INVESTIGATION OF THE PHYSIOLOGICAL EFFECTS OF PLANT CONDITIONERS IN FIELD EXPERIMENTS OF WINTER WHEAT

NÖVÉNYKONDÍCIONÁLÓK ÉLETTANI HATÁSÁNAK VIZSGÁLATA ŐSZI BÚZA NAGYPARCELLÁS KÍSÉRLETBEN

RITA TURY – SZILÁRD ZSOLT TÓTH – ÉVA LEHOCZKY – RÉKA LÁPOSI
Tury.Rita@uni-mate.hu

Abstract

Our study aimed at to test the effects of two different plant conditioners on some morphological parameters, yield and grain quality of winter wheat (Babona) in a field experiment with medium plots, and to investigate some physiological parameters closely related to yield quantity and quality at the beginning of ear emergence by in vivo field measurements. At the beginning of ear emergence we determined the relative chlorophyll content of leaves (SPAD value), moreover leaf reflectance was measured with a portable spectroradiometer to produce spectral vegetation indices that can be used to evaluate the effects of treatments on chlorophyll, carotenoid, anthocyanin and water content of leaves, and to infer photochemical efficiency and stress sensitivity. The results were strongly influenced by the unfavourable rainfall distribution during the growing season. Precipitation deficit in spring significantly reduced the development of the crop stand (yield was below the national and county levels), and its effect was also observable in quality parameters (low raw protein and gluten content), but the positive effect of treatment 1 was detectable: higher yield and quality, higher plant height and ear length compared to the control. At the beginning of ear emergence, some spectral vegetation indices indicated the positive effect of treatment 1 despite the drought: chlorophyll content and photochemical activity of leaves were higher, and higher stress sensitivity and protective pigment concentration in the control.
Keywords: *plant conditioners, winter wheat, in vivo measurements, spectral vegetation indices*
JEL code: *Q19*

Összefoglalás

Vizsgálatunk célja az volt, hogy teszteljük két különböző növénykondícionáló készítmény hatását mezoparcellás kísérletben az őszi búza (Babona) egyes morfológiai paramétereire, termésátlagára és termésminőségére, in vivo terepi mérési módszerekkel a kalászolás kezdetén egyes élettani paramétereire, melyek szoros kapcsolatban vannak a termés mennyiségével és minőségével. Kalászolás kezdetén mértük a levelek relatív klorofill-tartalmát (SPAD-érték), illetve hordozható spektroradiometerrel mértük a levelek reflektanciáját, melyekből olyan a spektrális vegetációs indexek állíthatók elő, melyek segítségével értékelhető a kezelések hatása a levelek klorofill, karotinoid, antocián és víztartalmára, következtethetünk belőle a fotokémiai hatékonyságra és a stresszérzékenységre. Az eredményeket a vegetációs időszakra jellemző kedvezőtlen csapadékeloszlás nagymértékben befolyásolta. A tavaszi csapadékhiány jelentősen visszavetette az állomány fejlődését (a termésátlag az országos és a megyei szint alatt maradt), *hatása érzékelhető volt a minőségi paraméterekben is (alacsony nyersfehérje és sikértartalom), de az 1. kezelés pozitív hatása kimutatható volt: nagyobb termésátlagot, jobb minőséget, nagyobb növénymagasságot és kalászhosszt mértünk a kontrollhoz képest. A kalászolás kezdetén egyes spektrális vegetációs indexek a szárazság ellenére is jelezték az 1. kezelés pozitív hatását: magasabb volt a levelek klorofill tartalma, illetve fotokémiai aktivitása, a kontroll esetében pedig a stresszérzékenység és a védő pigmentek mennyisége volt magasabb.*

Introduction

In addition to its more than 100 years of breeding activity, the MATE Kompolt Experimental Station's important mission is to help farmers by testing and developing environmentally friendly nutrient supply systems that can be adapted to the region. Our aim is to test the applicability of different products in as many field crops as possible, thus helping to support the advisory activity. In the present work, we aimed to test the effects of two complex plant conditioning products on winter wheat in a field experiment with medium plots during a growing season with unfavourable rainfall distribution in 2021. In addition to investigation of yield, grain quality, plant height, spike length, *in vivo* measurement techniques (ground remote sensing) were used to obtain a large amount of data without destroying the plants (spectral vegetation indices) and to provide information on the organic matter production potential and stress sensitivity of the plants already at the beginning of ear emergence.

One of the liquid plant conditioners we used (treatment 1) enhances the defence mechanism of plants against various abiotic and biotic stresses. Its composition is patent protected, the main types of components are seaweed extract, hydrolysed proteins, macro-, meso- and microelements (N, P, K, B, Zn, Cu, Mn, Fe, Mo), various secondary metabolites (e.g. tannins, mannitol, alginate). The combined effect of these nutrients enhances the stress tolerance of plants, and the nutrients provide a continuous optimum supply of nutrients even in soils of poor quality. The various amino acids and the algae extract help in nutrient uptake. The formulation has been proven in many crops. In the field of winter cereals it is recommended for use in autumn to promote the breakdown of the crop residues and to promote rooting in the early stages of development, which also enhances winter hardiness. Spring application is recommended before flowering, either in one application with the pesticides, but can be used up to 4 times until the end of the growing season to increase stress tolerance. The formula used in the first treatment increased yields, improved crop quality parameters and increased stress tolerance in both field crops (maize, soybean, potato, sunflower, winter oilseed rape, sugar beet) and horticultural crops (apple, pear, plum, melon, tomato, pepper, cucumber, grape). In winter wheat, it resulted in an average yield increase of 10% in different soil types and under different ecological conditions.

In the second treatment, we used a liquid biostimulant formulation with a high oil content, which stimulates the proliferation of mycorrhizal fungi, which affects the physiological processes of the plants at several points. Its composition is also patent protected, and the name of the product is also withheld at the request of the manufacturer. Its composition is characterised by the presence of algae extract, plant extracts, plant essential oils and mineral oils. Its composition is completely environmentally friendly and completely biodegradable in the environment. Its positive effect on soil life is mainly due to the fact that it contains a readily available carbon source for several beneficial soil microbes, which multiply quickly after application, thereby increasing the decomposition of organic matter in the soil (and hence the temperature) and the conversion of nutrients into available forms. In addition, conditions are made unfavourable for many pathogenic microbes and soil-dwelling pests. The increase in soil life leads to higher carbon dioxide concentrations, which also has a positive effect on soil structure (together with oil content) and increases the solubility of certain nutrients. All these combine to increase the stress tolerance of plants, leading to an increase in average yields and improved yield quality. As with the previous formulation, applications in the autumn and spring are recommended. The effect of this biostimulant formulation was also tested in different field (winter wheat, sugar beet, maize, soybean, sunflower, winter swede) and horticultural (pepper, tomato, grapes, melon, apple) crops. In winter wheat, the effect was more pronounced on the root system of the plants, which has a positive effect on the nutrient and water management of the plant, thus promoting drought tolerance.

By agreement with the manufacturers, we are not allowed to disclose the names of the products used in our trials, including the contact details of the website summarising the references.

Material and methods

The experimental site is located in Kompolt on the southern side of the Mátra, between Eger and Gyöngyös. The weather is moderately warm, drought-prone, and the precipitation distribution is unpredictable (HOLLÓ et al. 2009). The proximity of the North Central Mountains and its rain shadow, moreover harsh and snow-free winter weather makes it an excellent location for breeding autumn-sown crops.

Based on own soil sampling and investigation in 2015: the soil type in AGRO-2 plot is chernozem brown forest soil, the pH is basically acidic (pH H_2O: 6.26; pH KCl: 4.9), with a low calcium content ($CaCO_3$: 0%) and humus content (2.4%), moderate N (nitrate+nitrite: 18.5 mg kg^{-1} d.w.), poor P (P_2O_5: 63.4 mg kg^{-1}) and satisfactory K (K_2O: 212.3 mg kg^{-1}) supply.

The soil has unfavourable physical properties. Groundwater level is at a depth of about 11-12 m, so the amount and distribution of rainfall and the method of soil cultivation determines the effectiveness of fertilizers and the amount of yield (TÓTH 2011).

The experiment was set up in autumn 2020 on the 1 ha "Agro 2" plot, where 12 plots of 408 m^2 (12m×34m) were assigned. We randomly arranged 4-4 treated and 4 control plots. The Babona variety used in the experiment is milling-grade wheat. It has average tillering, good winter hardiness and medium maturity. In 2016, it yielded 10.87 t ha^{-1} on Kompolt and 10.74 t ha^{-1}in 2017. It is almost completely resistant to red and yellow rust and has better than average resistance to *Fusarium* (Internet 1, 2).

The applied agrotechnological operations are summarised in Tables 1 and 2.

Table 1. The agrotechnological operations of the experiment

Operations		**Date**
Preceding crop:	winter rapeseed	
Stubble stripping:	IH plate disc plough+roller	25/07/2020
Base fertilizer placement:	Sulky 30-RTK NPK 8:21:21 (280 kg ha^{-1})	20/10/2020
Incorporation:	IH plate disc plough+roller	21/10/2020
Seedbed preparation:	Seedbed combinator	21/10/2020
Sowing:	IH 6200	22/10/2020
Applied winter wheat cultivar:	Babona	
Date of emergence:		06/11/2020

Top dressing placement in Spring:	Sulky 30-RTK „CAN” N-fertilizer total active substance content: 39 % (112.5 kg ha^{-1})	09/03/2021
Plant protection treatments:	According to Table 2.	
Harvesting:	Wintersteiger plot combine	29/07/2021

The pre-sowing of wheat was winter rapeseed. After the autumn soil preparation, sowing took place on 22 October. The basic fertiliser (NPK 8:21:21) was applied two days before sowing. Emergence was relatively uniform, starting on 6 November. Spring top dressing took place on 9 March. At the end of tillering, on 29 April 2021, the first plant protection treatments and application of plant conditioners in different doses were carried out. None of the plant conditioners were applied in the 4 control plots. Subsequent measurements were thus carried out on 12 plots. At the time of flag leaf emergence (03 June 2021), additional pesticide treatments were applied. Harvest took place on 29 July 2021 (Table 2).

Table 2. Applied plant conditioner and plant protection treatments

Placement of plant conditioners		**Plant protection treatments**	
	At the end of tillering 29/04/2021	*At the end of tillering*	*Flag leaf emergence 03/06/2021*
Control	-	Granstar SuperStar (50 g + 0.25 l ha^{-1}) + Riza 250 EW (0.8 l ha^{-1})	Azaka (1.0 l ha^{-1}) + Riza 250 EW (1.0 l ha^{-1}) + Rapid CS (80 $mlha^{-1}$)
Treat-ment 1.	2 l ha^{-1}	Granstar SuperStar (50 g + 0,25 l ha^{-1}) + Riza 250 EW (0,8 l ha^{-1})	Azaka (1.0 l ha^{-1}) + Riza 250 EW (1.0 l ha^{-1}) + Rapid CS (80 $mlha^{-1}$)
Treat-ment2.	3 l ha^{-1}	Granstar SuperStar (50 g + 0,25 l ha^{-1}) + Riza 250 EW (0,8 l ha^{-1})	Azaka (1.0 l ha^{-1}) + Riza 250 EW (1.0 l ha^{-1}) + Rapid CS (80 ml ha^{-1})

Two weeks after the second pesticide treatment (17.06.2021), the relative chlorophyll content of leaves was measured using a Minolta SPAD-502 (Konica, Minolta, Japan) instrument (SPAD-Soil Plant Analysis Development). 10-10 individuals per plot were randomly selected, covering the entire length of the plot. For each individual, the leaf under the flag leaf was measured at midlength. SPAD has a measuring area of 0.06 cm^2 and calculates the index in SPAD units based on the absorbance measured at 650 nm and 940 nm (GITELSON AND MERZLYAK 2004). The method is also used in agriculture to estimate, among other things, the health status, nitrogen supply and biomass production potential of plants (RAJCAN et al. 1999).

Spectral vegetation indices (Table 3) were determined on the same leaves by field spectroscopic reflectance measurements (ASD FieldSpecPro portable spectroradiometer, USA) to estimate leaf chlorophyll, carotenoid, anthocyanin and water content, light utilization and stress sensitivity. The instrument has a spectral range of 350-2500 nm. Spectra containing stored raw DN values were converted into reflectance values using ViewSpecPro software. Optical vegetation indices were calculated in Microsoft Excel using the formulae given in Table 3. Among a large number of vegetation indices, we selected those that have already been tested on agricultural crops and have been shown to be related to the mentioned physiological parameters (GARCIA-ROMERO et al. 2017) and are well applicable in practice for mapping qualitative and quantitative parameters of agricultural crops (GABRIEL et al. 2017). We investigated whether the effect of the treatment can be detected already at the beginning of ear emergence by means of spectral vegetation indices, which, in addition to the hyperspectral tool we used, can be obtained from multispectral camera images from drones and from satellite databases (Sentinel-2). These indices have been tested for a long time to see if they can be used in precision farming practices to inform farmers about the health status of individual crop populations.

Plant height and spike length measurements were performed on 28/06/2021. In each plot, 10 plants were randomly sampled, resulting in a total of 40 plants per treatment.

After harvesting, the yield, thousand kernel weight and hectolitre weight of each plot were measured using a special measuring device (OS-1). The quality parameters were determined from a mixed sample using a FOSS InfratecTM 1241 instrument, which required approximately 500 g of grain yield. The instrument measures simultaneously grain moisture content (%), protein content (%), gluten content (%), W-value (10-4 J) and Zeleny index (ml) at harvest.

The effects of treatments on each parameter studied were examined by one-way analysis of variance (ANOVA) and Tukey's-b test (SPSS 20.0).

Table 3. Applied vegetation indices

Structural indices	**Formulae**	**References**
Normalized Difference Vegetation Index (NDVI)	$(R_{800}-R_{670})/(R_{800}+R_{670})$	Rouse et al. (1974)
Renormalized Difference Vegetation Index (RDVI)	$(R_{800}-R_{670})/((R_{800}+R_{670})^{0,5})$	Rougean 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)
Optimized Soil-Adjusted Vegetation Index (OSAVI)	$[(1 + 0.16) \times (R_{780} - R_{670})]/[(R_{780} + R_{670} + 0.16)]$	Rondeaux et al. (1996)
Red-edge position index (REP)	$(705\text{-}35)\ [((R_{783}-R_{665})/2)-R_{705})/(R_{740}-R_{705})]$	Gholizadeh et al. (2016)
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. (2002)
Transformed Chlorophyll Absorption in Reflectance Index (TCARI)	$3\times [(R_{700}-R_{670})-0.2\times (R_{700}-R_{550}) \times (R_{700}/R_{670})]$	Haboudane et al. (2002)
Modified Chlorophyll Absorption in Reflectance Index (MCARI)	$[(R_{700}-R_{670})-0.2\times (R_{700}-R_{550})] \times (R_{700}/R_{670})$	Daughtry et al. (2000)
Anthocyanin Reflectance Index (ARI)	$R840\times (1/R550-1/R700)$	*Gitelson ez al. (2001)*
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)
Simple Ratio Water Index (SRWI)	R_{858}/R_{1240}	*Zarco-Tejada et. al. (2003)*

Source: ZARCO-TEJADA et al. (2005)

Results

Effect of precipitation amount and distribution on winter wheat productivity

Overall, the weather, rainfall and distribution of autumn 2020 and spring 2021 can be considered as an average year for autumn cereals (Table 4). The prolonged drought in summer and autumn, followed by heavy rainfall in October, significantly hampered both pre-sowing operations and sowing. The rainfall in September and October was still sufficient for the germination and initial development of the plants. Emergence was relatively uniform, with a significant proportion of the crop populations easily reaching the phenological stage of tillering and thus being able to establish until the onset of winter. Due to the relatively mild winter, the overwintering of the crops was good and no winter frost damage occurred. The significant lack of rainfall in the first months of 2021 hampered their development, and the spring cold did not favour the development of crops for agricultural work (Internet 3). In March, rainfall was 20% of the 30-year average. Precipitation was low during the critical developmental stages in spring: before stem extension in April (44.5 mm); during the flowering period in May (59.2 mm) and at ripening in June (2.8 mm). The total amount of precipitation during the entire growing season was more than 20% below the 30-year average (Table 4).

Table 4. Monthly precipitation between 09/2020 and 07/2021 (mm)

Months	Sept.	Oct.	Nov.	Dec.	Jan.	Febr.	Mar.	Apr.	May.	Jun.	Jul.	Sum
Rainfall (mm)	40.8	124.9	27.3	39.4	27.6	41.7	5.5	44.5	59.2	2.8	70.7	484.4
Average over the past 30 years	42.8	36.6	45.9	39.6	30.6	31.4	28.9	41.9	62.9	71.4	74.4	506.4
Difference	-2	88.3	-18.6	-0.2	-3	10.3	-23.4	2.6	-3.7	-68.6	-3.7	**-22**

Source: Agricultural Research Institute in Kompolt

The resulting water shortage has significantly reduced yields. This resulted in a medium yield level. According to the KSH data, the average winter wheat yield in 2021 was 5.6 t ha^{-1} in Heves county, which is the same as the typical yield in the North-Hungary region and slightly lower than the national average (5.9 t ha^{-1}) (Internet 4). In the control plot, the winter wheat yield (3.7 t ha^{-1}) was significantly below the county average for the year, which can be attributed to the drought (for several years now) during the growing season. The yield of the treatment 1 (5.2 t ha^{-1}) was close to the average for the county of Heves and not far behind the national average. Treatment 2 also had a positive effect on the yield (4.1 t ha^{-1}), but yielded about 20% less than treatment 1. Both the thousand-grain weight and the hectolitre weight were the highest in treatment 1, but the thousand-grain weight was below the expected level (39-41 g) in all three treatments (Table 5). It can be concluded that treatment 1 resulted in significantly higher yield despite the drought, probably due to better nutrient utilisation.

Table 5. Yield, thousand-grain weight and hectolitre weight of winter wheat variety Babona at harvest under the different treatments (mean+SD, n=4) 29/07/2021

Treatments	Parameters		
	Yield (t ha^{-1})	*Thousand grain weight (g)*	*Hectolitre weight (kg hl^{-1})*
Control	3.701+0.57 (a)	35.3	73.8
Treatment 1	5.196+0.32 (b) **	37	76.6
Treatment 2	4.052+0.33 (a)	36.3	75.6

Effect of treatments on winter wheat yield quality

The unfavourable vintage in many aspects also resulted in low values for quality parameters. The gluten content was significantly higher in treatment 1, 2, the W-value and the Zeleny index in treatment 1 (Table 6). Among the treatments, the positive effect of treatment 1 was mainly observed for gluten content, W-value and Zeleny index, whereas the effect of treatment 2 was significant only for gluten content compared to the control. The plant conditioning treatments therefore slightly improved the quality. At harvest, grain moisture content was 9.6% for the control and treatment 2, with the lowest grain moisture content measured in treatment 1 (8.8%), indicating an acceleration of physiological processes. The protein content was below optimal (12-13%) in all three cases, with the highest value in treatment 1 (9.5%). The gluten content was also significantly below optimal (minimum 26%): 15.9% in control, 17.8% in treatment 2 and 19.3% in treatment 1. The Alveograph W value was well below the limit value (250); the lowest value was 59 for the control, 66 for treatment 2 and 91.8 for treatment 1. The optimal value for the Zeleny index is 30 ml, the measured value was slightly below this value for the control (29.4 ml), treatment 2 reached the optimal value (30.5), the highest value (34 ml) was measured in treatment 1. Also in terms of quality parameters, a positive effect of treatment 1 was observed (Table 6).

Table 6. Effect of treatments on the values of quality parameters of the winter wheat variety Babona (mean+SD, n=4)

Treat-ments	**Parameters**				
	Grain moisture [%]	*Protein content [%]*	*Gluten content [%]*	*W-value (10^{-4} J)*	*Zeleny-index (ml)*
Control	9.6+0.74 a	8.8+0.88 a	15.9+0.86 a	59.0+7.7 a	29.4+0.75 a
Treatm. 1	8.8+0,60 a	9.5+0.58 a	19.3+0.71 b**	91.8+3.3 b***	34.0+0.79 b**
Treatm. 2	9.6+0.62 a	8.8+0.74 a	17.8+1.13 b**	66.0+6.4 a	30.5+2.55 a

When examining the effect of the vintage (amount of precipitation, rainfall distribution), in most cases a negative relationship between yield average and quality was found (BÉLTEKI 2019, AMBRUS et. al 2020). MÁNYI-FEKETE (2022), based on 3 years of data (2017-2019), showed a positive weak relationship between yield and quality, and a positive strong relationship between nutrient supply and quality parameters (crude protein, gluten, Zeleny index). In the year under study, there was a significant lack of rainfall during the growing season, which resulted in yields well below the average expected for the variety, and the same was true for the quality parameters in all three treatments. In the first treatment, the plant conditioner applied promoted the nutrient uptake of the plants and increased their stress tolerance, the positive effect of which was reflected in both yield and the improvement of some quality parameters.

Effect of treatments on plant height and spike length

At the end of June, two months after the application of the plant conditioners, differences in plant height and spike length between control and treated plots were also measurable. At treatment 1, the height of the test plants was 10 cm higher (94.8 cm) than the control (84.3 cm), but at treatment 2 plant height was also higher than the control. The spike length was also higher in both treatments, by 0.7 cm in treatment 1 and 0.5 cm in treatment 2 (Table 7). BÉLTEKI (2019) has shown a positive correlation between yield average and plant height in several wheat varieties.

Table 7. Effect of the treatments on plant height (cm) and spike lenght (cm) (mean, n=40) 28/06/2021

Treatments	**Parameters**	
	Plant height (cm)	*Spike length (cm)*
Control	84.3	6.9
Treatment 1.	94.8	7.61
Treatment 1.	86.5	7.45

Photosynthetic parameters based on spectral vegetation indices

The efficiency of photosynthesis is one of the most important feature for crop yield and quality. However, photosynthetic processes can be significantly influenced by environmental stresses, such as water deficit, high light intensity or high temperatures. The quantity and composition of photosynthetic pigments are very informative for photosynthetic activity, therefore, by examining chlorophyll content and chlorophyll/carotenoid ratio, valuable information on the biomass production capacity of plants can be obtained. The relative chlorophyll content of leaves is can be determined by, among other things, the SPAD value, which can also give an indication of the nitrogen supply of plants, and is therefore widely used in agricultural practice to characterise plant health and to plan nutrient supply. Its value varies with the phenological stages of the plant, being highest at the beginning of flowering. In her studies, MÁNYI-TÖRÖK (2022) found a positive medium relationship between yield and chlorophyll content in winter wheat at all phenological stages. In her studies, leaf area index (LAI) was more strongly correlated with yield and thus more useful for yield estimation.

At the beginning of ear emergence, the chlorophyll content of the plants was assessed by determining the SPAD value and the spectral vegetation indices, which can be related to chlorophyll content and LAI. With regard to SPAD, we found in several of our field experiments that the effect of treatments was measurable but not significant due to the large variability of the data. In the present study, we found that treatment 1 had the highest chlorophyll content in leaves, but the variance was the lowest (Table 8). Indices indicating chlorophyll content (NDVI, EVI, VOG, REP, TCARI/OSAVI, MCARI/OSAVI) were significantly higher in treatment 1, NDVI was also significantly higher in treatment 2. NDVI is the most widely used vegetation index related to photosynthetic activity of vegetation. It is also available from satellite databases and can be used to estimate plant growth, health, biomass, among other things (Internet 5).

The photochemical efficiency index (PRI) was significantly higher in treatment 2, while the stress sensitivity index (SIPI) and the protective pigment levels CRI (carotenoids) and ARI (anthocyanins) were significantly higher in control and treatment 2 (Table 8). From these indices we can infer photosynthetic processes. The PRI index is inversely proportional to the amount of sun-protective pigments (xanthophylls) and the intensity of the membrane-protective mechanism (xanthophyll cycle) they perform (GAMON et al. 1997). The chlorophyll/carotenoid ratio of plants (SIPI index) indicates the sensitivity of the plant to environmental effects (stress) (PENUELAS el al. 1995). Experience shows that changes in the chlorophyll/carotenoid ratio are the best indicator of stress sensitivity. Our previous studies in a winter wheat nutrient replenishment experiment yielded similar results (KAPRINYÁK et al. 2018; LÁPOSI et al. 2020). PWI and SRWI indices indicating leaf water content did not differ significantly in the 3 plots, but were highest in treatment 2. Their values were influenced not only by water content but also by leaf structure, dry matter content and LAI (ZARCO-TEJADA and USTIN, 2001).

Importantly, the correlation between these vegetative indices and specific physiological processes varies between plant phenophases (HUANG et al. 2013). In our experiments, they were found to be sensitive to specific treatments and can be recommended for practical characterization of biomass production potential, health and stress status of crops at the onset of flowering. Many of them are also available from satellite databases.

Table 8. Relative chlorophyll content and spectral vegetation indices in wheat leaves in the middle of June in 2021. (Note: a, b, c 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=40) 17/06/2021

Parameter	Level of significance	(1) control	(2) treatment 1	(3) treatment 2
SPAD-value	ns 132-a a a	40.32±6.67	43.23±4.73	41.41±6.10
NDVI	* 132-a b b	0.675±0.090	0.700±0.051	0.698±0.085
RDVI	ns 132-a a a	0.543±0.088	0.565±0.063	0.550±0.077
EVI	* 132-a a b	0.655±0.116	0.686±0.084	0.656±0.103
VOG1	*** 312-a a b	1.312±0.076	1.353±0.092	1.300±0.103
REP	*** 312-a a b	686.3±1.52	687.1±1.63	686.0±2.13
TCARI/OSAVI	*** 312-a a b	0.918±0.368	1.148±0.514	0.861±0.397
MCARI/OSAVI	*** 312-a a b	0.306±0.122	0.382±0.171	0.287±0.132
PRI1	*** 312-a a b	0.273±0.063	0.317±0.070	0.267±0.056
SIPI	* 231-a ab b	0.719±0.162	0.681±0.067	0.712±0.084
CRI	*** 231-a a b	4.75±1.56	3.83±0.86	3.90±1.13
ARI	* 321-a a b	0.032±0,028	-0.058±0.025	-0.075±0.037
PWI	ns 132-a a a	0.966±0.013	0.976±0.057	0.969±0.007
SRWI	ns 312-a a a	1.077±0.069	1.086±0.032	1.077±0.041

Conclusions

The Kompolt Experimental Station considers it an important task to test and develop environmentally friendly nutrient supply methods that can be adapted to the region. In two experiments with modern plant conditioners, we investigated the yield, postharvest grain quality after harvest; some growth parameters after flowering, and photosynthetic processes and stress sensitivity of the wheat variety Babona using spectral vegetation indices at the beginning of flowering. The year under study was quite extreme in terms of rainfall and distribution, with plants having to cope with a significant drought in spring. As a result, the average yields in both control and treated plots were well below the expected levels, and the quality was also poor. However, treatment 1 resulted in higher yield, better quality, higher plant height and spike length compared to the control and treatment 2. This treatment presumably provided a more balanced supply of nutrients and water to the plants, which contributed to an increase in stress tolerance, and the smaller standard deviation of data suggest that the homogeneity of the plots increased.

The vegetation indices we tested were already sensitive to the effect of treatment 1 at the beginning of flowering, so significant differences were detectable. Most of these indices can be used in agricultural practice to plan nutrient replenishment or crop protection treatments, or to estimate yield. Many of them are also available from satellite databases and reflectance measurements from drone-mounted multispectral cameras, and can be integrated into precision farming.

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Authors

Dr. Rita Tury, PhD
assistant professor
Hungarian University of Agriculture and Life Sciences, Károly Róbert Campus, Institute of Environmental Sciences, Group of Agroecology
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, Károly Róbert Campus, Institute of Agronomy
H-3200 Gyöngyös, Mátrai. u. 36.
toth.szilard.zsolt@uni-mate.hu

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

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