

## WATER SCARCITY PROBLEM TREATMENT USING PRECISION IRRIGATION TECHNIQUES ON TISZA-RIVER BASIN

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### ABSTRACT

Over the past decades, - as in other parts of the world - the variability of the climate has increased, which has also affected the Tisza River Basin (Ukraine, Romania, Slovakia, Serbia and Hungary). Most of the climate scenarios predict an increase in water scarcity in arid areas, such as Hungary. However, the trend of annual precipitation is still very uncertain in this region. The frequency of drought has already increased significantly due to the rising temperatures, and decrease precipitation in the vegetation periods. Beside water retention measures, one of the main trends in water management is precision irrigation. However, the irrigation area is 200,000 hectares in Hungary covering approximately 2% of agricultural land, mostly with outdated irrigation technology. The task of precision water management is to optimally satisfy the current demand for water in cultivation technology. It uses automated real-time data collection and evaluation systems in the observed crop systems. It continuously processes the 2-3-dimensional hydrological water balance elements in time and controls the technical equipment for water supply or drainage. In moving systems, in addition to GPS control, sprinkler irrigation systems are able to adapt to the continuous changes in soil and plant water balance.

The aim of the research was to develop an alternative water source based water-saving precision sprinkler irrigation system on an arable land (85 ha), which is located in the reference area of the Tisza River Basin. During the research we developed a real-time eco-potential measurement methodology for water management by processing real-time remote sensed data series. Real-time water balance calculations were made and the irrigation water requirements were determined for different soil and plant conditions. Finally, we developed a real time correction based control technology of the linear irrigation systems, taking into account the agro-ecological properties of the cultivating area, where the amount of the supplied nutrient solution can be regulated at the nozzle level according to the user requirements (flow-level control l / s, speed and zone control). In this research, high precision soil maps and 3-D DEM are presented which were created to support establishing the water saving variable rate irrigation system by selecting and identifying sites for different agro technical implementations and precision management zones.

**Keywords:** precision irrigation system, LiDAR, water scarcity, alternative water resource

### 1. INTRODUCTION

Growing population requires a direct increase of goods, as a consequence for an even higher demand for food and fibers and reaching the requested amount of these results to a more water directed for irrigation (Kanget et al. 2017). Continuous warmer climate, rapid weather fluctuation and unpredicted change of rainfall distribution while considering that crop production has to be increased in the future (Thornton et al. 2014). We need to determine which land and crops have the capabilities give the best

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produce in the given conditions for the available resources, beginning from plot farm level to up-scale, using up to date technological innovations such is remote sensing technology (Demelezi 2019).

Water scarcity will become a fundamental problem that will trigger changes on agricultural cultivation and management practices especially in arid and semi-arid conditions (Falkenmark 2013). Setting off changes in soil and water management and cultivation requires detailed information and planning about soil parameters, water resources and cultivation plans (Gálya et al. 2018; FAO 2003). Laboratory analysis with technology improvements can help us to easily determine where different issues come from (different problems occur and ease solutions). Increase of temperature, change of rainfall patterns, intensified drought frequency and severity will lead to higher water demand and decrease of supply (Tamás 2003; Tamás et al. 2015a). Supplementary irrigation is likely to become more important in agriculture to support and maintain crop yields and its quality in multiple climate types (Nagy et al. 2018; Tamás et al., 2015b). Evaporation levels of soil moisture are measured regularly since we need to adjust it with crop water needs to achieve the increased crop production yield (FAO 1998). Therefore, scheduling irrigation according to the average soil moisture content of the entire profile may be beneficial for plants and farmers (FAO 2003).

Soil analysis recovers enough information about soil characteristics and linking them with LiDAR (Light detection and ranging) data of the arable land results in better management of the water, soil sustainability and sustainable production. In recent years, LIDAR sensors have been widely used to measure environmental parameters such as the structural characteristics of surface, features, or forests (Tamás et al. 2015c; Csiha et al. 2017). LIDAR elevation data have been used successfully in several studies (Gombosné 2016). We can use remote sensing technology for monitoring of agro-environment landscapes such as percentage of arable land covered (e.g. soil/no soil), buffer strips and margins, land use, land cover, burning, harvest dates, hay cutting dates, cover crops dates, irrigation by flooding, etc (Lawson et al. 2005).

The ratio of agricultural fields which are equipped for irrigation is growing year by year (FAO 1998). Nowadays, the total area equipped for irrigation is more than 300 million hectares around the world, which is the 22.5% of the arable lands. This ratio in Hungary is about 2%. There are three main types of irrigation technologies in Hungary; sprinkler irrigation (83.75%), surface irrigation (13.41%) and micro irrigation (2.84%). (EUROSTAT, 2011). Considering the spatial and temporal heterogeneity of soil, water management and vegetation on the field, precision agriculture tools can enhance the crop production and save water and energy irrigation. Several experiments were made worldwide to evaluate the efficiency of variable rate irrigation (VRI), and investigate its impact on yield and soil.

Based on vegetation status, management zones can be created, which can be effective in water control. Soil geological, water management, terrain and vegetation data are useful for planning a precision irrigation system (Neupane &Guo, 2019).

## **2. METHODS**

### **2.1 Sample Area**

The aim of the research was to develop an alternative water source based water-saving precision sprinkler irrigation system on an arable land (85 ha), which is located in South-East Nyírség, Szabolcs-Szatmár-Bereg county in the North-Eastern region of Hungary. Figure 1 shows the location of the sampling area.



**Figure 1.** Location of the sample area

In this area we can distinguish between two types of farming and land use, which is forestry and cultivated arable land. The arable land covers an area of 28000 ha, while forest covers 20.000 hectares.

## **2.2 Climate Conditions of the Studied Area**

The sample area is situated on the edge of a moderately warm and moderately cool climate belt. The number of annual sunshine hours is less than 2000 and is closer to 1900. On average there are approximately 800 sunshine hours in the summer and 170 hours in the winter. The average annual temperature is 9.5 - 9.7 °C, which increases during the growing season and reaches a value of around 16.6 °C. On the hottest summer days, the maximum temperatures are around 34 °C. The average temperature of the coldest winter days can drop down to between -17.0 °C and -18.0 °C. The annual rainfall is 570-600 mm, in the summer it is about 350-360 mm. The most common wind direction in the north is north-east and south-east, with an average speed of 2.5 m / s. To summarize, the climate of small region of Southeast Nyírség is suitable for not very heat and water intensive agricultural crop production.

## **2.3 Soil Sampling and Analysis**

In our investigation, precision grid-based soil sampling was carried out on an agricultural field (85.5 ha). Different databases and maps (for example Hungarian soil database, digital aerial photo archive, geological map by the Mining and Geological Survey of Hungary) were used to the soil sampling strategy(Figure 2).



**Figure 2.** Sampling strategy in the field

Core soil samples in two layers (30 cm and 60 cm) were taken. On the analysed arable land we modelled at 102 points representing more than 1 sample per hectare (1.19 samples / ha) from a total of 510 samples (Figure 2).

Determining the soil structure and other important soil water content is key to giving shape to this research of soil water requirements (Gálya et al.2015). Choosing the best sampling method proposed for this analysis (Christakos & Olea 1992).The physical parameters of each sample were measured (> 2 mm, 200 µm - 2 mm, 50-200 µm, <50 µm) to determine soil texture and soil water retention parameters as: maximum water capacity, minimum water capacity, moisture capacity, wilting point, available water, gravitational water and capillarity gravitational water content. The soil samples were examined in the Laboratory of Soils of the University of Debrecen, Institute of Water and Environment Management. After laboratory testing, high precision soil maps and 3-D model of deep root zone were created to support establishing the water saving variable rate irrigation system by selecting and identifying sites for different agro technical implementations and precision management zones.

Based on the measured data, GIS database (X and Y coordinates, and Z variables) were created, and then maps prepared using an appropriate interpolation method. We used the kriging method to create the maps, which is one of the most effective and commonly used methods for most spatial analysis in scientific articles, known as an interpolating technique (Virdee & Kottegoda 1984; Yao et al. 2013).We had to define the future map limits manually so that the convex and concave angles of the area can be fully represented accordingly, in the UTM system (zone N34) the map axes were set with the following limits: minimum X coordinate: 585800, maximum X coordinate: 586400, minimum Y coordinate: 5295000, maximum Y coordinate: 5297000. We also determined the spatial resolution of the map manually, which was 0.5 m. To process this data, we used Surfer and ArcGIS environment.

## **2.4 Lidar Survey**

In order to identify the elevation characteristic of the arable land, high resolution LiDAR data was analysed. The aerial LiDAR survey was done by the Institute of Water and Environmental Management and Eurosense Ltd. using IGI LiteMapper system.

The survey of arable land was conducted between harvesting of a crop and sowing of the next one. The combination of the resulted appropriate factors provided a good opportunity to understand topography of area and evaluate differences in micro-relief, ignoring the vegetation. The area was made up of in a total of 129.072.937 points. The resolution of LiDAR data points is 14.58 point/km<sup>2</sup> thus it can be used to build high resolution models.

The laser point cloud processed by photogrammetry was pre-processed with Global Mapper software. A preliminary elevation profile analysis was also carried out in the software for the arable land. On the basis of LiDAR image, the digital elevation model of the sample area was made and prepared the maps of slope categories. During processing we used different optimisation methods for pixel aggregation. Then the roads, canals and reservoirs were sorted. Using ENVI LiDAR 5.3, we created DEM and DSM of the arable land. During the next phase, the run-off and accumulation relations were investigated on the basis of slope conditions.

## **3. RESULTS AND DISCUSSION**

### **3.1 Soil Water Retention Capacity**

The in-situ measurement of field water parameters provides the spatial distribution of water quality which affect ground water quality. Different soils have different water holding capacity, depending on their texture classification. The higher the percentage of silt and clay sized particles, the higher the water holding capacity. Smaller

particles, less than 50 µm (clay and silt) have a much larger surface area than the larger sand particles. This large surface area allows the soil to hold a greater quantity of water and have high porosity as well. The water holding capacity of the soil depends on the amount of organic matter.

Our soils contain pore spaces between the soil particles, and that the size of these pores is determined by the particle size distribution of soil (Table 1-2).

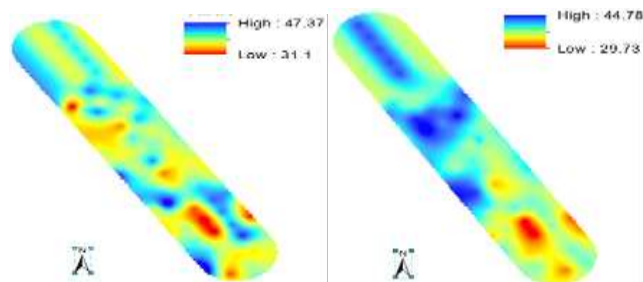
**Table 1.** Statistical distribution for soil water retention capacity

Descriptive Statistics for soil samples at 30 cm depth					
	Std. Deviation	Minimum	Maximum	Mean	
					Std. Error
Total water content	3.21	30.92	48.34	38.42	0.344
Minimum water capacity	6.58	11.09	40.96	27.03	0.70
Field Capacity	8.09	4.61	36.58	19.05	0.86
Wilting point	4.31	1.43	25.21	10.90	0.46
Available water content	4.12	4.01	25.85	11.14	0.442
Gravitational water	4.22	0.11	20.42	8.94	0.45

**Table 2.** Statistical distribution for soil water retention capacity

Descriptive Statistics for soil samples at 60 cm depth					
	Std. Deviation	Minimum	Maximum	Mean	
					Std. Error
Total water content	2.96	29.42	45.008	38.17	0.317
VK minimum water capacity	7.35	9.19	40.62	26.17	0.78
Field capacity	8.25	1.75	37.73	18.95	0.88
Wilting point	3.89	2.16	23.507	10.83	0.41
Available water content	4.55	1.95	25.94	10.78	0.48
Gravitational water	4.42	0.807	20.77	9.606	0.47

Total water content of the soil for 30 cm depth (Table 1) the minimum measured was 30.92 % while the maximum 48.34 % and the mean value was 38.42 % with a standard deviation of 3.21 %. For the deeper layer of 60 cm (Table 2) we have gained lower values for each of total water content of soil with the minimum of 29.42 % and the maximum 45 % and the mean value is 38.17 % with a standard deviation of 2.96 %. Figure 3 shows the total water content at 30cm (left) and 60cm (right) depth of the soil.



**Figure 3.** Total water content at 30cm(left) and 60cm(right) depth

Figure 3 shows the spatial distribution of total water content on field and we can delineate that two depths have major differences on spatial distribution and spreading

in the area. Also shown in the histograms (Figure 4) below their distribution got reduced within the scale of 35 to 40 % of total water content of the soil samples.

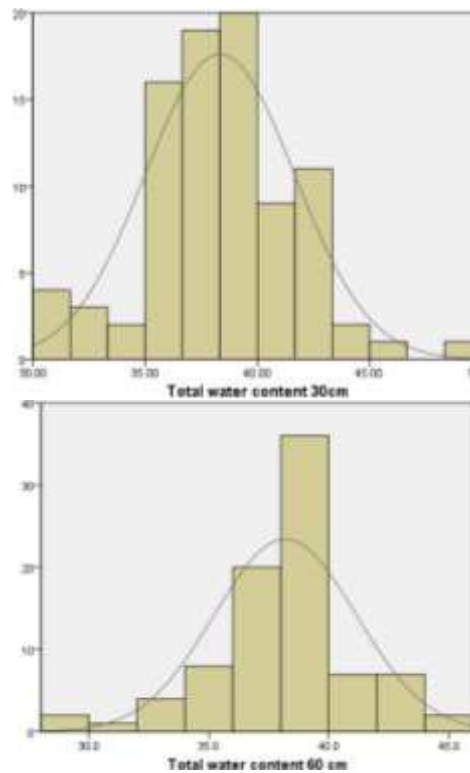


Figure 4. Total water content of investigated soil

The minimum water capacity is the amount of water held by the soil after few days of free drainage from the depth of up to 30 cm (Table 1). We have measured a minimum of 11.09 % and the maximum of 40.96 % and the mean of 27.03 % with a standard deviation of 6.08 %. In the 60 cm (Table 2) depth we have measured a minimum of 9.19 % and the maximum 40.62 % and the mean of 26.17 with a standard deviation of 7.35 %.

### 3.2 Lidar Data Analysis

Figure 5/A. shows the digital elevation model of arable land based on LiDAR data.

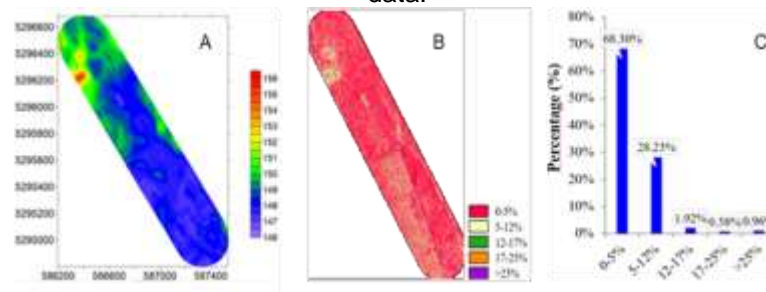
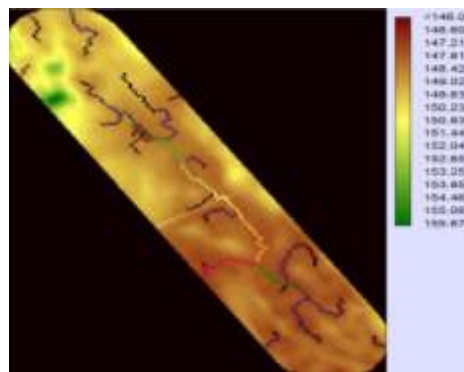


Figure 5/B. DEM and slope categories of arable land based on LiDAR survey

The elevation difference is 10 meters in the northern part of the area (151-156 m), while the southern part of it is lower (149-146 m) indicated by the blue colour. This

data helps decision making to be much faster in the agricultural sector particularly in productivity and environment management by analysing and adding GIS maps and digital terrain and field operation information. Accuracy of the survey is much more accurate for a larger area compared to field surveys with a GPS receiver. From raw LiDAR data a digital elevation model of a slope map of the area was created, shown on Figure 5/B. In the case of the slope category map, 5 categories were created (0-5%; 5-12%; 12-17%; 17-25%; > 25%). Figure 5 of slope categories showed that almost the whole area was in the 1st category (0-5 %) thus determined that this arable land can be considered flat based on colour distribution. We can also see that there are some straight lines displayed with purple colour which have an area with the slope bigger than 25 %. To determine the area of the different categories, we generated a histogram (Figure 5/C). As seen in the histogram above, we have 68.30 % of the arable land which is categorized as flat land with a slope less than 5 % and 28.23 % of the arable land belongs to the second category of the slope. Slope categories 12-17%, 17-25% and more than 25% represent smaller percentage of the area in total 3.49% of the total arable land (Figure 5C). Finally, based on the DEM we can create the runoff map of the arable land (Figure 6). Runoff lines which are generated from the elevation data differences in connection with soil water retention under the climatic information of the region show that there might be waterlogged areas (Bales et al., 2007). Runoff lines created by DEM can help drain the field even though the south area is more prone to waterlogging.



**Figure 6.** Digital Elevation Model of arable land with runoff lines

Based on the Figure 6, we can say that the water could be accumulated in the lowest part of the field and runoff water can be move from the northern part of the field to the southern part where elevation is in the lowest point. Runoff lines are important to create channels to remove potentially harmful excess water from the field. Even though this area is prone to excess water based on Table 1 and 2 and Figures 3 to 4 the south part of the field shows lower values of the field distribution in each parameter. The total available water content and gravitational water (Kirkham 2014) content is lower, meaning that this part of the field can be prone to creating moist soil to wet soil. For this case we have to evaluate irrigation programs for the field to separate the area for better water management and soil cultivation. More possibilities for LiDAR data can be used to delineate the areas and the factors contribution to soil water management.

#### 4. CONCLUSIONS

Farm soil survey in arable land resulted that we have the soil with a good texture, (great for cultivation and farming) good water retention capacity and can support the crop with enough water during the vegetation period. Variation of soil analysis in two depths 30 cm and 60 cm could be seen more easily when they were displayed using

ArcMap for their spatial distribution. Arable land texture is classified as silt-loamy, results obtained from two soil depth shown in histograms and spatial distribution figures of soil texture showed that clay and sand content has increased in the upper layer (28 % and 7.37%) while silt content dropped (6.4%) compared to the deeper soil layer. Smoothed spatial distribution in the upper layer and scattered in 60 cm layer, changes which have come from soil cultivation, conventional soil tillage practice, and weather condition. Soil cultivation practices made an impact up to 30 cm of the soil depth. Since the water holding capacity of the soil is important for crop production, silty loamy soil texture has great attributes of supporting plants during vegetation. Excluding the total water content, an increase of maximum values reached can be seen and the available water content of the soil is lower in the deeper layer. Other soil water retention parameters of the soil did not show major fluctuation of two layers related to pF values of the soil.

LiDAR data assists us to see the whole field and understand the DEM, DSM. It resulted that the area is not susceptible to erosion since 68 % is in the first category of the slope and 28 in the second category of the slope. We have to make special care for water flow and logging possibilities in the field since within the area are patches where the elevation will create water logged area. Elevation models and surface models which were created to a raster display permits to optimise cultivation and irrigation practices in the field. Farm irrigation is required in crop production when in summer time the amount of rainfall (350-360 mm) of region does not fulfil crop water requirement during the vegetation period. Field can be well drained but in the case of irrigation we should apply scheduled/separated irrigation types for different areas of the same field. DEM and runoff line would improve irrigation planning and water use efficiency.

## 5. ACKNOWLEDGEMENT

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