Research article

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Revista
Facultad Nacional
de Agronomía

Effect of integrated plant nutrient management on indicators related to yield and productivity of spring barley (*Hordéum vulgáre*) under drought conditions in the growing season

Efecto del manejo integrado de nutrientes de las plantas en los indicadores relacionados con el rendimiento y la productividad de la cebada de primavera (*Hordéum vulgáre*) en condiciones de sequía en etapa de crecimiento

https://doi.org/10.15446/rfnam.v75n2.97384

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ABSTRACT

Keywords:
Abiotic stress
Integrated plant nutrient management system
Localization of fertilizers
Mineral fertilizers
Stress protector

The agricultural production of the world is becoming increasingly vulnerable to extreme weather conditions, but adaptation to such conditions still suffers from a lack of integrated solutions and approaches that should cover relevant plant nutrition management issues, as well as technological mechanisms and tools. This study aimed to investigate the impact of fertilizer systems on yield indicators and the productivity of spring barley under arid growing conditions and determine the correlation between yield indicators and barley productivity to form a fertilization strategy for this crop under drought conditions. Two separate field experiments were conducted in 2018 in a small plot in six replications based on a long-term research field experiment on chernozem-type soil (black soil). As components of an integrated plant nutrient management system, the combined application of mineral fertilizers and stress protectors was used (for seed inoculation and foliar treatment), as well as the local application of mineral fertilizers at different depths (10-12 cm, 20-22 cm and at two depths simultaneously). The application of components of an integrated plant nutrient management system increased the chlorophyll content, leaf water content, and grain yield. These benefits of integrated fertilizer management led to significant improvement in grain yield. The maximum values of this indicator were noted for foliar treatment of plants by a stress protector at a rate of 1.0 L ha^{-1} (once per growing season) or 0.5 L ha^{-1} (twice per growing season) and for deep localization of mineral fertilizers (to a depth of 20-22 cm). The content of chlorophyll and bound water in the tissues of barley plants can be used as an indicator to determine the resistance of plants to arid growing conditions since these physiological characteristics are closely correlated with the yield of barley.

RESUMEN

Palabras clave:
Estrés abiótico
Sistema integrado de gestión de la nutrición vegetal
Localización de fertilizantes
Fertilizantes minerales
Protector de estrés

La producción agrícola del mundo se está volviendo cada vez más vulnerable a las condiciones climáticas extremas, pero la adaptación a tales condiciones todavía adolece de una falta de soluciones y enfoques integrados que deberían cubrir los problemas relevantes de gestión de la nutrición vegetal, así como los mecanismos y herramientas tecnológicos. El objetivo de este estudio fue investigar el impacto de los sistemas de fertilizantes en los indicadores de rendimiento y la productividad de la cebada de primavera en condiciones de crecimiento áridas y determinar la correlación entre los indicadores de rendimiento y la productividad de la cebada para formar una estrategia de fertilización de este cultivo en condiciones de sequía. En 2018 se llevaron a cabo dos experimentos de campo separados en parcelas pequeñas con seis repeticiones basadas en un experimento de campo de investigación a largo plazo en un suelo tipo chernozem (suelo negro). Como componentes del sistema de manejo integral de la nutrición vegetal, se utilizó la aplicación combinada de fertilizantes minerales y protectores de estrés (para inoculación de semillas y tratamiento foliar), así como la aplicación local de fertilizantes minerales a diferentes profundidades (10-12 cm, 20-22 cm y a dos profundidades simultáneamente). La aplicación de componentes del sistema integrado de gestión de la nutrición vegetal aumentó el contenido de clorofila, el contenido de agua de las hojas, producción de grano. Estos beneficios del manejo integrado de fertilizantes condujeron a una mejora considerable en el rendimiento de grano. Los valores máximos de este indicador se observaron para el tratamiento foliar de las plantas con un protector de estrés a una tasa de 1.0 L ha^{-1} (una vez por temporada de crecimiento) o 0.5 L ha^{-1} (dos veces por temporada de crecimiento) y para la localización profunda de fertilizantes minerales (hasta una profundidad de 20-22 cm). También se determinó que el contenido de clorofila y agua unida en los tejidos de las plantas de cebada se puede utilizar como indicadores para determinar la resistencia de las plantas en condiciones de crecimiento árido, dado que estas características fisiológicas están estrechamente relacionadas con el rendimiento de la cebada.

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Received: January 25, 2022; Accepted: April 14, 2022
Rev. Fac. Nac. Agron. Medellín 75(2): 9909-9918. 2022

ISSN 0304-2847 / e-ISSN 2248-7026

Spring barley (*Hordéum vulgáre*) is an early ripening crop with a significant variety of forms. It withstands air drought better than other spring grains, providing sustainable yields. The grain of barley is widely used for food, feed, and brewing purposes. In terms of sown area, it ranks second among spring grain crops in Ukraine (Statistical Yearbook, 2020). The general demand of the state for barley grain significantly exceeds the level of modern production. A successful solution to this problem lies in the stable increase in its grain productivity. Barley has a short growing season; therefore, it reacts negatively to insufficient soil moisture during the period of active growth of leaf mass. Drought as abiotic stress mostly limits the growth and development of crops (Barnabás *et al*., 2008; Sehgal *et al.,* 2019). Water stress hinders growth by diminishing the water turgor of the plant cells, which adversely affects biochemical and physiological processes in plants (Liang *et al.,* 2019). One of the primary physiological consequences of water deficit is the prohibition of photosynthesis, because of a deficit of Ci (intercellular CO_2 concentration) as a result of chlorophyll destruction, stomatal closure, and disorder of the photochemical system (Liu *et al.,* 2016). Morgun *et al.* (2010) in their scientific review also noted, that suppression of plant growth under conditions of soil moisture deficit occurs mainly due to a decrease in their carbon dioxide balance (the difference between the absorption and loss of CO_2), which depends on the ratio of photosynthesis and respiration. Salehi (2016), Agami (2016), Manivannan *et al*. (2007), and Mamnabi *et al.* (2020) describe a deterioration of the physiological characteristics of plants, due to water deficiency, as a sign of oxidative stress damage. The production of reactive oxygen species (ROS) is a physiological response of plants to drought stress. The participation of ROS in the work of some signaling systems and the activation of genes involved in defense reactions has already been proven (Suzuki and Mittler, 2006; Kolupaev and Karpets, 2010).

Water deficit limits the physiological performance of plants by decreasing chlorophyll a (Chl a), chlorophyll b (Chl b), membrane stability index (MSI) (Ghassemi *et al.,* 2018), and chlorophyll content index (CCI) (Ghassemi-Golezani and Afkhami, 2018), the water content in plant tissues (Mamnabi *et al.,* 2020), and the supply of nutrients (N. P, K) (Rouphael *et al*., 2012). For instance, one of the main reasons for the decrease in plant productivity under hydrothermal stresses conditions is the inhibition of photosynthesis, which quickly reacts to water deficit. It was found that the gas exchange of H_2O and CO_2 and cell growth are very sensitive to water deficit in the soil (Sadras, 1996). A slight decrease in soil moisture causes inhibition of the photosynthetic assimilation of carbon dioxide, primarily due to the partial stomatal closure. Chlorophyll concentration is considered to be a sensitive indicator of the state of the plant and the resistance of the genotype to water stress (Chernyad'ev, 1997). The chlorophyll content in plants is an important physiological parameter that characterizes the potential capacity of the photosynthetic apparatus. In general, the intensity of photosynthesis for plants under drought conditions plays an important role. It has already been established that changes in the temperature and water regimes of the leaf, which occur during atmospheric and soil drought, lead to a destruction of the fine structure of chloroplasts, the configuration of protein macromolecules, and the degree of aggregation of pigments adsorbed by the protein. The most important vital processes of plants are associated with photosynthesis, primarily mineral nutrition. It was found that during soil drought, with increasing water deficit, the chlorophyll content in all studied wheat varieties decreased by 13-15% (Kozhukhar *et al*., 2010). The use of different fertilizer systems can positively influence this indicator. It is shown in the examples of different crops that the application of fertilizers, biologicals, and other growth regulators has a positive effect on the chlorophyll content in the leaves, intensifying photosynthetic activity (Ahmadpour *et al*., 2016; Hosseinzadeh *et al*., 2018).

The state of water in plant tissues is also an important indicator of the plant's response to water deficiency. Fractional composition and ratio of water fractions (free, bound) also depends on species characteristics of plants, age, season, time of day, and conditions of mineral nutrition. Bound water supports the structure of colloids and ensures the functioning of enzymes, organelles, and cells. It is inactive and does not participate in the dissolution and transport of substances, but there is a direct relationship between the content of bound water and the resistance of plants to stress (Galasheva *et al*., 2013). Plant nutrition management can improve water conditions in plant tissues. Therefore, inoculation by bio-fertilizer under water limitations increased the leaf water content (Kheirizadeh *et al.*, 2016). This could be the result of enhancing root growth by indole-3-acetic acid (IAA) produced by bacteria (Marulanda *et al.*, 2009). Also, vermicompost has a porous structure, more water holding capacity, organic ions, and plant hormones, so it can improve the leaf water content (Beykkhormizi *et al.*, 2016). On the other hand, the improvement of water content in the leaf due to the use of fertilizers may be associated with an increase in the content of osmolytes such as soluble sugars.

In drought conditions, a lower transpiration rate reduces the transfer of nitrogen from plant roots to shoots, thereby limiting nutrient absorption (Rouphael *et al.*, 2012). The availability and absorption of phosphorus and potassium also declines with decreasing soil moisture content (Marschner, 2012). However, the total annual precipitation has a minor effect on the change in available phosphates content in chernozem soil (black soil) compared to the nitrogen. In general, according to Sun *et al.* (2009), the synergism of moisture, nitrogen, and phosphorus for cereals, decreases in the following order: nitrogen and moisture> phosphorus and moisture> nitrogen and phosphorus. In such conditions, the use of optimal fertilizer systems can significantly increase the availability of important nutrients for plants.

In such conditions, the soil management approach must rely on an integrated plant nutrient management system (IPNMS), such as optimization of fertilizer application methods (in particular, localization methods), joint use of mineral fertilizers, and stress-protective preparations (plant growth regulators and physiologically active substances). Using these components of IPNMS can lead to better nutrients uptake and improve drought tolerance (Mittler, 2006). IPNMS is one of the basic pillars of sustainable agriculture. However, the relationship between fertilizer application optimization technologies and physiological yield indicators has not yet been established; it is not clear whether these indicators can be an important diagnostic value of plant responsiveness to drought growth conditions. Therefore, the aim of this study was to investigate the impact of fertilizer systems on yield indicators and productivity of spring barley under arid growing conditions and to determine the correlation between yield indicators and barley productivity of barley to form a strategy for fertilizing this crop under these conditions.

MATERIALS AND METHODS

Experimental conditions

Two field experiments were conducted in 2018 at the long-term research field experiment on chernozem (black soil) of the NSC "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky" (State Enterprise "Experimental Farm "Grakivske", Kharkiv oblast, Ukraine, geographical coordinates: 49°46′N lat., 39°40′ E long). This experiment was located in a chernozem typical heavy loamy (Haplic Chernozems according to WRB classification) with the following characteristics: pH_{Kl} 5.3; humus content 5.4% (it was determined by the Tyurin method); total nitrogen content 0.2% (it was determined by the Kjeldahl method), the content of mobile phosphorus and potassium 57 and 114 mg kg^{-1}, respectively (these were determined in acetic acid extract).

In the first experiment, the complex effect of stress-protective preparations (synthesized in the laboratory of Agrochemistry Department) and mineral fertilizers were studied (at a rate of 30 kg ha^{-1} for each element nitrogen, phosphorus, and potassium). Mineral fertilizers were used as an agrochemical background (control), inoculation of seeds was carried out by a stress protector for seeds (SPs) at a rate of 1.0 L t^{-1}, foliar treatment was performed by a stress protector for foliar (SPf) at a rate of 0.5 L ha^{-1} and 1.0 L ha^{-1}. The scheme of the field experiment is presented in full accordance with the options in Table 1. Foliar treatment was carried out once during the growing season in the tillering phase (BBCH 23) of barley or twice during the tillering (BBCH 23) and first node stage (BBCH 32). Stress protectors for seeds included a complex of trace elements, sodium tripolyphosphate, phytohormones, silicon, and liposam (a polysaccharide of the natural origin with sticky and moisture-retaining properties). Stress protector for foliar in addition to the above contained a complex of amino acids of the L-configuration and macronutrients in mineral form. The second experiment studied the effect of the depth localization of mineral fertilizers (at a rate of 60 kg ha^{-1} for each element nitrogen, phosphorus, and potassium). The fertilizers band was placed 4-5 cm away from the seed row at three different depths: 10-12 cm, 20-22 cm, and in two strips simultaneously (10-12 cm and 20-22 cm).

Table 1. Schemes of field experiments.

No. options	Field experiment No. 1	Field experiment No. 2
1	$N_{30}P_{30}K_{30}$ - (Control)	Control (without fertilizers)
2	Control + SPs (at rate 1.0 L t^{-1})	$N_{60}P_{60}K_{60\ (complex)}$ 10-12 cm
3	Control + SPs (at rate 1.0 L t^{-1}) + SPf (at rate 0.5 L ha^{-1} twice)	$N_{60}P_{60}K_{60\ (complex)}$ 20-22 cm
4	Control + SPf (at rate 1.0 L ha^{-1} once)	$N_{60}P_{60}K_{60\ (complex)}$ 10-12 cm and 20-22 cm
5	Control + SPf (at rate 0.5 L ha^{-1} twice)	$N_{60}P_{60}K_{60\ (fertilizer\ mixture)}$ 20-22 cm

The experiments were laid out as small plots in six replications; the area of each plot was 4 m^2. All technological operations (fertilization, sowing, loosening, weeding, harvesting, and crop accounting) were carried out manually except for tillage. In both experiments, seeds were sown at the end of March in about 2–3 cm in depth with a row spacing of 15 cm. Barley was harvested in the first week of July.

The weather conditions for the growing season of spring barley in 2018 were very unfavorable (Table 2). The air temperature in April-May and July 2018 was higher compared to the long-term average. At the same time, April-May and July 2018 were very dry. The listed features of weather conditions characterize the growing season of 2018 as arid at the beginning and at the stage of grain ripening.

Table 2. Weather conditions during the study period.

Month	Air temperature (°C)		Precipitation (mm)	
	2018	Average long-term	2018	Average long-term
April	12.4	11.0	12.9	34.5
May	19.9	17.9	15.9	38.9
June	21.6	21.9	43.5	42.2
July	23.0	21.9	28.7	50.2
mean	19.2	18.2	25.25	41.45

Measurements

Chlorophyll content. Measurement of chlorophyll content in the leaf was performed using a portable device SPAD-502 Plus (Konica Minolta, Japan). This method is a non-destructive measurement of plant chlorophyll. The SPAD-502 Plus enables quick and easy measurement of the chlorophyll content of plant leaves without damaging the leaf. The content of chlorophyll in barley leaves was determined once during the growing season at the beginning of booting (BBCH: 41).

Leaf water content. The main characteristics of the water regime of plants (free and bound water content) were determined using a portable refractometer RHB 0-90 (REF107, HT119) (Kelilong Electron, China) and by thermostat-weight method (total water content). Determination of water fractions or, as they are called, water forms, was carried out by the refractometric method, under the action of a hypertonic 30-40% sucrose solution according to the principle proposed by Dumansky (Chmeleva and Kucher, 2016). Determinations were carried out at 20 °C. Using this method, the free water content was found, and the bound water content was determined from the difference between total and free water. The content of the water regime of plants was determined once during the growing season at the beginning of booting (BBCH: 41).

N, P, K contents. The content of nitrogen, phosphorus, and potassium in barley grain was defined according to the method to determine the total forms of nitrogen, phosphorus, and potassium in one sample of plant material, described in MVI 31-497058-019-2005. The essence of the method lies in the decomposition of organic matter in the sample in the presence of a catalyst with boiling sulfuric acid, which leads to the formation of ammonium salts. Separate determination of nitrogen, phosphorus, and potassium was carried out in the hydrolyzate using a spectrophotometer (Spekol). The N, P, and K contents in barley plants was determined after harvesting.

Grain yield. The barley plants were harvested in 4 m^2 of the middle part of each plot and the grains with about 14–17% moisture content were separated from siliques and weighed.

Statistical analysis

All the data were analyzed using STATISTICA 13.5.0.17. Differences among all experimental data were compared by employing the least significance difference (LSD) test at $P<0.05$ probability level.

RESULTS AND DISCUSSION

Chlorophyll content

Analysis of the data for two experiments showed a significant influence of components of IPNMS on chlorophyll of barley (Tables 3 and 4). In the first experiment, foliar treatment of plants by a stress protector at a rate of 1.0 L ha^{-1} (once per growing season) or 0.5 L ha^{-1} (twice per growing season) was the most effective. An increase in the chlorophyll content by 13.6-11.4 units was observed. The results of the second experiment (Table 3) showed a positive trend towards the accumulation of chlorophyll with an increase in the depth of localization fertilizers, however, within the least significant difference (LSD) at a significance level of 95%.

Table 3. Fractional composition of water and chlorophyll content in the tissues of spring barley plants using stress protectors.

Treatments	Total water content (%)	The content of individual fractions of water (%)		Chlorophyll content in plant tissues, (nmol cm^{-2})
		free water	bound water	
$N_{30}P_{30}K_{30}$ - agrochemical background (control)	64.4	55.4	9.0	35.3
Control + SPs (at rate 1.0 L t^{-1})	67.9	55.4	12.5	45.7
Control + SPs (at rate 1.0 L t^{-1}) + SPf (at rate 0.5 L ha^{-1} twice)	67.5	56.7	10.8	45.0
Control + SPf (at rate 1.0 L ha^{-1} once)	68.5	54.7	13.8	48.9
Control + SPf (at rate 0.5 L ha^{-1} twice)	68.1	55.1	13.0	47.0
LSD($P \leq 0.05$)	0.9	2.2	2.5	5.9

Table 4. Fractional composition of water and chlorophyll content in leaves of spring barley, depending on the depth of application and forms of fertilizers.

Treatments	Total water content (%)	The content of individual fractions of water (%)		Chlorophyll content in plant tissues, (nmol cm^{-2})
		free water	bound water	
Control (without fertilizers)	55.3	45.2	10.2	45.4
$N_{60}P_{60}K_{60\ (complex)}$ 10-12 cm	61.2	49.3	11.8	48.0
$N_{60}P_{60}K_{60\ (complex)}$ 20-22 cm	71.8	55.7	16.1	51.9
$N_{60}P_{60}K_{60\ (complex)}$ 10-12 cm and 20-22 cm	70.5	58.2	12.4	49.8
$N_{60}P_{60}K_{60\ (fertilizer\ mixture)}$ 20-22 cm	67.2	54.4	12.8	48.9
LSD ($P \leq 0.05$)	0.5	0.6	2.0	7.2

In treatments 1-4, mineral fertilizers were used in the form of compound NPK fertilizer, in treatment 5 - in the form of ammophos, ammonium nitrate and potassium chloride.

In addition, the combined analysis of the data from two experiments showed a close correlation (r=0.90) between the chlorophyll content in the leaves and the barley grain yield (Figure 1). These results indicate the possibility of using data on chlorophyll content in leaves as an indicator of the responsiveness of barley plants to arid growing conditions, as well as form a strategy for fertilizing barley for growing in drought conditions using the IPNMS components. To determine the tolerance of plants to water stress, chlorophyll content has already been introduced as an index (Hosseinzadeh *et al*., 2018).

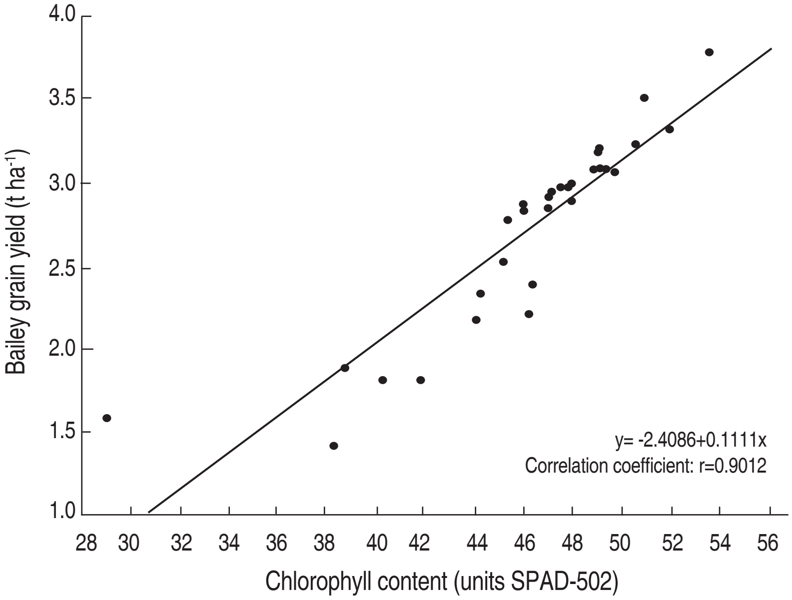

Figure 1. Relationship between indicators of chlorophyll content in plants and the barley grain yield.

In general, mineral nutrition conditions have an influence on the chlorophyll content in plants previously studied. Mamnabi *et al*. (2020) observed the highest chlorophyll content of rapeseed plants under drought stress when the fertilizer treatment was combined, which could be due to the positive effects of the fertilizer treatment on nitrogen and phosphorus supply. These macro-elements have the main role in manufacturing chlorophyll in leaves, cytosine, and oxine, and increase the physiological activity and total chlorophyll. The results of this study presented in TableS 3 and 4 confirm the observations made by Mamnabi *et al*. (2020) and validate the positive effect of additional fertilizers treatments and stress protector agents on the total amount of chlorophyll in barley plants.

Leaf water content

One of the conditions to determine the intensity and direction of physiological processes in plants and their tolerance to changes in the external environment is the degree of water supply and its state in plant tissues. In general, the use of the components of IPNMS had a positive effect on the content of bound water in the tissues of barley plants under drought conditions during the growing season (Tables 3 and 4). The maximum values of the content of bound water (4.8-5.9% higher compared to control) were noted during foliar treatment of plants by a stress protector at a rate of 1.0 L ha^{-1} and deep localization of mineral fertilizers (to a depth of 20-22 cm).

The combined analysis of the two experiments also allows to establish a close correlation between indicators of the content of bound water in plant tissues and barley grain yield (r=0.84) (Figure 2).

The state of water in plants depends on many conditions, one of which is mineral nutrition, optimization of which leads to the formation of the optimal balance of the fractional composition of water in plant tissues. Mamnabi *et al.* (2020) proved that the water content in the leaves of plants treated with biofertilizers was higher than the

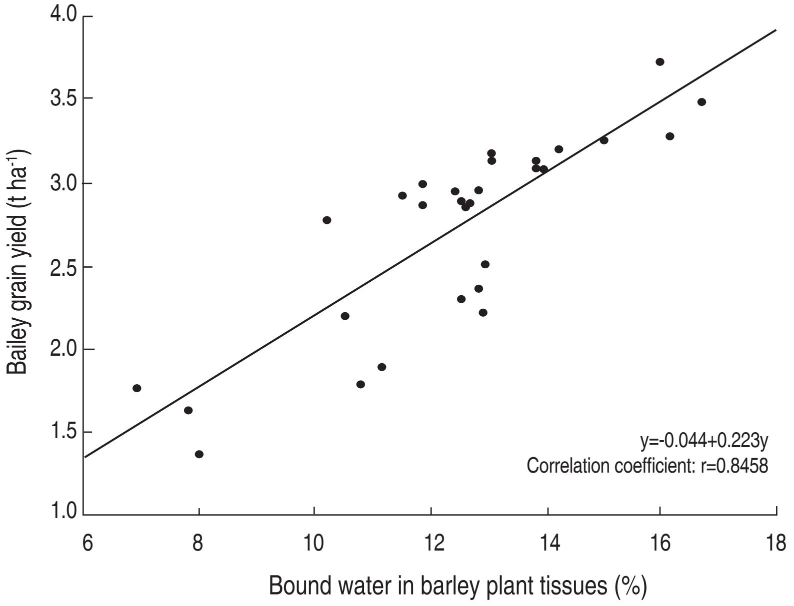

Figure 2. Relationship between indicators of bound water in plants tissues and the barley grain yield.

control, which is similar to the findings of this research (Tables 3 and 4).

N, P, K content

The use of stress protectors in combination with mineral fertilizers under drought conditions improved the content of nitrogen, phosphorus, and potassium in barley grain (Table 5). However, a component of IPNMS (such as the use of stress-protective preparations and mineral fertilizers in a complex) was significant only for the nitrogen content in plants; changes in the content of phosphorus and potassium were at the trend level.

Uptake and utilization of nutrients by barley plants were maximal with using foliar treatment of plants by a stress protector at a rate of 1.0 L ha^{-1} (Table 5). In comparison to the control, the uptake of nutrients was 38–48% higher, which is identical to the results obtained by Mittler (2006). He showed that the treatment of plants with stress protectors and growth stimulants increases the efficiency of using mineral nutrients since their uptake increases by 19-48%. Therefore, there was a positive influence of management of the soil nutrient regime on the efficiency of using nutrients by plants, and it coincides also with the opinion of Studer *et al.* (2017).

In general, the results of the current field experiment (Table 5) carried out in arid growing conditions of barley showed that the content of nutrients (P and K) in the plant cannot be used as an indicator of the application of IPNMS components performance.

Table 5. Content and uptake of nutrients (N, P, K) by the grain of spring barley.

Treatments	Content (%)			Uptake by barley (kg ha^{-1})		
	N	P	K	N	P	K
$N_{30}P_{30}K_{30}$ - agrochemical background (Control)	1.54	0.86	0.53	30.7	17.1	10.5
Control + SPs (at rate 1.0 L t^{-1})	1.81	0.91	0.56	42.6	21.4	13.2
Control + SPs (at rate 1.0 L t^{-1}) + SPf (at rate 0.5 L ha^{-1} twice)	1.81	0.91	0.52	41.9	21.2	12.1
Control + SPf (at rate 1.0 L ha^{-1} once)	1.72	0.90	0.54	48.8	25.4	15.4
LSD($P \leq 0.05$)	0.13	0.03	0.01	-	-	-

Grain yield

Compared to the control, all the components of IPNMS that were studied had a significant increase in grain yield (Tables 6 and 7). Foliar treatment of plants by a stress protector at a rate of 1.0 L ha^{-1} (once per growing season) or 0.5 L ha^{-1} (twice per growing season) turned out to be the most effective method for the combined use of mineral fertilizers and stress protectors (Table 6). The localization of the tape of mineral fertilizers at a depth of 20-22 cm maximized the yield of barley grain, which was almost twice as high as at a depth of 10-12 cm (Table 7). Combining NPK in one granule in compound mineral fertilizer turned out to be more effective (in treatments 1-4) than applying a mixture of simple and complex fertilizers (in treatment 5), when the granules of N, P, and K of fertilizers are separated from each other.

Table 6. Yield of spring barley grain by the application of stress protectors in combination with mineral fertilizers.

Treatments	Yield (t ha^{-1})	Increase (%)
$N_{30}P_{30}K_{30}$ - agrochemical background (Control)	2.00	-
Control + SPs (at rate 1.0 L t^{-1})	2.36	18.0
Control + SPs (at rate 1.0 L t^{-1}) + SPf (at rate 0.5 L ha^{-1} twice)	2.32	16.0
Control + SPf (at rate 1.0 L ha^{-1} once)	2.84	42.0
Control + SPf (at rate 0.5 L ha^{-1} twice)	2.69	34.5
LSD($P \leq 0.05$)	0.67	-

Table 7. Yield of spring barley grain by the depth of application and forms of fertilizers.

Treatments	Yield (t ha^{-1})	Increase (%)
Control (without fertilizers)	2.80	-
$N_{60}P_{60}K_{60\ (complex)}$ 10-12 cm	2.99	6.8
$N_{60}P_{60}K_{60\ (complex)}$ 20-22 cm	3.33	18.9
$N_{60}P_{60}K_{60\ (complex)}$ 10-12 cm and 20-22 cm	2.97	6.1
$N_{60}P_{60}K_{60\ (fertilizer\ mixture)}$ 20-22 cm	2.87	2.5
LSD($P \leq 0.05$)	0.25	-

In treatments 1-4 mineral fertilizers were used in form of compound NPK fertilizer, in treatment 5 – in form of ammophos, ammonium nitrate and potassium chloride.

Improving grain yield of barley plants by using components of IPNMS was related to higher chlorophyll and concentrations of N, bound water content in plants tissues (Table 3 and 4). In general, the amount of chlorophyll increased by enhancing the amount of nitrogen available to the plant and followed by the ability to absorb sunlight and produce more assimilates, and finally increasing the growth and yield in barley grain by 16-42% (Table 3 and 4), which was also confirmed by Salehi *et al*. (2016) and Sorokin *et al*. (2017). They reported that the application of various stress protectors of adaptive action increased the yield of grain crops by 200-400 kg ha^{-1}, in particular, winter wheat by 15-22% and spring barley - by 50-73%.

CONCLUSIONS

The use of components of IPNMS, such as the combined application of mineral fertilizers and stress-protective agents, and deeper localization of mineral fertilizers, significantly impact the yield indicators and the productivity of spring barley under arid growing conditions. In particular, it resulted in higher chlorophyll content by 13.6-11.4 units, bound water in plants tissues by 4.8-5.9%, uptake of nutrients by plants by 38–48%, and barley grain yield by 16-42%.

A strong positive correlation was found between the content of chlorophyll (r=0.90), bound water (r=0.84) in plants, and the yield of spring barley, which confirms the important diagnostic value of these physiological characteristics for optimizing fertilizer application technologies, especially during the droughty growing season.

The strategy for fertilizing spring barley for growing in drought conditions includes the following components of an integrated plant nutrition management system: using a stress protector at a dose of 1.0 L ha^{-1} (once during the growing season) or 0.5 L ha^{-1} (twice during the growing season) in combination with mineral fertilizers; localization of the band of mineral fertilizers at a depth of 20-22 cm.

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