THE EFFECT OF PLANT CONDITIONERS ON SOME PHYSIOLOGICAL PARAMETERS OF MAIZE IN A DROUGHT YEAR

NÖVÉNYKONDÍCIONÁLÓK HATÁSA A KUKORICA EGYES ÉLETTANI PARAMÉTEREIRE ASZÁLYOS ÉVBEN

RÉKA LÁPOSI – SZILÁRD ZSOLT TÓTH – ILDIKÓ BÉLTEKI – ÉVA LEHOCZKY – RITA TURY
Laposi.Reka@uni-mate.hu

Abstract

At Kompolt, since 2015 we have been testing environmentally friendly nutrient supply methods for arable crops. The utilisation of the nutrients depends on the amount and distribution of rainfall during the growing season. In 2022, there was an extreme drought in Hungary, with rainfall from May to September 60-80% below the 40-year average, which resulted in failures of maize yield in many parts of the country. In the given year, we set up experiments with 3 different plant conditioners (1. amino acids, 2. P+Zn+K+Mo, 3. ion Zn) on maize cultivars and measured some photosynthetic parameters with different plant sensors, moreover the yield and corncob parameters at harvest. The SPAD index and spectral vegetation indices, which determine some physiological features, showed a positive effect of all three treatments at the beginning of flowering. Yield were 155 and 159% higher in the first two treatments and 144% higher in treatment 3 compared to the control. Based on corncob parameters, all three treatments showed significantly better results than the control. The largest difference was measured for treatment 2, based on all parameters tested, where foliar fertilizers supplemented with macro- and micro elements in addition to amino acids. Overall, plant conditioners applied at the right time can reduce the effects of environmental stress on plants, and the sensors used can monitor the effects of treatments throughout the growing season.
Keywords: *drought, maize, physiological parameters, plant conditioners, amino acids, zink*
JEL code: *Q19*

Összefoglalás

Kompolton 2015 óta foglalkozunk környezetkímélő tápanyagutánpótlási módszerek vizsgálatával szántóföldi kultúrákban. Ismert, hogy a kijuttatott tápanyagok hasznosulása nagymértékben függ a tenyészidőszak csapadékmennyiségétől és eloszlásától. 2022-ben extrém mértékű aszály volt hazánkban, a csapadékmennyiség májustól szeptembering 60-80%-kal maradt alatta a 40 éves átlagnak, ezért sok helyen nem termett a kukorica. 2022-ben 3 különböző növénykondícionálóval (1. aminosavak, 2. P+Zn+K+Mo, 3. Ion Zn) állítottunk be kísérletet kukorica kultúrán és különböző növényi szenzorokkal vizsgáltuk virágzáskor a fotoszintézis és stressztűrés egyes jellemzőit, betakarításkor a termésátlagot és a kukoricacső egyes paramétereit. A SPAD-index, és a spektrális vegetációs indexek a virágzás kezdetén már jelezték mindhárom kezelés pozitív hatását. A termésátlag az első két kezelésnél 155 és 159%-kal, a 3. kezelésnél 144%-kal volt magasabb a kontrollhoz képest, a csőparaméterek alapján

mindhárom kezelés szignifikánsan jobb eredményt mutatott a kontrollhoz képest. A legnagyobb mértékű eltérést az összes vizsgált paraméter alapján a 2. kezelésnél mértünk, ahol az aminosavak mellett makro- és mikroelemek is pótlásra kerültek lombtrágyaként. Összességében elmondható, hogy a megfelelő időben kijuttatott növénykondícionálókkal tompítani tudjuk a környezeti stressz hatásait a növényekre, az alkalmazott szenzorokkal pedig a vegetációs időszak során nyomon követhetjük a kezelések hatását.
Kulcsszavak: *aszály, kukorica, élettani paraméterek, növénykondícionálók, aminosavak, cink*

Introduction

Efficiency of crop production depends on many factors, but environmental conditions play a key role. Optimal nutrient supply is useless if nutrient uptake is limited. This can be caused by certain soil properties (e.g. pH, oxygen content), of which water content is one of the most critical. In recent decades, the amount and distribution of rainfall during the growing season of plants has been below expected levels in many cases, for which global climate change may be responsible (GRAY and BRADY, 2016). It is not enough to choose the varieties that are best adapted to the landscape, you also need nutrient supply methods that can be used under the given environmental conditions. There is an increasing demand for the use of environmentally friendly methods that allow the long-term sustainable use of soils (KUMMERER et al. 2010).

The growing season for maize should be between the last frosty days of spring and the first frosty days of autumn. Its length depends on the amount of heat in addition to the irradiation. The speed of germination and seedling emergence is also temperature dependent. Faster germination reduces exposure to pathogenic fungi and pests, and the development of a proper root system increases stress tolerance in addition to nutrient and water uptake. The lack of precipitation causes permanent damage at several stages of plant development, notably the onset silking and grain filling. Efficient photosynthesis of the upper leaves (husks) around the cob is essential to achieve the yield average typical of the variety. From grain filling to full maturity, maize requires large amounts of nitrogen in late summer, which is negatively affected by drought, as this stage is shortened, resulting in lower yields and poorer kernel quality. Some characteristics of the corncob (e.g. the number of kernels per cob) are already influenced by the nutrient and water content at the emergence of the 6th leaf (V6), when the generative organs are developing. At silking (R1), it is determined whether the corncob will be fully covered by kernel sor not, at milk stage (R3), whether the kernels will be fully developed or aborted, and at dough stage (R4), there is intense grain filling, which will affect the thousand kernel weight (AMPONG et al. 2024). So there are several sensitive periods in the development of maize, depending on the water content (Website 1).

Nutrient supplementation in the form of foliar fertiliser is one solution to water shortages in the soil, but it is also important to time this at the optimum stage of development, as it can also establish the plant's stress tolerance (PUPPE and SOMMER 2018). A first step could be the use of soil microbes, already at the time of ploughing or sowing, which is also of great importance from a plant protection point of view, as well as increasing the availability of nutrients (MIRANSARI 2013, TÓTH et al. 2024).

In addition to more than 100 years of breeding activity, the MATE's farm in Kompolt (formerly the Fleischmann Rudolf Research Institute) has an important role in advising farmers in the region, for example on environmentally friendly nutrient supply systems adapted to the region's specific conditions. Therefore, the primary objective in our investigations is to test new plant conditioning formulations containing innovative technological advances on as many crops as possible. As our research area is particularly drought-prone and the soil structure is also not favourable, with this information, we can carry out the most effective advisory activities. In this paper, we present the results of testing three different plant conditioning products on waxy maize in an extremely droughty year, when maize failed to grow in most of the country. In addition to the classical yield measurements, we investigated in detail some parameters of the corncob, and two weeks after foliar fertilizer application, at the beginning of flowering, we used plant sensors to measure photosynthetic parameters and stress characteristics, which are the most critical for yield formation.

Applied plant conditioners (Amino-Komplex, Zsémic, Ion Zn) can contribute to the stress tolerance of maize under drought conditions. Amino-Komplex is a biostimulant containing 20 free amino acids derived from plant materials. Its stimulating effect is based on the fact that it contains building blocks of protein components essential for both cell structure and metabolism. In principle, plants take up the large quantities of nitrogen needed for this from the soil, provided that they are available in the right form, but this depends to a large extent on the specific conditions of the soil (water content, pH, microbial activity) and the conversion of the nitrogen taken up requires a significant amount of energy (ATP). In times of drought, when applied as a foliar fertiliser, the building blocks of proteins are available to the plants, so that metabolism (organic matter production) is not slowed down and the plant recovers more easily and quickly from environmental stresses. Some amino acids, as raw materials for plant hormones, stimulate growth, others, as osmotic substances, help drought tolerance. Some amino acids are components of antioxidant enzymes, others promote pollination and crop formation. The product can also be used in organic farming. For maize, the recommended application period is between 4-6 and 8-10 leaves.

Zsémix is a complex formulation containing phosphorus (30%), potassium (4.4%), zinc (10%) and molybdenum (0.1%) besides amino acids. The lack of phosphorus causes problems in root growth, which also has a negative effect on water and mineral uptake. It cannot be taken up by plants from acidic (pH below 5), low temperature (below 13^{o}C) and dry soils. In acidic soils, potassium and molybdenum uptake is also inhibited, and in alkaline soils (above pH 9), the plant cannot take up zinc in addition to phosphorus. These elements can only be taken up by plants together at pH 6 to 8, which is not guaranteed in many agricultural areas. In addition, phosphorus limits the uptake of zinc by inactivating part of it. Potassium plays an important role in drought tolerance, reducing leaf transpiration. Molybdenum is a key enzyme in nitrogen metabolism. Zinc is an important enzyme constituent, affecting many metabolic processes. It also plays a very important role in longitudinal growth by stimulating the production of auxin, a growth hormone, and thus in particular root growth, which increases the drought tolerance of the plant. Its deficiency is not always visible on the plant (yellowish-white longitudinal stripes on young leaves), but it can cause yield losses of up to 10-20% even in latent conditions.

Ion-Zn biostimulant contain zinc in a concentrated ionic form, which does not crystallise on the treated surface but forms a thin film and is absorbed very quickly, avoiding phytotoxicity. Application is recommended at 4-5 leaf and 8-10 leaf stage (Website 2).

Material and methods

Stury site and technological parameters

For more than a century, the experimental area in Kompolt has been the site of plant breeding work and the development and testing of technological improvements adaptable to the region. The research area (47^{o}44’18.45” É, 20^{o}14’03.95” K) is located in the southern part of the Mátra, at an altitude of 125 m above sea level, and has a moderately warm climate, prone to drought, as amount and distribution of precipitation are rather rhapsodic, especially during the growing season (HOLLÓ et al. 2009). Table 1 clearly shows that in 2022, there was a significant precipitation deficit (60-80%) from May to August compared to the 40-year average precipitation. In September, however, high rainfall was received, which greatly facilitated the fruit formation of successfully pollinated crops.

Table 1. Climatic parameters during the growing season in 2022

2022	Daily average temperature [ºC]	Daily total precipitation [mm]	Average precipitation of 40 years	Difference %
April	9.59	48.1	34.8	38.2
May	17.98	14.5	58.0	-75.0
June	22.93	24.8	62.5	-60.3
July	24.30	14.3	72.0	-80.1
August	24.85	14.4	49.9	-71.1
September	13.75	135.7	45.6	197.5
October	12.78	21.6	46.6	-53.6

Source: Research Site (Kompolt, MATE)

The experimental site can be characterized by a non-carbonate chernozem brown forest soil with acidic pH (pH 4.7-5.1), 0% calcium carbonate (CaCO3) and 2.8-2.9% humus content. The subsoil is alkaline at a depth of 130-150 cm. The humus layer is 50-80 cm thick and the ploughed layer has a humus content of 2.5-3.0%. This indicates a moderate N supply, while the P and K availability is poor for P and satisfactory for K. The physical properties are rather unfavourable, difficult to cultivate, easily drying and cracking, which causes high evaporation. The groundwater level is between 11 and 12 m. The soil has poor water conductivity, can store and retain large amounts of water and has a relatively high dead water content (HOLLÓ et al. 2009; TÓTH 2011).

In 2022, for the first time in several field crops, we set up an experiment to investigate the effect of plant conditioners containing a specific combination of amino acids and micronutrients on yield and on photosynthetic processes at the onset of flowering, which are considered critical for crop production. Because the drought that year had caused very serious damage to agriculture, maize in many places grew very low or even failed to produce fruit. In this paper, we present the results obtained from the study of waxy maize at flowering and harvest. The main steps of the agrotechnology applied are shown in Table 2.

Table 2. The agrotechnological operations of the experiment (2022)

Operations		**Date**
Preceding crop:	winter wheat	
Base fertilizer placement:	Sulky DX30-RTK NPK 8:21:21 (280 kg ha^{-1})	02/11/2021
Poughing:	IH 6200	09/11/2021
Starter fertilizer placement:	Pétisó 150 kg ha^{-1}	09/03/2022
Seedbed preparation/sowing	Seedbed combinator	18/04/2022
Applied maize cultivar:	Waxy	
Herbicide treatment:	Laudis OD - BBCH18	16/05/2022
Row bed cultivation:	Cultivator	01/06/2022
Placements of plant conditioners:	BBCH19 BBCH51	24/06/2022 21/07/2022
Harvesting:	Wintersteiger plot combine	21/10/2022

Source: Research Site (Kompolt, MATE)

The experiment was set up in 4 replicates on 7.5 m^2 plots in Latin square design.

3 different plant conditioners were applied as foliar fertilizers (Hed-Land: Aminokomplex, Zsémix, Ion-Zn) in the last week of June at 8-10 leaf stage (BBCH19) and in the last week of July at tassel emergence (BBCH51) as follows:

Treatment 1 - Amino-Komplex 4 l/ha
Treatment 2- Amino-Komplex 2 l/ha + Zsémix 2 l/ha
Treatment 3 - Amino-Komplex 2 l/ha + Ion Zn 2 l/ha
The control plots (4) received all other nutrients except these.

Physiological measurements

The positive effect of the treatments was not only evaluated on the basis of the yield average and the different tube parameters, but also on some physiological parameters of photosynthesis (the amount and composition of photosynthetic pigments and the water content of the leaves), which is one the most important process for the yield formation. To achieve this, we used *in vivo* methods that allow us to collect large amounts of data from large areas without damaging the plants. Instead of the traditional method of spectrophotometry from solvent leaf extracts, we used methods based on leaf reflectance, from which spectral vegetation indices can be calculated from which a number of physiological processes can be estimated.

Table 3. Applied vegetation indices and related physiological parameters based on measurements by ASD FieldSpec 3 instrument

Structural indices	**Formulae**	**References**
Normalized Difference Vegetation Index (NDVI)	$(R_{800}-R_{670})/(R_{800}+R_{670})$	Rouse et al. (1974)
Optimized Soil-Adjusted Vegetation Index (OSAVI)	$[(1+0.16)\times(R_{780}-R_{670})]/[(R_{780}+R_{670}+0.16)]$	Rondeaux et al. (1996)
Vogelmann index (VOG1)	R_{740}/R_{720}	Vogelmann et al. (1993)
Leaf pigments		
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)
Carotenoid Reflectance Index (CRI)	$1/R_{550}-1/R_{700}$	Gitelson et al. (2002)
Anthocyanin Reflectance Index (ARI)	$R_{840}\times(1/R_{550}-1/R_{700})$	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		
Normalized Difference Moisture index (NDMI)	$NIR_{860}–SWIR_{1240}/(NIR_{860} + SWIR_{1240}$	Gao (1996)
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)

To determine the relative chlorophyll content of leaves, we used a SPAD 502 instrument (KONICA, MINOLTA, JAPAN), which measures leaf absorbance in an area of 0.06 cm^2 at 650 and 940 nm (GITELSON AND MERZLYAK 2004). In maize, we measured the third leaf below the crest, the right side of the leaf, in the middle, at 10-10 individuals per plot. Leaf reflectance was also measured at the same site using an ASD FieldSpec3 portable field spectroradiometer, between 400 and 2500 nm. From reflectance values measured at given wavelengths, we calculated vegetation indices using the formulas given in Table 3 (ZARCO-TEJADA et al. 2005), which have been successfully applied in agricultural crops, e.g. to characterize the health of maize (GABRIEL et al. 2017). NDVI, TCARI, MCARI, OSAVI, Vogelmann indices are used to estimate chlorophyll and indirectly nitrogen content. CRI refers to the amount of carotenoids and ARI to the amount of anthocyanins. The latter two groups of pigments play an important role in plant stress tolerance, mainly as antioxidant compounds. Their quantity increases under stress, while that of chlorophylls decreases. The SIPI provides information on the stress sensitivity of the plant through the carotenoid/chlorophyll ratio and the amount of xanthophylls, which are important for photoprotection within the carotenoids, and the PRI index indicates photochemical efficiency. These two processes are inversely related, since xanthophylls are involved in the emission of excess light in the form of heat, which is no longer used in photosynthesis. In drought conditions, the water content of leaves is an important parameter, since metabolic processes are impaired by water deficit, and the NDMI, PWI and SRWI indices are used to indicate this.

Significant effects of treatments were tested by one-way analysis of variance (ANOVA) and differences between treatments by Tukey's b test (SPSS 27.0).

Results

Photosynthetic pigments were measured at the beginning of tassel emergence, as photosynthesis is of paramount importance for biomass production. Under field conditions, there is always a large variation in the SPAD value indicating chlorophyll content, despite the fact that leaf of the same development was selected for measurements for each individual and the same site within the leaf is measured. Nevertheless, the positive effect of the treatments was already clearly visible at the beginning of August. Relative chlorophyll content was significantly higher in all treatments compared to the control: by 16.5% in treatment 1, 19.8% in treatment 2 and 12% in treatment 3. However, there was no significant difference between the 3 treatments, although the highest value was obtained in treatment 2 (Figure 1).

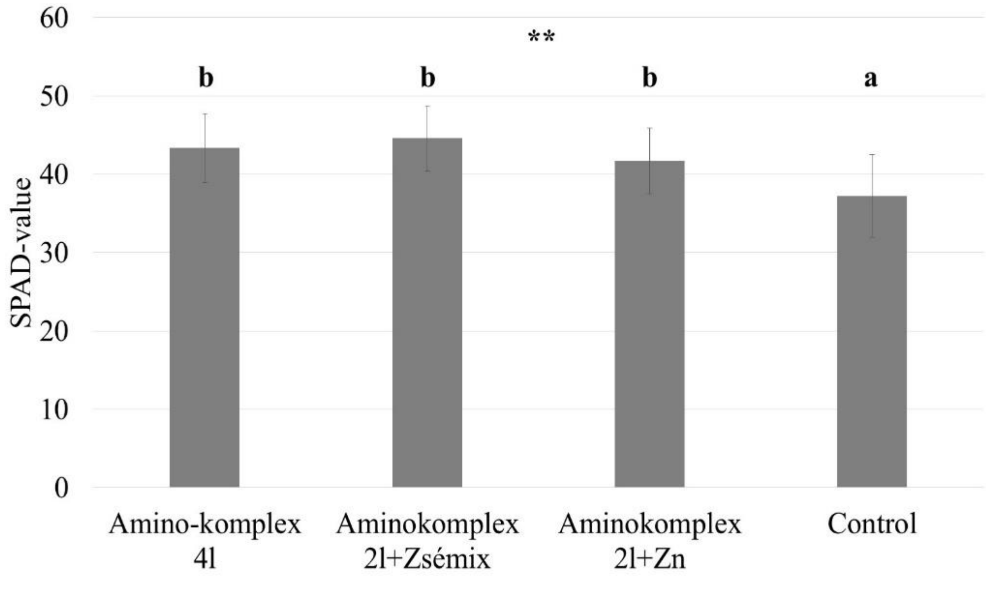

Figure 1. Relative chlorophyll content (SPAD-value) of waxy maize at the beginning of tassel emergence (Mean+SD, n=40; 01/08/2022)

*(Note: ANOVA significance: **-p<0.01; a, b, c index: significance groups by Tukey's-b test at p<0.05)*

The physiological processes in leaves can also be characterised by a number of spectral vegetation indices, in addition to the SPAD value, obtained by analysing the spectral composition of the solar radiation reflected from the leaves. Several vegetation indices are available to characterize the health status of agricultural crops (N supply, yield estimation, infestation) and have been successfully applied to maize crops (FLORES et al. 2020). In our previous research, several indices were effective in maize to evaluate the results of soil bacterial treatments (LÁPOSI et al. 2020). Among these hyperspectral vegetation indices, significant differences between treatments were obtained for NDVI and Vogelmann index, and the ratio of TCARI/OSAVI and MCARI/OSAVI indices at the onset of flowering (Table 4). The MCARI/OSAVI and TCARI/OSAVI integrated indices have been shown to be more closely correlated (R2=0.94 and 0.88, respectively) than, for example, the commonly used NDVI index, and the value is relatively independent of LAI and can be used at low chlorophyll concentrations (WU et al. 2008). Based on these indices, the chlorophyll content was significantly higher in treatment 2 compared to the control and treatments 1 and 3. Based on the VOG index, there was no difference between treatments 2 and 1, and based on the NDVI, only the control could be distinguished from the treatments. Chlorophylls, in particular chlorophyll-b, are sensitive to a number of environmental stresses (high light intensity, UV-B), which easily damage them and reduce their abundance and proportion (TEVINI et al. 1981). But chlorophyll content alone is not a sufficient factor to evaluate biomass formation, since it does not tell us whether the incoming light is used photochemically or whether the excess is emitted, e.g. as heat, from the protective pigments, certain carotenoids. The PRI index indicates the photochemical efficiency in leaves, which was highest in treatment 3, followed by treatments 2 and 1, all three significantly higher than the control. The PRI index is inversely proportional to the amount of photoprotective pigments (xanthophylls) and the intensity of the membrane protection mechanism (xanthophyll cycle) they perform (GAMON et al. 1997). Under environmental stress, the vulnerability of chlorophylls and the photoprotective role of carotenoids also increase the carotenoid/chlorophyll ratio (YOUNG AND BRITTON 1990).

The CRI index indicates the amount of carotenoids involved in photoprotection, and the activity of the xanthophyll cycle within carotenoids is indicated by the SIPI index, which is also considered a stress sensitivity parameter (PENUELAS el al. 1995). CRI and SIPI index values were highest in control leaves and lowest in treatments 3 and 2, indicating that foliar fertilizer-treated leaves were more effective in coping with stress caused by high light, high heat and drought. In maize, the accumulation of anthocyanins can also be observed in response to various stresses (high light intensity, UV-B radiation, drought, wounding, bacterial and fungal infections, nitrogen and phosphorus deficiencies), even in the epidermis of leaves exposed to sunlight, where they reduce the entry and negative effects of excess light, thus protecting photosynthetic processes (PIETRINI et al 2002). The ARI index refers to the amount of anthocyanins, in our experiment it was highest in the control leaves and in treatment 1, and significantly lower in treatments 2 and 3, indicating a lower sensitivity of these leaves to stress.

For optimal functioning of the various metabolic processes, adequate leaf water content is essential. PWI and SRWI are the indices used to estimate leaf water content, but they are strongly influenced by leaf structure, dry matter content and LAI (SERRANO et al. 2000, ZARCO-TEJADA and USTIN, 2001), which can vary greatly during different phenophases. In our experiment, both indices were significantly highest in treatment 2 and lowest in the control, with treatments 3 and 1 not sharply different. According to RAHMAN & MESEV (2019), the NDMI index is the best marker of moisture content in the plant canopy because it takes into account a number of influencing factors and is therefore used to identify water stress levels. NDMI values between 0.2 and 0.4 indicate significant water stress, above 0.4 no water stress and below 0.2 high water stress (LYKHOVYD AND SHARII 2024). Our data fell in the range 0.2-0.3, indicating a significant water deficit in all plots. All three treatments had significantly higher values than the control, with the highest value in treatment 2. Thus, at the beginning of tassel emergence, the positive effect of the treatments was already evident from the spectral vegetation indices, of which the 2nd treatment proved to be the most optimal for several parameters.

At harvest, the average yield was significantly higher in all three foliar fertilizer treatments compared to the control, 159% in treatment 1, 155% in treatment 2 and 144% in treatment 3 (Figure 2). There was no significant difference between the three treatments, although the variance between the 4 plots was relatively high for treatment 3 and lowest for treatment 2. In the control plot, we obtained the average of 1.5 t of 2022 in Heves County, but the treatments resulted in a yield average of 3.4 t above the national average of 3.4 t in all three plots.

Table 4. Statistics of spectral vegetation indices in waxy maize leaves at the beginning of tassel emergence (Mean+SD, n=40; 01/08/2022)

Treatments	**Amino-komplex 4l/ha**	**Amino-komplex 2l/ha + Zsémix 2l/ha**	**Amino-komplex 2l/ha + Ion Zn 2l/ha**	**Control**	**ANOVA**	**Tukey's-b**
Vegetation indices						
NDVI	0.735±0.063	**0.741±0.051**	0.738±0.059	0.704±0.062	*	4132-a b b b
TCARI/OSAVI	0.629±0.217	**0.706±0.159**	0.622±0.150	0.594±0.152	**	4312-a ab ab b
MCARI/OSAVI	0.209±0.072	**0.235±0.053**	0.207±0.050	0.198±0.050	**	4312-a ab ab b
VOG	1.582±0.089	**1.584±0.077**	1.536±0.095	1.524±0.097	***	4312-a a b b
PRI	0.253±0.075	0.261±0.062	**0.283±0.080**	0.235±0.056	**	4123-a ab ab b
SIPI	0.748±0.072	0.738±0.052	0.721±0.059	**0.751±0.063**	*	3214-a b bc c
ARI	0.627±0.052	0.482±0.028	0.441±0.022	**0.729±0.040**	***	3214-a a b c
CRI	4.830±0.410	3.893±0.208	3.457±0.165	**4.889±0.246**	*	3214-a ab b b
NDMI	0.249±0.037	**0.262±0.024**	0.243±0.038	0.226±0.024	***	4312-a b bc c
PWI	0.959±0.007	**0.965±0.014**	0.967±0.008	0.953±0.016	***	4132-a ab bc c
SRWI	1.087±0.044	**1.110±0.043**	1.099±0.022	1.079±0.024	***	4132-a ab bc c

*(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)*

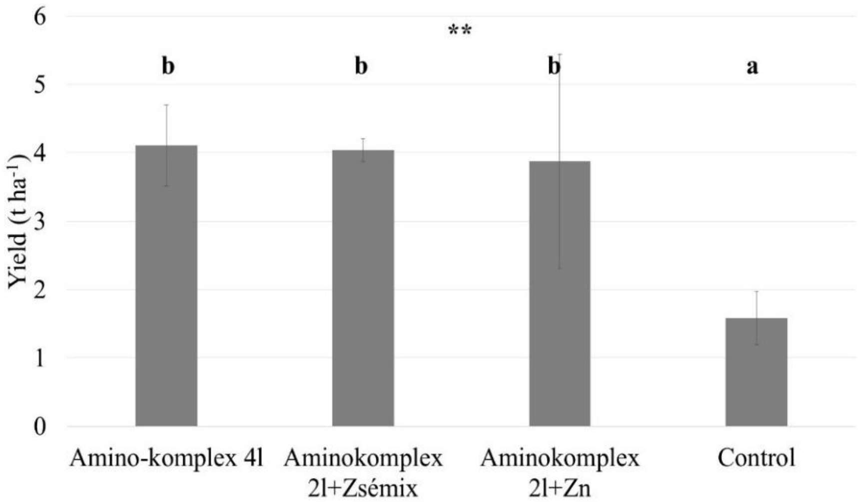

Figure 2. Average yield at harvest under the different treatments (Mean+SD, n=4; 21/10/2022)

*(Note: a, b, c index: significance groups by Tukey's-b test (p<0.05); ANOVA significance: ***-p<0.001, **-p<0.01, *-p<0.05, ns-not significant)*

At harvest, we also examined in detail the individual corncob parameters to evaluate the effect of the treatments (Table 5). Corncob length, diameter, cob weight, thousand kernel weight, kernel weight per cob, number of kernels per row and number of kernels per cob were significantly higher in all three treatments than in the control, but there was no significant difference between the three treatments. Based on the number of rows per tube, treatment 3 was slightly above the other two, but there was no difference between treatments 1 and 2. It should be noted that only one corncob per plot was investigated, so there were relatively large variations between the four replicates. In the future, it will be worthwhile to include a larger number of corncobs in the tests, as they can be relatively sensitive parameters.

Table 5. Statistics of corncob parameters of waxy maize at harvest (Mean+SD, n=40; 31/10/2022)

Treatments	**Amino-komplex 4l ha^{-1}**	**Amino-komplex 2l ha^{-1} + Zsémix 2l ha^{-1}**	**Amino-komplex 2l ha^{-1} + Ion Zn 2l ha^{-1}**	**Control**	**ANO-VA**	**Tukey's-b**
Corncob parameters						
Length (cm)	18.83±1.72	**19.66±1.65**	19.17±1.67	16.75±1.36	***	4132-a b b b
Diameter (mm)	**37.50±4.33**	35.42±5.57	36.25±4.62	29.17±6.07	**	4231-a b b b
Thousand grain weight (g)	**308.83±+52.95**	280.50±42.44	299.00±45.52	225.17±35.36	***	4231-a b b b
Grain weight (g/cob)	**167.38±35.55**	155.56±38.68	160.63±28.63	99.46±14.89	***	4231-a b b b
Cob weight (g)	**27.63±8.25**	26.07±9.34	26.85±4.75	18.17±2.42	**	4231-a b b b
Line number per cob	15.00±1.00	14.67±1.25	**15.33±0.94**	14.17±0.55	*	4213-a ab ab b
Grain number per line	38.33±3.06	38.17±4.34	**39.17±3.89**	33.50±3.66	**	4213-a b b b
Grain number per cob	576.00±67.79	558.83±74.93	**599.17±57.80**	434.67±54.46	***	4213-a b b b

*(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)*

Conclusions

In 2022, very extremely low rainfall and an unfavourable distribution were observed in the maize growing season. Accordingly, yields were well below the expectations, and presumably quality was also much lower than in better years. The three plant conditioners we used all resulted in significantly higher average yields than in the control plot, and for all three, a positive effect was also measured for the corncob parameters tested. The positive effect of the treatments was already measurable at the beginning of flowering by the applied vegetation indices, i.e. better stress tolerance, higher leaf water content, more efficient photosynthesis of the plants, which is probably due to a more balanced nutrient supply. Since in our experiments all three preparations resulted in better physioligal status of plants and significantly higher yields than the control plot, so the soil conditions should be taken into account when choosing the right product. However, the combination of amino acid + P + K + Zn + Mo is worth highlighting, as it provides all the necessary elements for maize growth and drought tolerance. However, it is worth starting the application at the 4-5 leaf stage, as recommended by the manufacturer.

To estimate expected yields, among several vegetation indices the NDVI is mainly used as an indicator of chlorophyll and nitrogen content in the leaves, but this does not provide clear information on the stress tolerance of the plant. The data used to generate the indices are derived from ground, airborne remote sensing and free satellite databases. Their values are influenced by a number of environmental factors (atmospheric and soil properties, stand structure), but it is also important to note that they correlate differently with physiological processes in different phenological phases (HUANG et al. 2013; SULTANA et al. 2014). With the indices we use, we have been able to indicate the positive effects of each treatment at the beginning of tasseling. In addition to yield estimation, these indices provide a snapshot of the physiological state of the stands and allow us to correct any errors (nutrient deficiencies, infestation) by means of agrotechnical tools, so that their application can be integrated into precision farming practices.

In Hungary, 57% less maize (2.8 m tonnes) was harvested in 2022 than in 2021 (6.5 m tonnes). The purchase price was 110 HUF kg^{-1} in 2022 and 70.7 HUF kg^{-1} in 2021. The national average yield was around 3.4 tonnes, the highest in Zala county (7.5 t ha^{-1}) and the lowest in Heves county (1.5 t ha^{-1}) (Website 3). In 2022, the latter was also observed on Kompolt for the control plot (1.583 t/ha), while the treated plots yielded one and a half times more. The average yield showed the highest variance in 4 replications of treatment 3 (Ion-Zn) and the lowest in treatment 2 (Aminocomplex + Zsémix). In treatments 1 and 2, the average yield increased to over 4 t ha^{-1}. The control plots produced maize worth about 175.000 HUF ha^{-1}, while the treated plots produced 440.000 HUF ha^{-1}. The cost of the applied foliar fertilizer was below 10.000 HUF per hectare, so its application is highly recommended, as it will significantly increase in profit even in such an extreme drought year.

References

AMPONG, K.; PENN, C.J.; CAMBERATO, J.J. (2024): The Timing of Phosphorus Availability to Corn: What Growth Stages Are Most Critical for Maximizing Yield? Agronomy 14, 2731. https://doi.org/10.3390/agronomy14112731

FLORES M. DA S, PASCHOALETE W.M., BAIO F.H.R., CAMPOS C.N.S., PANTALEÃO A. DE A., RIBEIRO TEODORO L.P., SILVA JÚNIOR C.A. DA. AND TEODORO P.E. (2020): Relationship between vegetation indices and agronomic performance of maize varieties under different nitrogen rates. Bioscience Journal [online], vol. 36, no. 5, pp. 1638–1644. https://doi.org/10.14393/BJ-v36n5a2020-47993; Available from: https://seer.ufu.br/index.php/biosciencejournal/article/view/47993.

GABRIEL J.L., ZARCO-TEJADA P.J., LOPEZ-HERRERA P.J., PEREZ-MARTÍN E., ALONSO-AYUSO M., QUEMADA M. (2017): Airborne and ground level sensors for monitoring nitrogen status in a maize crop. Biosystem Engineering 160: 124-133. https://doi.org/10.1016/j.biosystemseng.2017.06.003

GAMON J.A., SERRANO L., SURFUS J.S. (1997): The photochemical reflectance index: an optical indicator of photosynthetic radiation use efficiency across species, functional types, and nutrient levels. Oecologia 112: 492-499. http://dx.doi.org/10.1007/s004420050337

GITELSON A.A., MERZLYAK M.N. (2004): Non-destructive Assessment of Chlorophyll Carotenoid and Anthocyanin Content in Higher Plant Leaves: Principles and Algorithms. Papers in Natural Resources. 263. http://digitalcommons.unl.edu/natrespapers/263

GRAY S.B., BRADY S.M. (2016): Plant developmental responses of climate change. Developmental Biology Vol. 419. Issue 1.64-77. https://doi.org/10.1016/j.ydbio.2016.07.023

HOLLÓ S., PETHES J., AMBRUS A. (2009): A tartós szerves és műtrágyázás hatása a talaj könnyen oldható foszfortartalmára Kompolton, csernozjom barna erdőtalajon/. Effects of permanent use of organic and mineral fertilizers on easily soluble P content of Chernozem brown forest soil in Kompolt. (In Hungarian) Tartamkísérletek jelentősége a növénytermesztés fejlesztésében. Jubileumi tudományos konferencia. Martonvásár, 2009. október 15. 227-234.

HUANG J., WANG X., LI X., TIAN H., & PAN Z. (2013): Remotely Sensed Rice Yield Prediction Using Multi-Temporal NDVI Data Derived from NOAA's-AVHRR. Plos One, 8(8). https://doi.org/10.1371/journal.pone.0070816

KAPRINYÁK T., LÁPOSI R., BEKŐ L., TÓTH SZ. Effetcs of combined nutrient supply treatments on some physiological parameters of autumn wheat. Acta Agraris Debreceniensis 241-251. https://doi.org/10.34101/actaagrar/150/1720

KUMMERER K., HELD M., PIMENTEL D. (2010) Sustainable use of soils and time. Journal of soil and water conservation. 65 (2): 141-149. https://doi.org/10.2489/jswc.65.2.141

LÁPOSI R., BEKŐ L., KAPRINYÁK T., MOLJÁK S., TÓTH SZ. ZS. (2020): Evaluation of soil bacteria treatments on some physiological parameters of crops by spectral vegetaion indices. Ecocycles, 6:1 pp. 134-145. https://doi.org/10.19040/ecocycles.v6i1.167

LYKHOVYD P.V. - SHARII V. O. (2024): Normalised difference moisture index in water stress assessment of maize crops. Agrology, 7(1), 21–26. https://doi.org/10.32819/202403

MIRANSARI M. (2013): Soil microbes and the availability of soil nutrients. Acta Physiologiae Plantarum 35: 3075-3084. https://doi.org/10.1007/s11738-013-1338-2

PABAR S.A., KOTROCZÓ ZS., TAKÁCS T., BIRÓ B. (2024): Evaluation the Efficacy of Selected Plant Growth-Promoting Microorganisms in Optimizing Plant Growth and Soils Health in Diverse Soil Types. Agriculture 14(9): 1586 https://doi.org/10.3390/agriculture14091586

PEÑUELAS J., BARET F., FILELLA I. (1995): Semi-empirical indices to assess carotenoids/chlorophyll a ratio from leaf spectral reflectance. Photosynthetica 31(2): 221-230. https://www.researchgate.net/publication/229084513

PIETRINI F. IANNELLI M. A. & MASSACCI A. (2002) Anthocyanin accumulation in the illuminated surface of maize leaves enhances protection from photo-inhibitory risks at low temperature, without further limitation to photosynthesis. Plant, Cell and Environment (2002) 25, 1251–1259. https://doi.org/10.1046/j.1365-3040.2002.00917.x

PUPPE D. – SOMMER M. (2018) Chapter One – Experiments, Uptake Mechanisms and Functioning of Silicon Foliar Fertilization – A Review Focusing on Maize, Rice and Wheat. Advances in Agronomy 152: 1-49. https://doi.org/10.1016/bs.agron.2018.07.003

RAHMAN S. AND MESEV V. (2019) Change Vector Analysis, Tasseled Cap, and NDVI-NDMI for Measuring Land Use/Cover Changes Caused by a Sudden Short-Term Severe Drought: 2011 Texas Event. Remote Sens. 2019, 11(19), 2217; https://doi.org/10.3390/rs11192217

SERRANO, L., USTIN, S. L., ROBERTS, D. A., GAMON, J. A., & PEÑUELAS, J. (2000): Deriving water content of chaparral vegetation from AVIRIS data. Remote Sens. Environ., 74, 570– 581. http://dx.doi.org/10.1016/S0034-4257(00)00147-4

SULTANA S.R., ALI A., AHMAD A., MUBEEN M., ZIA-UL-HAQ M., AHMAD S., ERCISLI S., JAAFAR H.Z.E. (2014): Normalized Difference Vegetation Index as a Tool for Wheat Yield Faisalabad, Pakistan. Hindawi Publishing Corporation The Scientific World Journal, Volume 2014, Article ID 725326, 8 pages, https://onlinelibrary.wiley.com/doi/10.1155/2014/725326

TEVINI M., IWANZIK M.W., THOMA U. (1981): Some effects of enhanced UV-B radiation on the growth and pigment composition of plants. Planta, 153: 388-394. https://doi.org/10.1016/S0044-328X(83)80127-5

TÓTH E., CSAMBALIK L., BIRÓ B., GERE A., KOREN D., KOTROCZÓ ZS., SZALAI Z. (2024) Are the Nutritional Properties of Organic Tomatoes Altered by Single and Combined Microbial Soil Inoculants? A Multiperspective Approach. Journal of Plant Growth Regulation 43: 3718-3728. https://doi.org/10.1007/s00344-024-11358-z

TÓTH N. (2011): Effects of environmental factors on brewing characteristics of malting barley and malt (In Hungarian). PhD Thesis, Szent Istvan Egyetem. Gödöllő https://szie.hu/file/tti/archivum/Toth_Nikolett_ertekezes.pdf

TURY R., TÓTH SZ. ZS., LEHOCZKY É., LÁPOSI R. (2023): Investigation of the physiological effects of plant conditioners in field experiments of winter wheat. Journal of Central European Green Innovation. 11(1): 3-14. https://doi.org/10.33038/jcegi.4489

YOUNG A. AND BRITTON G. (1990): Carotenoids and stress. In Stress Responses in Plants: Adaptation and Acclimation Mechanisms (ed. Alscher R.G. and Cumming J.R.), pp. 87-112. Wiley-Liss, New York

WU C., NIU Z., TANG Q., HUANG W. (2008): Estimating chlorophyll content from hyperspectral vegetation indices: Modeling and validation. Agricultural and Forest Meteorology 148: 1230-1241. https://doi.org/10.1016/j.agrformet.2008.03.005

ZARCO-TEJADA, P. J., & USTIN, S. L. (2001): Modeling canopy water content for carbon estimates from MODIS data at land EOS validation sites. International Geoscience and Remote Sensing Symposium, 2001. IGARSS ’01, Vol. 1 (pp. 342–344). https://doi.org/10.1109/IGARSS.2001.976152

ZARCO-TEJADA P.J., USTIN S.L., WHITTING M.L. (2005): Temporal and Spatial Relationships between Within-Field Yield Variability in Cotton and High-Spatial Hyperspectral Remote Sensing Imagery. Agronomy Journal, 97(3): 641-653. https://doi.org/10.2134/agronj2003.0257

Website references

Website 1: https://www.agroinform.hu/szantofold/kukorica-barometer-mikor-es-hogyan-erik-a-kukorica-40933-001 Letöltés dátuma: 2024. 08. 22.

Website 2: https://hedland.hu/?fbclid=IwZXh0bgNhZW0CMTAAAR1cRMh99vMuuwbT1V3hfPKbUsbqrS6ESFn58XVG-KkEvbhWaEL6MU5GsVg_aem_f2a9ibdqY9PUuqVoWN4MbA Letöltés dátuma: 2024. 09. 02.

Website 3: https://www.ksh.hu/s/kiadvanyok/fobb-novenykulturak-termeseredmenyei-2022/index.html Letöltés dátuma: 2024. 08. 31.

Authors

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

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

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

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

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