moisture storage profiles measured with BR-150 device for the quartiles of daily groundwater depths at T-16 measuring point between 1995 and 2012

Table 5 Effect of groundwater level on the moisture storage of soil layers in Dunasziget

	Ground water level (cm)	Soil moisture storage (mm)			
Case number: 211		10–50 cm	10–100 cm	110–200 cm	210–300 cm
Minimum	209	73	115	165	223
Maximum	405	187	368	444	510
Mean	316	130	228	266	395
Standard deviation	41	20	43	55	63
Correl. coeff.	–	–0.022	–0.053	–0.455	–0.685

2012. It is due to the relative thick fertile topsoil layer mentioned above (345 cm). As the mean groundwater level reached 180 cm from the surface it provides acceptable conditions for poplars. It is worth to indicate here that the spatial variability of topsoil thickness was found to be a key factor influencing forest growth after diversion. Due to water level drop and rarer floods the nearby areas with shallow topsoil and groundwater level staying in the gravelly subsoil cannot offer reasonable circumstances for plantation forestry. Our measurements showed that in the whole region the growth rate of forests decreased by approximately 30% in comparison with growth rates before diversion.

Soil moisture measured several times and continuously in 2020 and 2021

The daily average of the soil moisture values continuously measured at the T-03 site at Dunakiliti arable land and the BR-150 moisture data averaged over the soil depth of 20–50 cm are shown in *Figure 5* as a "good example". The figure shows the calibrated (c.) moisture contents of the raw data recorded from the W8 Campbell probe. In the figure, however, the nearly identical moisture values of the two soil moisture meters were significantly different even at different soil depths. Finding and resolving the causes is a task to be performed in the near future.

The need for continuous soil moisture measurements in the Szigetközi monitoring program can be attributed to several reasons. One reason is that the capacitive moisture meter (BR-150) developed in the mid-1980s has become obsolete, has no spare parts and no service, and may need to be replaced at any time. With the Campbell CS616 moisture meters buried in the soil, the extent of the groundwater effect can be detected right after the water level change. From the change in soil moisture content, the extent of the increase in moisture storage from the groundwater can be predicted. The supply of cultivated crops from soil moisture can also be clearly established if a micro-meteorological station is

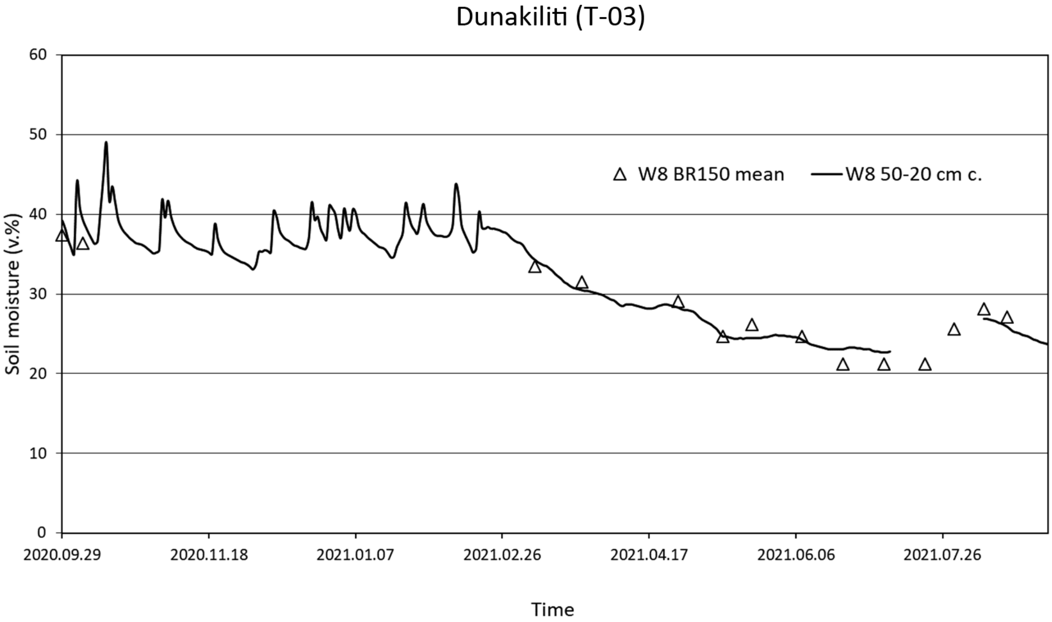

Figure 5 Calibrated data for the 20–50 cm root depth by W8 Campbell CS616 and BR-150 moisture meters between September 2020 and August 2021

installed at the measurement site. We have already submitted a request for this. The on-site meteorological station together with the soil moisture dynamics allows the use of crop models. With these, in addition to the weather and the cultivation method, the effect of the groundwater effect on the yield becomes clearly detectable even during the ongoing year. In addition, the monitoring program should be supplemented with plant development and physiological observations (SPAD measurements, phenological observations, etc.) to effectively complement modelling.

Conclusion

In the Szigetköz region, the depth of groundwater is influenced by the Danube watercourse. In arable lands, the rising of capillary water up to the root zone (120–150 cm) would be important, for which groundwater would have to rise twice a year to 280–290 cm or above in areas with a thick soil cover layer as at the T-03 and T-16 monitor points. When the amount and distribution of precipitation do not cover the water demand of arable crop production, and there is no excess water from the rise in groundwater level to the bottom of the root zone, only irrigation can provide water replenishment. The 700–900 mm water demand required for the annual increase in the tree mass of poplar plantations can be provided by the additional amount of water transferred to the old Danube riverbed in addition to precipitation. In order to approximate the previous water conditions of the Szigetköz region, in the floodplain of the Danube at least two floodings of a ten-day duration in the spring and summer period would be necessary for the groundwater to rise and to exert its effect in the Szigetköz area. The flood wave with high water flow rate would result in a water level of approx. 500 cm on the water level of the Danube in Dunaremete *(Palkovits–Koltai 2003)*.

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References

Andrén O., Rajkai K., & Kätterer T. (1991) A non-Destructive Technique for Studies of Root Distribution in Relation to Soil Moisture. Agriculture Ecosystem & Environment, 14. pp. 269–278.

Göcsei I. (1979) The Natural Geography of Szigetköz. Budapest, Akadémiai Kiadó. (in Hungarian)

Illés G., & Szabados I. (2008) The 20 Years of the Monitoring of Forests in the Szigetköz. Proceedings of the Forest Research Institute, Vol. 92. pp. 95–120.

Koltai G., Milics G., Neményi M., Nagy V., & Rajkai K. (2008) Plant Water Supply of Layered Alluvial Soils Under Different Weather Conditions. Cereal Research Communications, Vol. 36. pp. 167–170.

Koltai G., Nagy V., Milics G., & Štekauerová, V. (2013) Evaluation of Soil Moisture According to Climate Change. Növénytermelés, Vol. 62. pp. 339–342.

Koltai G., Mikéné Hegedűs F., Milics G., Nagy V., Stekauerova, V., & Rajkai, K. (2012) Moisture Status of Land Use Types in the Zitny Ostrov and Szigetköz Danube Lowlands. In: Halasi-Kun G. J. (ed.) Pollution and Water Resources. Columbia University Seminar Proceedings, Vol. XLI: Impact of Anthropogenic Activity and Climate Changes on the Environment of Central Europe and USA. New York, Columbia University. pp. 181–188.

Koltai G., Giczi Zs., & Rajkai K. (2019) The Effect of Groundwater on Soil Moisture in Szigetköz 1995-2012. In: Fazekas I., & Lázár I. (eds) Function and Image of Landscapes. Debrecen, Hungarian Academy of Sciences, Regional Committee, Commission for Earth Sciences. pp. 89–95. (in Hungarian)

Lámer Á. (2010) Szigetköz 2010, the Possibilities of the Past and Present. PhD thesis, Corvinus University, Budapest. p. 21. (in Hungarian)

Major P. (1992) A Szigetköz talajvízjárása. Szigetközi ankét. A Magyar Hidrológiai Társaság kiadványa. pp. 109–114. (in Hungarian)

Nagy V., Stekauerová, V., Neményi M., Milics G., & Koltai G. (2007) The Role of Soil Moisture Regime in Sustainable Agriculture in both Side of River Danube in 2002 and 2003. Cereal Research Communications, Vol. 35. pp. 821–824.

Palkovits G., & Koltai G. (2003) Water Demand in Agriculture. In: Berczik Á., & Guti G. (eds) Determining the Ecological Water Demand of Szigetköz, with Special Regard to the Continuation of the Slovak-Hungarian Negotiations. Vácrátót, Research Institute of Ecology and Botany of the Hungarian Academy of Sciences – Hungarian Danube Research Station. pp. 463–492. (in Hungarian)

Várallyay Gy. (1992) Results of Soil Research in Szigetköz. In: Proceedings of the Szigetköz Workshop of the Hungarian Hydrological Society. Győr, Magyar Hidrológiai Társaság. pp. 179–187. (in Hungarian)

Web_1: http://www.gabcikovo.gov.sk/index.php?page=Pristup-k-udajom-monitoring (Accessed: 2021. 09. 20.). (in Slovakian)

Web_2: http://www.szigetkozi-monitoring.hu/mainpage_nemzeti-jelentes.htm (Accessed: 2021. 09. 20.). (in Hungarian)