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SOIL WATER MANAGEMENT AND IRRIGATION WATER DEMAND CALCULATION POSSIBILITIES

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Abstract. *The water content and water management of soils basically determine the productivity and the cultivation and agronomic structure of the soils. Water acts as a solution in soils and also as a transporter of nutrients and dissolved substances. Water is involved in the physical, chemical and biological processes of soils. Different soil structure results in different water management structure. Knowing this, we have adequate information about the water supply required for plants and the amount of water stored in the soil. The efficiency of plant water consumption is very important for plant cultivation. Different plant species and varieties take up water through the roots in different ways and with different efficiency. Today's agriculture uses modern irrigation systems to prevent water shortages (drought) to reduce crop loss. It is necessary to continuously monitor the absorbable water content of soils for modern irrigation. It is advisable to start watering before the appearance of visible symptoms of lack of water (drought). Plant water absorption is most efficient when the soil moisture content is above 50% of the water absorption capacity. Irrigation should be started when the soil's absorbable water capacity approaches 50%. In our thesis, we describe the irrigation water calculation methods for determining the irrigation water requirement. We present a case study showing the effects of a modern irrigation system on sweet corn and corn and the yields of irrigated sunflowers. In the case of corn, the changes in average yield and yield parameters were investigated using the tape drip irrigation method. The irrigation, which satisfies 100% of the plant's water needs, was supplemented with a complex water-soluble fertilizer (N-P-K). The results show that the average yield of sweet corn and sunflower can be significantly increased with irrigation.*

***Keywords**: soil, water management, irrigation*

INTRODUCTION

Hydrology deals with the manifestations of water on Earth, the laws of the water cycle, and certain elements of the cycle. All of that water forms constitute the “water shell” of our planet, the so-called hydrosphere. In the hydrosphere, water occurs in all three states in a varied distribution in space and time. The hydrosphere overlaps with other terrestrial spheres: the Earth’s solid rocks layer the lithosphere (up to a depth of about 5 km), the atmosphere, and the biosphere, respectively (GOMBOS, 2011). The water cycle, also known as the hydrological cycle, is the continuous and natural cycle of water in the Earth's hydrosphere (VERMES, 1997; HUNT et al., 2020), maintained by energy from solar radiation. Surface and groundwater, as well as atmospheric and groundwater content participate in the cycle.

Soils can be classified into different groups in terms of water transport (BOORMAN et al. 1995). Soils can be categorized into four main types in terms of water transport, which are as follows:

a) Strong surface runoff (sloping soil surface, surface runoff, erosion damage) e.g. rocky skeletal soil.

b) Leaching water flow, strong downward water movement (the greater proportion of the large amount of precipitation trickles into the soil, excessive leaching) e.g. luvisol.

c) Equilibrium water balance (annual water flow balance of upward and downward water movements, alternations within the year; periodic motion of materials are typical, e.g. calcic chernozem soil.

d) Evaporative water flow (predominantly upward water movement, low-lying areas, the impact of groundwater, low groundwater salinity → no salinization; effect of stagnant saline groundwaters → salinization) e.g. typical meadow soil, solonchak soils.

Soil water capacity provides information about the soil's water content, the amount of water retained against gravitational force and the water supplying capacity of the soil. These soil properties help us make decisions about crop water and nutrient management.

It is essential to clarify two concepts regarding plant cultivation. These are: the dead water content of the soil, and the concept of water resources that can be taken up (available water). These concepts are necessary to clarify so that the total water content of the soil, which may vary depending on the soils, might not confuse the irrigation plan and crop production technology decisions. (FUTÓ and BODNÁR, 2021.)

Dead water is defined as the water content that is very tightly bound to soil colloids and in the smallest capillaries (smaller than 2 microns). The compaction force is greater than 15 atm (bar). Using the wilting experiment: the vessels of test plants are allowed to dry out until only the dead water content remains, then we can infer the amount of dead water based on the wilting point.

Available Water Content (AW) is the amount of water that is bounded by less than 15 atm (bar) of force. Available water is the form of water utilizable by plants, since it is bound to soil particles by less than 15 bars of pressure, so the suction pressure of roots can exceed it.

Determination of the soil water content is most important parameters of plants of irrigation. Modern irrigation is used to prevent water shortage. In order to avoid yield loss, it is advisable to start irrigation before the onset of the visible symptoms of water deficiency, when the moisture content of the soil falls below 50% of its water capacity.

Naturally, the current soil moisture content may also be determined by measurements, e.g. using tensiometers that can be installed in various depths. Tensiometers are used for the measurement of soil moisture suction, from which the moisture content of a given layer can be inferred. A cup-shaped object made of a variety of porous materials (plaster, ceramics, plastic) is sunk into the ground, where it is connected to a vacuum monometer by a tube.

The theoretical basis for conductivity based measurement is the significant difference between the conductivity of solid soil and water. Electrodes are inside a gypsum block, their life span is limited, about a year, but there can be significant differences. Resistance increases in proportion with the decreasing moisture content. Soil moisture content can be measured with these tools more accurately in lower ranges, although as moisture content increases, measurement errors increase as well. The measurement is affected by the salinity of soil water content as well. (FUTÓ and BODNÁR, 2021.)

The method based on the measurement of neutron scattering is fast, and is therefore also suitable for frequent measuerments; its disadvantage is that the device is expensive (VEREECKEN et al. 2015), probe pipes have to be installed, and in the top 30-40 cm layer where the soil is disturbed, the outcome is uncertain.

Determining water requirement (wr) with simple lysimeters (ZSEMBELI et al. 2018; SOLTYSIAK and RAKOCZY 2019) this method is the most reliable, the water balance of cultivation tanks lowered into the soil can be easily measured and traced. Its greatest advantage is that there is no surface onflow and leakage, and that the quantity and quality of water leaking and flowing through the soil can be measured. The results of lysimeter studies demonstrate that among identical circumstances the water requirement related to the leaf area of the varieties of the same plant species with different leaf areas increases at a decreasing rate. This correlation may be characterized with a saturation curve (SZALAI 1989).

During irrigation-related researches the water consumption of plants can be precisely quantifiable and measurable. Based on the research of SZALÓKI (1991) the water consumption of main plant species can be determined, which were measured on the lysimeter-plant of IRI (Irrigation Research Institute) during water management research projects.

Preliminary results show the NASA Land Information System (LIS) model is suitable for estimating percolation indirectly from the equation of soil water balance. Outcomes of deep percolation rates are connected with precipitation meanwhile coupled with the topography. The relationship between surface and ground-water flow is taken into consideration in the LIS model (ELBANA et al. 2019).

Water uptake of plants is very different. Higher terrestrial plants take up water with their cuticle-free roots, the emission of which is reduced by the cuticle and the regulated movement of the stoma. In the case of higher plant species water uptake via the parts above the ground is minimal (BERRY et al. 2018). If the water requirement of the plant was 100% satisfied during the irrigation, yields of 12-13 tons of hybrids were formed. The favorable water supply resulting from irrigation in hybrids shows that the decreasing effect of ever-increasing dry periods in climate change is significant, yields decreased in the control plots with bad water supply by 6.72 t/ha (P9903) and 6.07 t/ha (DKC4541). (FUTÓ and BENCZE, 2018). During the course of evolution plants have developed drought resistance to a certain extent, which depends on the species, and in particular on the given tribe (NEMESKERI and HELYES 2019). Nevertheless, even draught resistant plants are unable to fend off extensive water shortage lasting for a long time. Finally the plant dies in the end after an irreversible process of withering.

Modern irrigation works on different principles than the old technologies of a few decades ago. The spreading practice of modern irrigation uses lesser water standard with more frequent irrigation. A single dose is 15-30 mm. This submits to the requirements of the plants. The method can be started earlier and can be finished later, therefore it lengths the irrigation season. This means better utilization of machines and best irrigation practices (CHARTZOULAKIS and BERTAKI 2015).

MATERIAL AND METHODS

We tested the effect of tape drip irrigation on the change of corn yields and yielding elements of maize. In the study we used the Aqua Traxx tape drip system, sold by Metra company. During the experiment, non-irrigated (control) plots were used, then plots satisfying 75% and 100% tape drip irrigation parcels in the maize water requirement and finally, irrigation satisfying the 100% water requirement was supplemented with complex water-soluble fertilizer (NPK) in the fourth treatment.

The soil of the experiment is characterized by the fact that its physical characteristics is clay, as for its acidity it is acidic and slightly acidic, the cultivated layer does not contain $CaCO_3$, and the N-content of the soil is medium ranged based on humus content. The water management of the soil is characterized by poor water flow capability and high water retention capacity. The cultivated level is compressed, its porosity, and within that, the ratio of gravity pores is smaller.

The development of plants and the development of the crop average are largely influenced by the photosynthetic activity of the plant. Photosynthesis depends most strongly on two important factors: 1. the surface and the durability of the plant, 2. the photosynthetic chlorophyll content of the leaf. That is the reason why in this experiment, we measured the relative chlorophyll content of the plant, which shows how much the photosynthetic activity of the leaf can be influenced by continuous nutrient supply (hydroponic treatment) with irrigation and irrigation water. The relative chlorophyll content was measured with a Konica Minolta SPAD 501 meas75% and 100% of the water requirement for maize was carried out in the knowledge of the average temperature of the experimental area and the evapotranspiration of the stock. The water demand of the 100% parcels was completely replaced by the evapotranspiration, the area had a natural water capacity of about 85-100%. In response to a 75% water demand, evapotranspiration only gave ¾ of the amount of water evaporated occasionally resulting in a constantly decreasing water supply. Plots have a natural water capacity of between 45-80%. The control plots did not receive any irrigation, the natural precipitate determined the natural water capacity of the area. Since precipitation was favorable in the year, the water capacity of the parcels was similar to the control parcels, ranging from 40 to 75%.

RESULTS AND DISCUSSIONS

CALCULATION OF THE IRRIGATION WATER REQUIRETMENTS

The amount of irrigation water can be calculated knowing the water requirements of the plant, the amount of precipitation and the moisture of the soil. The starting available moisture of the soil and the amount of the precipitation are subtracted from the water demand.

$$IWr = Wr - W0 - P \text{ [mm]}$$

- IWr - irrigation water requirement (mm)
- Wr - water requirement of the plant (mm)
- W0 - the starting available water content of the soil (mm)
- P - amount of precipitation (mm)

The amount of precipitation is not previously known, and the fault of prognostication is very high. This can be calculated with the area-specific average precipitation data, therefore irrigation water requirements can be determined in a certain level of probability. If the precipitation is measured, the calculation based on the averages can be corrected by the actual measurements. This way, the calculation becomes more accurate.

The amount of the irrigation water is usually measured in mm or m^3/ha. Conversion is simple: 1 mm of moisture content means 10 m^3 water on 1 ha. It is advisable to carry out irrigation in a way that the dispersed water amount is 70-80% of the total water capacity of the soil. Dispersion above 80% or by the total water capacity can have several negative effects and bear a great risk:

• Moisture content above the static water demand prevents the root system to take up the required oxygen amount, therefore the water and nutrient uptake is being impeded, and damages can occur in the root fibers.

• The microbiological life of the soil changes due top the excessive moisture content, denitrification becomes dominant, and nitrogen loss can occur.

• Chemical processes in the soil shift toward negative reduction, and poisonous reduced ions can develop.

• The structure of the soil is damaged, proliferation can occur.

• On slope areas, run-off water and erosion problems can occur.

To calculate irrigation water needs, the losses during application must be considered, besides the irrigation water needs. Losses originate from evaporation, leakage and run-off water. Losses change depending on several factors. Evaporation losses, for example, primarily depend on the temperature and humidity of the air, droplet size and wind conditions. Losses caused by run-off water are affected by the irrigation intensity, the water capacity of the soil and the slope of the fields.

$$IWn = IWr + E + L + R \text{ [mm]}$$

• IWr = irrigation water requirement
• E - evaporation loss (mm)
• L - leakage loss (mm)
• R - run-off water (mm)

Irrigation water requirement can be calculated by the dispersion efficiency as well: [mm]

$$IWr = IWd / \eta$$

• IWr = irrigation water requirement
• η = dispersion efficiency

Efficiency depends on the irrigation conditions, usually varies between 0.7 and 0.95. Traditional irrigation practice disperses a higher amount of water at once (even 60-80 mm). This is disadvantageous from several viewpoints. This method does not consider the requirements of the plant, and water excess can negatively affect the vegetation, the microbiological life of the soil, the chemical processes and the soil structure. Some damages can be permanent, for example the structure damage of the soil. Its advantage is to decrease the number of irrigation turns, and due to less relocation, treading causes less damage and it requires less manpower.

The spreading practice of modern irrigation uses lesser water standard with more frequent irrigation. A single dose is 15-30 mm. This submits to the requirements of the plants. Due to lesser water amounts, this enables irrigation of soils that did not allow irrigation due to low water capacity. Its disadvantage is the frequent relocation, although with modern irrigation equipment (linear system, center pivot) this is not a problem. Lesser water amount means increased evaporation loss.

SOME RESULTS OF IRRIGATION EXPERIMENTS

First of all, the average yield of sweet corn was examined. During the measurement of the averge yields, we compared the yields of plots without irrigation (control), the irrigated plots to 75% water demand, the irrigated plots to 100% water demand and the irrigated plots with fertilization. The yields of sweet corn were expressed by a higher (~60-70%) moisture content than the average and a cob harvest weight.

Table 1

The relative chlorophyll content of maize (SPAD value)

	Control	75% water-based irrigation	100% water-based irrigation	100% water-base and nutrient solution
Sweet Corn	41.7	41.6	46.1	46.6
P9903	43.2	43.5	46.7	46.8
DKC4541	43.0	43.6	46.6	46.8
Average 2016	42.63	42.90	46.46	46.73
P9903	44.1	43.7	45.9	46.4
DKC4541	43.2	43.9	45.8	46.7
Average 2017	42.80	43.17	45.67	46.33

From the results, it can be seen that the yields of sweet corn could be significantly increased by the use of tape drip irrigation technology (Fig. 1). Due to the favorable precipitation, there was no difference between the yield of parcels without irrigation (control) and those with irrigation of 75% water demand in the experiment. However, the crop-enhancing effect of irrigation, which satisfies the entire water demand of the plant, was very significant even in this year's favorable water supply. The yield of sweet corn reached 22.97 t/ha, which is very favorable. This yield in the experiment was only surpassed by the yields of the plots with nutrient supply, the yield reached 26.24 t/ha.

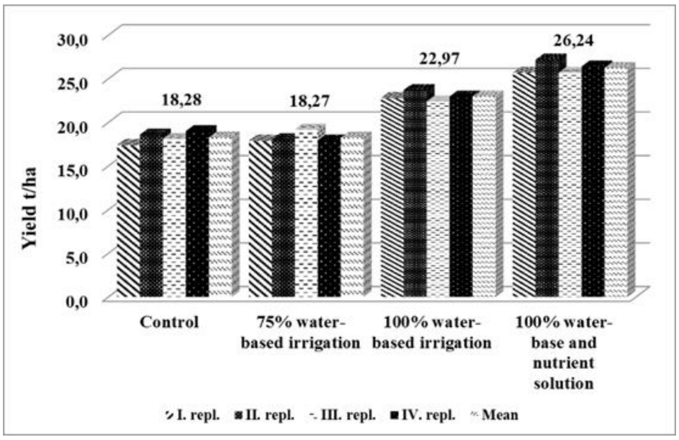

Fig. 1. The average yield of sweet corn in a tape-drip irrigation experiment

In the next group of studies, we examined two feedstuff maize hybrids whose crops were monitored during the test. The analysis of the yields of feedstock corn showed similar results than sweet corn hybrid (Fig. 2-3). There was no difference between the yields of no irrigation and the yields with irrigation that meet the 75% water demand. This was due to the satisfying amount and distribution of precipitation. However, the total water demand of the plant could not be covered by the naturally falling rainfall even in this favorable year, which meant that the yield could be increased by satisfying the 100% of water demand of corn. The yields increased by 22.3-24.5% compared to the yields of control plots.

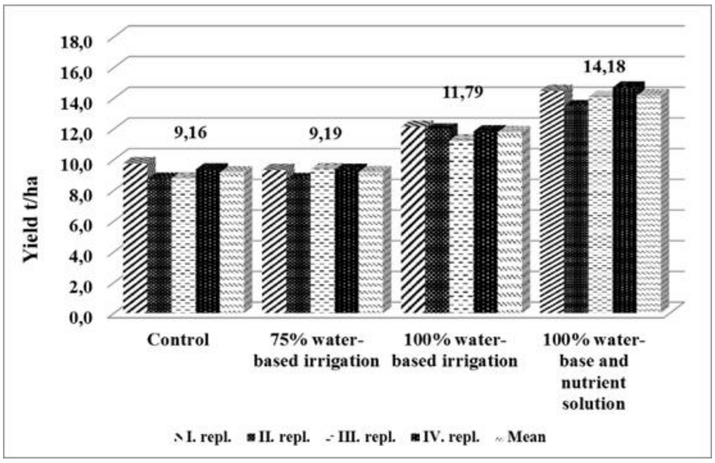

Fig. 2. Evolution of the yield of P9903 hybrid in a tape drip irrigation experiment (Szarvas)

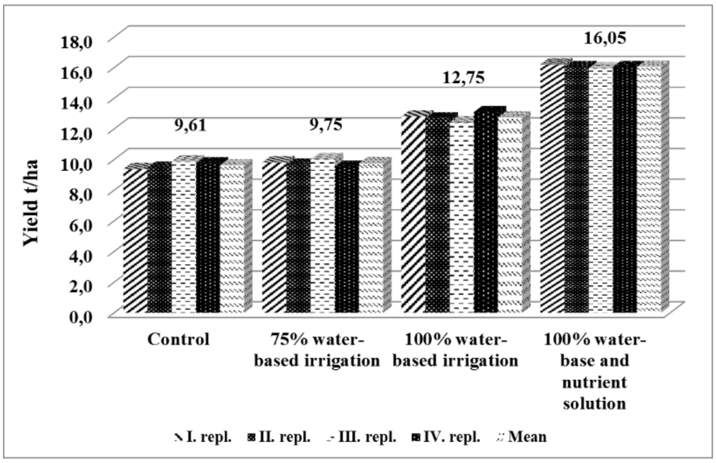

Fig. 3. Evolution of the DKC4541 hybrid yield ratio in a tape drip irrigation experiment (Szarvas)

If the water requirement of the plant was 100% satisfied during the irrigation, yields of 12-13 tons of hybrids were formed. The favorable water supply resulting from irrigation in hybrids shows that the decreasing effect of ever-increasing dry periods in climate change is significant, yields decreased in the control plots with bad water supply by 6.72 t/ha (P9903) and 6.07 t/ha (DKC4541).

In the experiment the nutrient parcels could further increase this, which is primarily due to the favorable phytophysiological condition of the plant that the plant immediately comes to the dissolved form of nutrient in the root hair zone of the root. This also refers to the important fact that optimal nutrient supply is possible only in the presence of sufficient amounts of water in the form of being available for the plant. The average yield of the plots with nutrient supply ranged from 14.18 to 16.05 t/ha, which reached the limit of the economically favorable production and profitability by the results of the experiment.

Sunflowers are not a classically irrigated crop in agriculture. You have many diseases that reduce your average yield in a rainy, wet year. However, professional and good irrigation can significantly increase yields *(Fig. 4.)*.

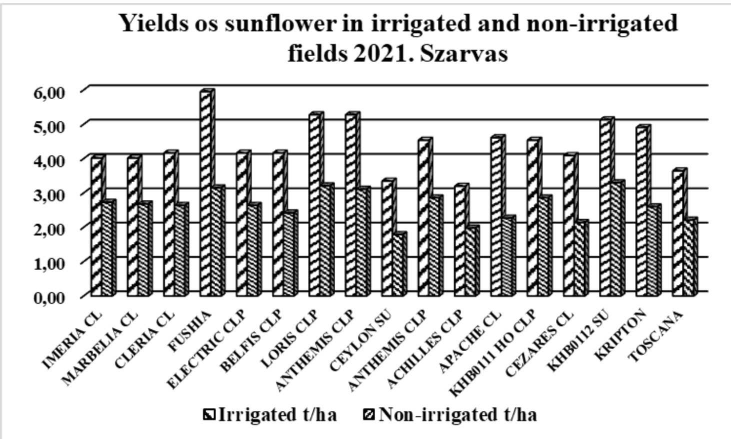

Fig. 4. Effects of irrigation on yields of sunflower (Szarvas)

Corn is extremely poor in tolerating dry conditions, dry soil. Soil drought or atmospheric drought significantly reduces yields. In our experiment, optimal irrigation with the calculated water dose increased yields by up to 4-6 t / ha *(Fig. 5.)*.

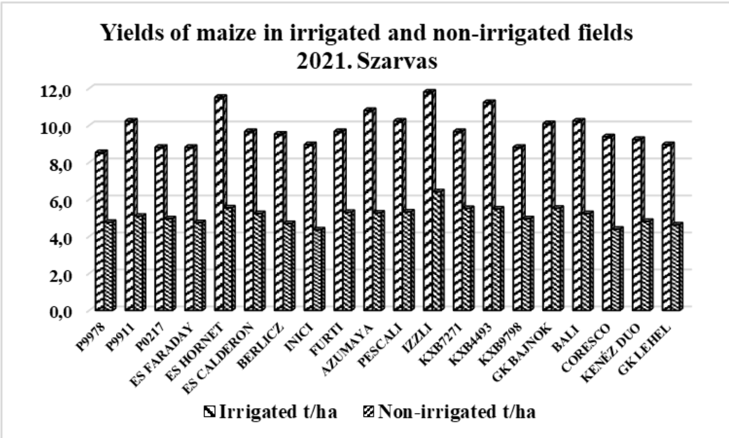

Fig. 5. Effects of irrigation on yields of maize (Szarvas)

CONCLUSIONS

Knowing the moisture content of the soil is extremely important in irrigation. Soil moisture content can be measured in several ways. However, the moisture content of soils varies, depending on the physical type of soil, the Available Water Content different. Modern irrigation replaces the missing water with 50% of the Available Water Content. This requires continuous monitoring of the soils. The most accurate soil moisture content measurements can be made with lysimeters. But the systems are slow and expensive, although they allow very accurate scientific measurement. In practice, radiofrequency and tensiometer measurements are most commonly used. The results can be used to calculate plant water consumption, evaporation and irrigation water demand.

In our own experiments, we examined the effects of different water supplies. Overall, it was found that tape drip irrigation of maize is of very low water-use, energy-efficient and generally efficient irrigation technology, which can be a major domestic technical innovation for maize irrigation in future for intensive farming. The favorable water supply resulting from irrigation in hybrids shows that the decreasing effect of ever-increasing dry periods in climate change is significant, yields decreased in the control plots with bad water supply by 6.72 t/ha (P9903) and 6.07 t/ha (DKC4541).

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