STUDY ON THE PHYSIOLOGICAL CHARACTERISTICS OF SUNFLOWER TREATED WITH BACTERIAL FERTILIZER

BAKTÉRIUMTRÁGYÁVAL KEZELT NAPRAFORGÓ ÉLETTANI SAJÁTOSSÁGAINAK VIZSGÁLATA

RITA TURY – SZILÁRD ZSOLT TÓTH – TÜNDE KAPRINYÁK – ÉVA LEHOCZKY – ILDIKÓ BÉLTEKI – RÉKA LÁPOSI
tury.rita@uni-mate.hu

Abstract

In 2019, in the experimental area on Kompolt, we tested the effect of Mikro-Vital in sunflower crops in a large-plot experiment using 2 doses (1 l ha^{-1} and 2 l ha^{-1}). The bacterial fertilizers were applied to the chernozem brown forest soil at sowing. At the beginning of July, before flowering, the relative chlorophyll content of the leaves was measured in vivo with field instruments (portable spectroradiometer and SPAD) and spectral vegetation indices were determined, which, in addition to photosynthetic processes, allow us to infer the stress tolerance of the plants and the nitrogen and water content of the leaves. These parameters are the most important determinants of fertility. We also measured the average yield at harvest. In the year of the study, weather conditions were not ideal for sunflower development. The minimal rainfall in spring resulted in poor crop development after sowing. Chlorophyll vegetation indices also indicated a significant positive effect of the bacterial fertilizer treatment, and photochemical activity (PRI), leaf water content (PWI) were higher compared to the control plots. In the control treatment, stress sensitivity (SIPI) and the amount of protective pigments (CRI, ARI) were higher. Water shortages also occurred at flowering, resulting in a medium average yield for all plots, which was lower than the average of Heves County, Northern Hungary and the country. Based on our tests, a treatment of 1 l ha^{-1} is considered optimal.

Keywords: *plant conditioner, sunflower, in vivo measurements, SPAD-value, vegetation indices*

JEL code: *Q19*

Összefoglalás

A Kompolton elhelyezkedő kísérleti területen, 2019-ben nagytáblás kísérletben vizsgáltuk a Mikro-Vital hatását napraforgó kultúrában, 2 dózis (1 l/ha és 2 l/ha) alkalmazásával. A csernozjom barna erdőtalajra vetéskor juttattuk ki a készítményeket. Július elején, a virágzás előtt in vivo terepi műszerekkel (hordozható spektroradiométer és SPAD) mértük a levelek relatív klorofill tartalmát és határoztuk meg azokat a spektrális vegetációs indexeket, melyekből a fotoszintetikus folyamatokon túl következtetni tudunk a növények stressztűrésére és a levelek nitrogén- illetve víztartalmára. Ezek a paraméterek befolyásolják a legjelentősebb mértékben a termőképességet. Betakarításkor mértük a termésátlagot is. A vizsgált évben az időjárási viszonyok nem voltak ideálisak a napraforgó fejlődéséhez. A tavaszi minimális csapadék következtében a vetés után az állomány gyengén fejlődött. Virágzáskor is vízhiány lépett fel, így

minden parcellánál csak közepes termésátlagot mértünk, ami a Heves megyei, az Észak-magyarországi és az országos átlaghoz képest is alacsonyabb volt. A klorofillra utaló vegetációs indexek, a fotokémiai aktivitás (PRI), a levélvíztartalom (PWI) is jelezték a baktériumtrágya kezelés szignifikáns pozitív hatását. A kontroll esetében pedig a stresszérzékenység (SIPI) és a védő pigmentek (CRI, ARI) mennyisége volt magasabb. Vizsgálataink alapján az 1 l/ha-os kezelés tekinthető optimálisnak.
Kulcsszavak: *növény kondícionáló, napraforgó, in vivo mérések, SPAD-érték, vegetációs indexek*

Introduction

The aim of our work, which has been going on for several years, is to help farmers by testing and developing environmentally friendly nutrient replenishment systems that can be adapted to the needs of the Heves region. Our goal is to test the applicability of various products in as many arable crops as possible, thereby providing assistance to advisory activities. In our current work, we set out to test the effect of a soil conditioner on sunflowers in a two-hectare field experiment, conducted during a growing season with unfavorable rainfall distribution in 2019., Sunflower is our most important oil crop, from an economic perspective, used to produce edible oil, animal feed, and energy crop. In 2019, the harvested area of sunflower in Hungary was 567,000 hectares, with a record yield per hectare of 3.0 t ha^{-1} on average, which is the highest average yield in the EU; a total of 1.7 million tons of sunflowers were harvested in Hungary. The purchase (producer) price in 2019 was 101 HUF kg^{-1} (http 1, http 2). In 2019, the total production quantity in Heves County was 73,372 tons from 23,910 hectares of harvested area, with an average yield of 3,070 kg ha^{-1} (http 3).

In addition to examining crop yields, we used in vivo measurement techniques (ground-based remote sensing) to obtain large amounts of data without damaging the plants (spectral vegetation indices), providing us with information about the plants' organic matter production potential and stress sensitivity at the beginning of flowering. We applied two doses (1 l ha^{-1} and 2 l ha^{-1}) of the Mikro-vital liquid soil conditioner, which has a positive effect on soil life. The product was developed with the aim of promoting healthy soil life and environmentally friendly plant nutrition. Its content is protected by patent. The soil inoculant contains free-living nitrogen-fixing and phosphorus-mobilizing soil bacteria (*Azospirillum brasilense, Azotobacter vinelandii, Pseudomonas gressardii*), microelements, and indole-3-acetic acid, which has a positive effect on plant growth (http 4, http 5, http 6). Its use makes phosphorus and potassium available, which increases root mass, contributes to the formation of appropriate soil colloids, and improves the microbiological condition, structure, cultivability, and nutrient-supplying capacity of the soil. The use of the product requires a soil pH of 5.0–8.5, a soil temperature of at least 5–6 °C, and an organic matter content of around 1%, depending on the soil type. It can be used in both autumn and spring, either before sowing or at the same time as sowing, by applying it to the soil. Its use is not only recommended for traditional arable- and horticultural crops, but is also permitted in organic farming (http 7). *Azospirillum brasilense* is a rod-shaped, Gram-negative bacteria that can fix nitrogen, thereby reducing the need for fertilizers. It promotes resistance to various abiotic stresses, such as drought (http 8). *Azotobacter vinelandii* is a gram-negative bacteria, that is also capable of fixing nitrogen from the air and converting it into a form that can be used by plants. It produces auxin, a plant hormone that has a positive effect on plant growth (http 9). In addition, it is a widely applicable resilient bacteria, as it does not require symbiosis (e.g., with leguminous plants), and can therefore be used with many different crops (corn, wheat, rice, sorghum, etc.). It is able to adapt to different soil conditions and, like blue-green algae, it can form cysts that help it survive (http 10, http 11). *Pseudomonas* *gressardii* is a rod-shaped, Gram-negative, mobile aerobic bacteria that can mobilize phosphate and potassium in the soil and is capable of binding iron (http 12).

All these effects enhance the plants' defense mechanisms and increase their stress tolerance, which leads to improved crop quality and higher average yields. Its composition is completely environmentally friendly and fully biodegradable. We have already used the product in numerous crops.

Material and methods

The experimental site is located in Kompolt, on the south-eastern side of the Mátra Mountains, between Eger and Gyöngyös. The weather is moderately warm, prone to drought, and precipitation distribution is uneven (HOLLÓ et al. 2009). Based on soil sampling and testing in 2015 (Table 1): on plot BTK 4, the soil type is chernozem brown forest soil, the pH is basically acidic (pH H_2O: 5.86; KCl: 4.6), with low calcium content ($CaCO_3$ 0 %), moderate nitrogen (nitrate+nitrite: 18.5 mg kg^{-1} dry weight), low phosphorus (AL-P_2O_5 63.4 mg kg^{-1}) and adequate potassium (AL-K_2O 212.3 mg kg^{-1}) content, and a humus content of 2.4 %. The soil has unfavorable physical features (it is heavily compacted, difficult to cultivate, and prone to crusting). The groundwater level can be found approximately at 11-12 m depth, therefore the amount and distribution of precipitation, as well as the method of soil cultivation, influence the utilization of fertilizers and crop yields (TÓTH 2011).

Table 1. The results of soil analysis of the experiment (2015)

Designation	Value
pH (KCl)	4.60
pH (H_2O)	5.86
H%	2.47
Plasticity (K_A)	43
humus (%)	2.4
Salinity (%)	0.07
N (nitrate+nitrite) (mg kg^{-1})	18.5
AL-P_2O_5 (mg kg^{-1})	63.4
AL-K_2O (mg kg^{-1})	212.3
$CaCO_3$ (%)	0
Mg (KCl) (mg kg^{-1})	408
AL-Na (mg kg^{-1})	13.20
Zn (EDTA) (mg kg^{-1})	1.66
Cu (EDTA) (mg kg^{-1})	4.07
Mn (EDTA) (mg kg^{-1})	166
S (KCl) (mg kg^{-1})	31.7

Source: based on the data of Fleischmann Rudolf Research Institute

The experiment was set up in spring 2019 on the two-hectare "BTK 4" field, where we marked out 4.5×75.9-meter plots. The rows were oriented in an east-west direction. The applied treatments were: 1. control, 2. fertilizer, 3. Mikro-Vital 1 l ha^{-1}, 4. Mikro-Vital 2 l ha^{-1}. The control plot did not receive any treatment. The strengths of the highly adaptable, mid-season maturing ES EMERIC HO CLP hybrid sunflower, used in the experiment include good stress tolerance, disease resistance, medium oil content, and high oleic acid content. Its sowing time is normal, the plant height is medium with turned head. Produces high and predictable yields even in less favorable areas. Its early vigour is very good. Its tolerance to stem sclerotinia, macrophomina and alternaria is also very good. Its lodging resistance and tolerance to head sclerotinia can be considered good (http12).

The agrotechnological operations used are summarized in Tables 2 and 3.

Table 2. The agrotechnological operations of the experiment

Operations		**Date**
Preceding crop	maize	20/10/2018
Stem crushing	RZ-3	22/10/2018
Disc cultivation	IH plate disc plough+roller	22/10/2018
Base fertilizer placement	Sulky 30-RTK; NPK 8:24:24 (250 kg ha^{-1})	11/11/2018
Plowing:	IH 4 plow	11/11/2018
Starter fertilization	Sulky 30-RTK; CAN (150 kg ha^{-1})	06/04/2019
Mikro-Vital 1 l ha^{-1}	Berthoud 2500/18. Water 200 l ha^{-1}	07/04/2019
Seedbed preparation	Seedbed combinator	07/04/2019
Sowing:	Matter Mac 6	23/04/2019
Rolling	Ring cylinder 3	23/04/2019
Applied sunflower hybrids	ES EMERIC HO CLP	
Date of emergence		02/05/2019
Top dressing placement in Spring	Sulky 30-RTK; CAN N-fertilizer total active substance content: 39 % (112.5 kg ha^{-1})	05/06/2019
Plant protection treatments	According to Table 2.	
Desiccation	Fozát 480 2 l ha^{-1}	12/09/2019
Harvesting	NURSERYMASTER ELITE 1,9 SD	26/09/2019

The preceding crop was corn, which was harvested on September 20, 2018. Two days later, stem crushing was followed by discing and closing with a ring roller, and basic cultivation was made with 30 cm deep plowing on November 11. The base fertilizer (NPK 8:24:24, 250 kg ha^{-1}) was applied before plowing (November 11, 2018). After applying starter fertilizer (CAN 150 kg ha^{-1}), seedbed preparation was carried out using cultivator (April 7, 2019). At the same time, the Mikro-Vital liquid soil bacteria preparation was also applied and worked into the soil. The sowing date was April 23, 2019. Emergence was uniform, beginning on May 2, nine days after sowing. Post-emergence weed control was carried out on May 28, 2019, when the plants had 5 pairs of leaves (Pulsar 40 SL 1.2 l ha^{-1}). Treatment against pests and fungal diseases was carried out at the bud emergence stage (June 25, 2019) (Karate Zeon 5 CS 0.2 l ha^{-1} + Pictor 0.35 l ha^{-1} + Atonik 0.5 kg ha^{-1} + Carbonboron 1 l ha^{-1} + Trend 90 0.1 % + Antifoam 3 ml in 200 l water). The harvest took place on September 26, 2019 (Table 2). Two weeks after the second pesticide treatment (July 11, 2019), the relative chlorophyll content of the leaves was measured by using a Minolta SPAD-502 (Konica, Minolta, Japan) instrument (SPAD-Soil Plant Analysis Development). We selected 20 plants per plot randomly, along the entire length of the plot. For each selected plant, we measured from the top, in the middle of the 3rd or 4th mature (neither young nor old) leaf.The SPAD measurement area is 0.06 cm^2, and the index is calculated in SPAD units based on the absorbance measured at 650 nm and 940 nm (GITELSON and MERZLYAK 2004). This method is also used in agriculture to estimate the nitrogen supply, health status, and biomass production potential of plants (RAJCAN et al. 1999).

Table 3. Applied plant conditioner and plant protection treatments

Placement of plant conditioners		**Plant protection treatments**	
	At the time of sowing 23/04/2019	*At 5 pairs of leaves stages 20/05/2019*	*At bud emergence stage 25/06/2019*
Control	-	Pulsar 40 SL 1.2 l ha^{-1}	Carate zeon 5 CS 0.2 l ha^{-1} + Pictor 0.35 l ha^{-1} + Athonic 0.5 kg ha^{-1} + Carbon 1 l ha^{-1} + Trend 90 0.1% + Antifoam 3 ml + 200 l water
Treatment 1	-	Pulsar 40 SL 1.2 l ha^{-1}	Carate zeon 5 CS 0.2 l ha^{-1} + Pictor 0.35 l ha^{-1} + Athonic 0.5 kg ha^{-1} + Carbon 1 l ha^{-1} + Trend 90 0.1% + Antifoam 3 ml + 200 l water
Treatment 2	1 l ha^{-1}	Pulsar 40 SL 1.2 l ha^{-1}	Carate zeon 5 CS 0.2 l ha^{-1} + Pictor 0.35 l ha^{-1} + Athonic 0.5 kg ha^{-1} + Carbon 1 l ha^{-1} + Trend 90 0.1% + Antifoam 3 ml + 200 l water
Treatment 3	2 l ha^{-1}	Pulsar 40 SL 1.2 l ha^{-1}	Carate zeon 5 CS 0.2 l ha^{-1} + Pictor 0.35 l ha^{-1} + Athonic 0.5 kg ha^{-1} + Carbon 1 l ha^{-1} + Trend 90 0.1% + Antifoam 3 ml + 200 l water

Spectral vegetation indices (Table 4) were determined on the same leaves using field spectroscopic reflection measurements (ASD FieldSpecPro portable spectroradiometer, USA) to estimate leaf chlorophyll, carotenoid, anthocyanin, and water content, light utilization, and stress sensitivity. The spectral range of the instrument is 350-2500 nm. The spectra containing the stored raw DN values were converted to reflection values using ViewSpecPro software. The optical vegetation indices were calculated by using Microsoft Excel with the formulas given in Table 4. From the large number of vegetation indices, we selected those that have already been tested in agriculture and are known to be correlated with the physiological parameters mentioned above (GARCIA-ROMERO et al. 2017), and are well suited for mapping the qualitative and quantitative parameters of agricultural crops in practice (GABRIEL et al. 2017). We examined whether the effects of treatments could be detected at the beginning of flowering using spectral vegetation indices. After harvesting, we measured the yield of each plot. The effect of the treatments on the examined parameters was assessed using one-way analysis of variance (ANOVA) and Tukey's b test (SPSS 20.0).

Table 4. Applied vegetation indices

Structural indices	Formulae	References
Renormalized Difference Vegetation Index (RDVI)	$(R_{800}-R_{670})/((R_{800}+R_{670})^{0,5})$	Roujean and Breon (1995)
Enhanced vegetation index (EVI)	$2.5\times(R_{840} - R_{670})/(R_{840} + (6\times R_{670}) - (7.5\times R_{450}) + 1)$	Huete et al. (2002)
Vogelmann index (VOG1)	R_{740}/R_{720}	Vogelmann et al. (1993)
Leaf pigments		
Carotenoid Reflectance Index (CRI)	$1/R_{550}-1/R_{700}$	Gitelson et al. (2004)
Anthocyanin Reflectance Index (ARI)	R840× (1/R550-1/R700)	Gitelson ez al. (2004)
Stress sensitivity – carotenoid/chlorophyll ratio		
Structure Insensitive Pigment Index (SIPI)	$(R_{800}-R_{445})/(R_{800}-R_{680})$	Peñuelas et al. (1995)
Light use efficiency – xanthophyll index		
Photochemical Reflectance Index (PRI)	$(R_{550}-R_{570})/(R_{550}+R_{570})$	Gamon et al. (1997)
Water content of leaves		
Plant Water Index (PWI)	R_{970}/R_{900}	Peñuelas et al. (1997)

Source: ZARCO-TEJADA et al. 2005

Results

Sunflower is a crop with moderate water requirements (500-550 mm during the growing season). They have a strong, deep taproot with intense suction power. The formation of roots and root hairs continues until the end of the growing season. It makes good use of water and nutrients that are inaccessible to other plant species, which gives it good drought tolerance. From a water management perspective, the critical periods are germination, emergence, intensive stem growth, and flowering. The latter is characterized by the fact that plants consume 40% of their total water consumption (up to 200 mm) during this period (PEPÓ 2019, http 14).

The effect of precipitation amount and distribution on sunflower yield

The top 20 cm layer of soil became increasingly dry due to low precipitation (30.2 mm) in the first three months of 2019. This amount is only one-third of the 40-year average (91.7 mm). The moisture content of the deeper soil layers also failed to reach ideal levels because winter precipitation was insufficient to replenish the soil after the autumn drought. The amount (32.2 mm) and distribution of precipitation during the sowing period had a positive effect on the initial development of sunflowers, resulting in relatively uniform germination. The cool May rainfall (107.6 mm), which was well above the long-term average across the country (http 15), reduced the severity of the drought. The upper part of the soil became saturated with moisture, which slowly seeped into the lower layers. In the first days of summer, the weather became significantly warmer and sunnier, and the growth of sunflowers, which had been slow in May, accelerated in the warmer weather. Dry, hot weather continued until mid-June. During the hottest hours, atmospheric drought also developed, and strong UV radiation scorched the leaves of plants in addition to the high sun. During the June heatwave, a total of 37.2 mm of precipitation fell, which is 40% less than the 40-year average and typically came in the form of showers. There was therefore little precipitation during the period of intensive stem growth and the formation of generative organs. Due to several thunderstorms in mid- and late July, a total of 88.9 mm of precipitation fell during the month, which is 20 % more than the 40-year average, improving soil moisture levels. The rainy period was not good for sunflower flowering. It reduced the success of insect pollination and contributed tot he onset of diseases. The warm, dry weather in August was favorable for sunflower ripening. The 47.5 mm of precipitation was necessary (which is around the 40-year average), because seed growth and oil accumulation account for 25-30 % of the total water requirement. The sunflower were already ripening in September and did not require any additional rainfall, so the 33.4 mm of rain was sufficient for ripening. During this period, heavy rainfall slows down the ripening process, reducing both crop yield and oil content (PEPÓ 2019). The amount of precipitation during the growing season was 10 % below the 40-year average (Table 5). Due to the resulting water shortage, we obtained lower (average) crop yields.

Table 5. Monthly precipitation between January and September in 2019 (mm)

Months	Jan.	Febr.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Sum
Rainfall (mm)	21.2	5.3	3.7	32.2	107.6	37.2	88.9	47.5	33.4	377.0
Average over the past 40 years	30.8	33.1	27.8	34.8	58.0	62.5	72.0	50.0	45.6	414.6
Difference	-9,6	-27.8	-24.1	-2.6	49,6	-25.3	16.9	-2.5	-12.2	**-37.6**

Source: Agricultural Research Institute in Kompolt

The effect of treatments on sunflower yield

According to data from the Hungarian Central Statistical Office (http 1 and 2), the average sunflower yield in Heves County in 2019 was 3,070 t ha^{-1}, which is in line with the typical yield for the Northern Hungary region and slightly higher than the national average (3.0 t ha^{-1}).

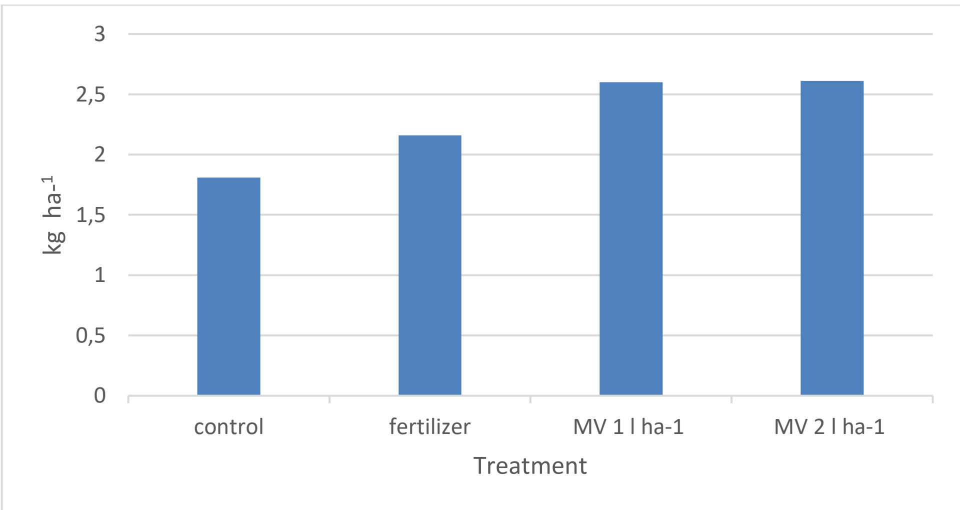

Figure 1. Effect of the treatment on the average yield of sunflower (at 9% of seed's moisture content) at harvest (September 26, 2019)
Source: Agricultural Research Institute in Kompolt

At harvest time, the moisture content of the sunflowers was 9 %. In the control plot, the average sunflower yield (1.81 t/ha^{-1}) was significantly lower than the county and national averages, which can be attributed to the drought that has prevailed during the growing season (for several years now). As a result of fertilizer treatment, the average yield increased (2.16 kg ha^{-1}), which is 20 % higher than the control. With Micro-Vital treatment at 1 l ha^{-1}, the average yield is 2.60 t ha^{-1}, which is 44 % higher than the control. With the Micro-Vital 2 l ha^{-1} treatment, the average yield was 2.61 t ha^{-1}, which is 45 % higher than the result of the control treatment. The average yields obtained with the 1 l ha^{-1} and 2 l ha^{-1} treatments were closer to the average for Heves County and the national average (Figure 1). It can be concluded that the lower concentration of Mikro-Vital treatment resulted in a significantly higher yield compared to the control despite the drought, thanks to better nutrient utilization, while the higher concentration of Mikro-Vital treatment barely increased the average yield in comparison.

Photosynthetic parameters based on spectral vegetation indices

The efficiency of photosynthesis is one of the most important characteristics in terms of crop yield and quality. However, it can be strongly influenced by environmental stress factors such as water shortage, high light intensity, or high temperatures. The amount and composition of photosynthetic pigments are very informative in terms of photosynthetic activity, so by examining chlorophyll content and the chlorophyll/carotenoid ratio, we can obtain valuable information about the biomass production capacity of plants. The relative chlorophyll content of leaves can be determined, among other things, by the SPAD value, which also indicates the nitrogen supply of plants, and is therefore widely used in agricultural practice to characterize plant health and plan nutrient supply. Its value changes with the phenological stages of the plant, reaching its highest level at the beginning of flowering (KANDEL 2020). At the beginning of flowering, the chlorophyll content of the plants was assessed by determining the SPAD value and some spectral vegetation indices, which can be correlated with chlorophyll content. In our previous field experiment, we found that the effect of the treatments on SPAD values was measurable but not significant due to the high standard deviation of the data. We observed the same in the present study, although SPAD values were highest in treatment 2 (Table 6). The values of the indices indicating chlorophyll content (RDVI, EVI, VOG1) were significantly higher in treatment 2. In parallel with this, the value of the index indicating photochemical efficiency (PRI) was also highest in treatment 2. This index is inversely proportional to the SIPI index, which refers to the amount and activity of xanthophylls playing a role in light protection (GAMON et al. 1997). The chlorophyll/carotenoid ratio (SIPI) of plants, primarily the amount of xanthophylls, indicates the sensitivity of plants to environmental (stress) effects (PENUELAS et al. 1995). There was no significant difference in the value of this index between treatments, but the highest value was found in the control. However, the amount of protective pigments (CRI-carotenoids; ARI-anthocyanins) was significantly higher in the control (Table 6). In addition to fertilization, the soil bacteria preparation also promoted nutrient uptake by the plants and increased their stress tolerance. All of these factors have a positive effect on crop yield. In our previous nutrient replenishment experiments, we successfully used these indices to characterize the physiological parameters of arable crops (wheat, corn, rapeseed, sunflower) (KAPRINYAK et al. 2018; LAPOSI et al. 2020; TURY et al. 2023). The PWI index, which indicates the water content of leaves, was significantly higher in treatment 2 than in the control. Although its value is influenced not only by water content but also by leaf structure, dry matter content, and leaf area index (LAI) (ZARCO-TEJADA et al. 2001), based on our results, it can be said that the water content of leaves treated with soil bacteria is more favorable than that of control leaves. This has a positive effect on numerous other metabolic processes in the plant.

Table 6. Relative chlorophyll content and spectral vegetation indices in wheat leaves 11. 07. 2019. (Note: a, b, c, d index: significance groups by Tukey-b test (p<0.05); ANOVA significance: * - p<0.001, ** - p<0.01, * - p<0.05, ns – not significant; mean+SD, n=20) 11/07/2019**

Parameter	Level of significance	(1) control	(2) treatment 1	(3) treatment 2	(4) treatment 3
SPAD	ns 34251-a a a a a	38.01±1.658	38.12±2.638	**38.79±2.618**	38.30±3.895
RDVI	***15423-a ab bc c c	0.592±0.496	0.634±0.028	**0.636±0.523**	0.621±0.028
EVI	***14352-a ab bc c c	0.729±0.071	0.796±0.043	**0.801±0.075**	0.775±0.045
VOG1	*** 15243-a a ab bc c	1.490±0.066	1.518±0.051	**1.555±0.069**	1.543±0.062
PRI1	*** 34215 a a a b c	0.159±0.032	0.174±0.032	**0.205±0.004**	0.190±0.030
SIPI	ns 35421-a a a a a	**0.780±0.041**	0.776±0.026	0.772±0.031	0.775±0.027
CRI	*** 32451-a a a a b	**5.844±1.541**	4.599±1.330	4.269±1.221	4.628±1.597
ARI	*** 321-a ab bc bc c	**0.305±0.235**	0.215±0.259	0.176±0.185	0.246±0.264
PWI	*** 41523-a a b c d	0.950±0.006	0.967±0.004	**0.969±0.005**	0.960±0.05

Conclusions

At the Kompolt Research Institute an important task was to test and develop environmentally friendly nutrient replenishment methods that could be adapted to the region. The experimental area is prone to drought, the soil is heavily compacted, difficult to cultivate, prone to crusting, and requires very careful agrotechnology to retain water on soil with a thin humus layer. The aim of this study was to describe the effects of a fertilizer and three levels of Mikro-Vital soil conditioner (1 l ha^{-1}, 2 l ha^{-1}) on the yield of the ES EMERIC HO CLP sunflower hybrid, moreover to characterize the photosynthetic processes and stress sensitivity of treated and control plants before flowering by vegetation indices. During the growing season of the under review, there was a significant lack of rainfall and its distribution was also quite extreme, which resulted in lower yields than would be expected from the hybrid in all treatments. However, both fertilizer and Micro-Vital treatments resulted in higher average yields than the control. Soil bacteria treatments provide plants with a more balanced supply of nutrients and water, which also contributes to increased stress tolerance. The vegetation indices we examined already indicated this at the beginning of flowering. Most of these indices can be used in agricultural practice to plan nutrient replenishment or plant protection treatments, or to estimate crop yields. Many of them are available from satellite databases and reflection measurements from multispectral cameras mounted on drones, and can be integrated into precision farming. Based on our results, a lower dose of Mikro-Vital treatment already results in a significant increase in crop yield (by 44 %), which was confirmed by the average yield and vegetation index values. A higher dose did not result in an increase in crop yield (10 kg ha^{-1}) that could be considered economical, taking into account the price of the product (8700 HUF l^{-1} in 2025 by http 16) and the purchase price of the sunflower (101000 HUF in 2025 by http 1).

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Authors

Dr. Rita Tury, PhD
assistant professor, corresponding author
Hungarian University of Agriculture and Life Sciences, Department of Soil Science, Institute of Environmental Sciences, Károly Róbert Campus, ,
H-3200 Gyöngyös, Mátrai. u. 36.
tury.rita@uni-mate.hu

Dr. Szilárd Zsolt Tóth, PhD
associate professor
Hungarian University of Agriculture and Life Sciences, Department of Agronomy, Institute of Agronomy, Szent István Campus,
H-2100 Gödöllő, Páter K. u. 1.
toth.szilard.zsolt@uni-mate.hu

Dr. Tünde Kaprinyák, PhD
University of Debrecen, Balásházy János Practical Technical School, Highschool and Dormitory
H- 4014 Debrecen, Mezőgazdász u. 1.
kaprinyak.tunde@gmail.com

Prof. Dr. Éva Lehoczky, PhD, DSc
professor
Hungarian University of Agriculture and Life Sciences, Department of Environmental sustainability, Institute of Environmental Sciences, Georgikon Campus,
H-8360 Keszthely, Deák F. u. 16.
lehoczky.eva@uni-mate.hu

Dr. Ildikó Bélteki, PhD
assistant professor
Hungarian University of Agriculture and Life Sciences, Department of Agronomy, Institute of Agronomy, Károly Róbert Campus,
H-3200 Gyöngyös, Mátrai. u. 36.
belteki.ildiko@uni-mate.hu

Dr. Réka Láposi, PhD
associate professor
Hungarian University of Agriculture and Life Sciences, Department of Agronomy, Institute of Agronomy, Károly Róbert Campus,
H-3200 Gyöngyös, Mátrai. u. 36.
laposi.reka@uni-mate.hu