JEE Journal of Ecological Engineering

Journal of Ecological Engineering 2022, 23(6), 14–21
https://doi.org/10.12911/22998993/148150
ISSN 2299–8993, License CC-BY 4.0

Received: 2022.03.30
Accepted: 2022.04.12
Published: 2022.04.20

Optimization of Water Consumption of High-Oleic Sunflower Hybrids under Non-Irrigated Conditions of the Steppe Zone of Ukraine

Yevhenii Domaratskiy[1*], Olga Kozlova[1], Andrey Dobrovol'skiy[2], Valerii Bazaliy[1]

[1] Kherson State Agrarian and Economic University, Stretenskaya St., 23, Kherson, 73006, Ukraine

[2] Mykolayiv National Agrarian University, George Gongadze St., 9, Mykolayiv, 54020, Ukraine

* Corresponding author's e-mail: jdomar1981@gmail.com

ABSTRACT

The article is devoted to highlighting the results of field studies conducted during 2019–2021 on the influence of multifunctional growth-regulating drugs with a fungicidal effect Architect[tm] and Helafit Combi on the productivity and optimization of water consumption of high-oleic sunflower hybrids in non-irrigated conditions of the steppe zone of Ukraine. The study was carried out under non-irrigated conditions in the experimental field of the "Mykolaiv DSDS IZZ NAAS" state institution of Ukraine (GPS: 46.980168, 32.148075) on southern low-humus chernozems. The program of scientific research provided for the foundation of a two – factor field experiment, in which sunflower hybrids were studied, namely Hector and Oplot (originator-V. Y. Yuryev Institute of crop production); DSL403 and P64GE133 (manufacturer Corteva, Brevant) and 8X477KL (manufacturer Dow Seeds). In the experiment, multifunctional growth – regulating preparations of chemical origin, i.e. Architect[tm], and biological origin, i.e. Helafit Combi, were used. They were introduced in the form of foliar treatments of sunflower hybrids in the Phase 6–8 of real leaves with a rate of 1 l/ha. The weather conditions in 2019–2021 can be classified as medium – arid, typical for this growing zone, but the most favorable year was 2021. As for the temperature indicators, the average monthly air temperature for the study years was higher than the corresponding long-term average data. The results of three-year field studies showed that foliar treatments of sunflower hybrids of high-oleic type with Architect and Helafit Combi multifunctional preparations had a positive effect on improving growing conditions and increasing plant resistance to stress from high temperatures and lack of moisture. The study preparations contribute to a more economical use of soil moisture for the formation of a crop unit, as evidenced by a decrease in the water consumption coefficient for all the studied hybrids. The lowest water consumption coefficient of 1283 m^3/t was found in the P64GE133 hybrid under the conditions of treatment of sunflower plants with a Helafit Combi combined preparation of biological origin. Foliar treatment of plants with combined growth-regulating preparations led to optimization of water consumption of agrocenosis in general.

Keywords: sunflower of high-oleic type, multifunctional growth-regulating preparations, Architect, Helafit Combi, hybrid, water consumption, yield.

INTRODUCTION

In recent years, the global climate has undergone significant changes: some countries suffer from abnormal high temperatures, others, on the contrary, suffer from too harsh and snowy winters, which are uncharacteristic for certain places. Environmentalists note global changes in climatic conditions, which are manifested in an increase in the average annual ambient temperature. As a result of this process, glaciers melt and the level of the world oceans rises. Due to climatic transformations, all natural systems are also unbalanced, which leads to a change in the precipitation regime, temperature anomalies, and an increase in the frequency of extreme events (hurricanes, hail, floods, droughts, soil erosion, etc.). The findings of many scientists suggest that climate change, which is becoming more frequent, can lead to even more unpredictable consequences in the future if humanity does not take appropriate preventive measures (Dudiak et al., 2019; Pichura et al., 2020; 2021; 2021).

Steppes are among the most threatened and least protected habitats globally, and therefore, the conservation and restoration of steppe biodiversity, especially in agriculture-dominated landscapes, are key priorities for research and practice (Török et al., 2020). In the acutely arid conditions of the southern part of the steppe zone of Ukraine, moisture remains a decisive factor, and therefore productivity-limiting one for most agricultural crops (Kotova et al., 2010; Domaratskiy et al., 2018). Its level in the soil and air depends on the peculiarity of the operating conditions of all agrocenoses without exception (Domaratsky et al., 2020). However, a certain part of the cases of formation of a high level of productivity of a particular agrocenosis have been established under conditions of a significant shortage of moisture supply. Plants have the mechanisms to use soil moisture reserves in different ways. This ability of plant organisms does not compensate for the entire deficit, but some of it can be easily covered by economical use of water (AbdAllah et al., 2018). Activating the processes of economical use of moisture by agricultural plants in the context of modern climate changes, both at the global and regional levels, is a priority task for the sustainable development of the crop production industry.

Plant growth, development, and response to the environment are mediated by a group of small signaling molecules named hormones. Plants regulate hormone response pathways at multiple levels, including biosynthesis, metabolism, perception, and signaling (Anfang et al., 2021). Most plants produce their own growth regulators (cytokines, gibberellins, auxins, etc.). However, in the context of stressful situations that cause climate change: drought, heat, wind, night frosts, phytotoxicity, the production of its own phytohormones is significantly reduced (Bhattacharia 2019; Kondhare et al., 2021). As a result, there is a noticeable weakening of plants, a violation of the internal program of their development and a decrease in immunity, making plants more sensitive to the effects of diseases, pests and other adverse environmental factors. To reduce the negative impact of stress factors and stabilize the vital processes of the plant body, the preparations containing phytohormones and other synthetic growth stimulators can be used. The action of such substances is aimed at prolonging the period of active photosynthesis processes, suspending the leaf apparatus of vital activity, and therefore strengthening the growth functions (Small et al., 2018; Muir et al. 2018).

Over the past 15 years, fundamentally new highly effective plant growth regulators have been created that can significantly increase the productivity of agricultural crops. According to calculations, the cost of using the best modern growth regulators on grain crops is recouped by the cost of yield gains of 30–50 times (Shourbalal et al., 2019; Wang et al., 2021; Melino et al., 2022). Today, the use of growth regulators is one of the most highly profitable measures to increase the yield of all crops without exception (Deepika et al., 2020; Zhang et al., 2022).

It was established from the research of scientists (Domaratsky et al., 2020; Koutroubas et al., 2020; Domaratskiy 2021; Jan et al., 2022) that sunflower was a demanding crop for providing moisture, but the need for it varied according to the periods of its development. By the beginning of the inflorescence formation phase, sunflower plants consume about 20% of the total amount of water, mainly from a layer of 0–50 cm. Critical for sunflower plants are the basket formation and flowering phases, during which up to 60% of the available moisture reserves are consumed. Due to its biological features, it is able to use moisture from a depth of up to 3 meters, while completely dehydrating the 1.5-meter soil layer.

The purpose of the article was to optimize the water consumption of high-oleic sunflower agrocenoses under the non-irrigated conditions of the steppe zone of Ukraine in the context of global climate change.

MATERIALS AND METHODS

The study was conducted during 2019–2021 yrs. on the experimental field of the Mykolaiv DSDS IZZ NAAS (GPS: 46.980168, 32.148075 Mykolaiv, Ukraine) in non-irrigated conditions (Figure 1).

The soil of the experimental sites is Southern low – humus powdery-heavy loamy chernozem on carbonate loess. The depth of the humus layer is 30 cm, the transition layer is 60 cm. The pH of the soil solution is close to neutral (pH 6.5–6.8), hydrolytic acidity is in the range of 2.00–2.52 mg EQ. per 100 g of soil. The sum of the absorbed bases is 32–35 mg EQ. per 100 g of soil, the degree of saturation with bases is 95.7%. The presence of humus in the arable soil layer is 2.90%. According to the content of mobile elements, the soil of the experimental site is characterized by an

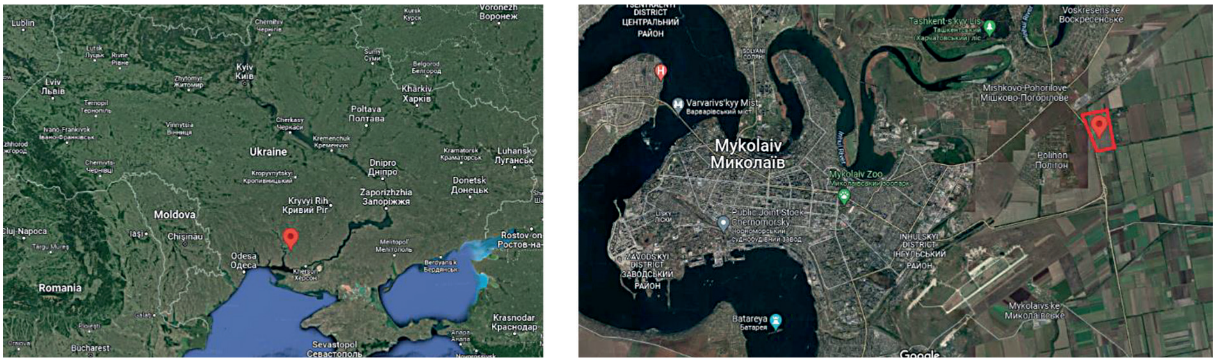

Figure 1. The place of research

average content of nitrate nitrogen (30.0 mg/kg), medium – mobile phosphorus (100 mg/kg) and very high – exchange potassium (300.0 mg/kg).

To achieve this goal, the scientific research program provided for the foundation of a two-factor field experiment, in which various high-oleic sunflower hybrids of domestic and foreign selection (Factor A) were studied, as well as foliar treatment of plants with multifunctional growth-regulating preparations with fungicidal properties (Factor B). The studied sunflower hybrids are Hector and Oplot (originator – V.Y. Yuryev Institute of crop production); DSL403 and P64GE133 (manufacturer Corteva, Brevant) and 8X477KL (manufacturer Dow Seeds). In the experiment, multifunctional growth – regulating preparations of chemical origin, i.e. Architect^{tm}, and biological origin, i.e. Helafit Combi, were used. They were introduced in the form of foliar treatments of sunflower hybrids in the phase 6–8 of real leaves with a rate of 1 l/ha. The versatility of the studied drugs lies in the fact that in addition to growth-stimulating properties, they also have a fungicidal effect. Treatment was carried out with a satchel sprayer until 11 o'clock in the afternoon in calm weather. At the control variant, no preparations were applied, and the plants were treated with clean water.

Repetition was three times, the sown area of the First – Order plot was 168 m^2, accounting plot was 120 m^2. The field experiment was based on the predecessor winter wheat. Sowing was carried out with an UPS-8 seed drill with a rate of 48.7 thousand units / ha. All records and observations were carried out in accordance with generally accepted methods for conducting field experiments in crop production and variety testing, methodological recommendations of the V.Y. Yuryev Institute of crop production of the National Academy of Sciences, existing DSTU. Soil moisture was determined by using the thermostatic-weight method during sowing and harvesting of the crop.

The seed yield was recorded manually, followed by recalculation of the yield in tons per hectare at Standard humidity and 100% purity. Evaluation of seed quality indicators was carried out in the laboratory of agro plus.

RESULTS AND DISCUSSION

According to numerous studies by scientists around the world, the level of realization of the biological potential of sunflower when growing under non-irrigated conditions of insufficient moisture does not exceed 50% (Howell et al., 2015; Giannini et al., 2022). However, the practical experience of advanced farms in Ukraine, which use modern means of intensifying technological schemes for growing crops, can significantly improve the realization of genetic potential. One of the decisive factors for improving the life of sunflower plants is the use of modern substances of combined action, which, in addition to the stimulating effect, also have a fungicidal component, which also improves the resistance of plants to pathogenic microflora.

Analysis of the weather conditions of 2019–2021 yrs. studies allows classifying them as medium – arid typical for this growing zone. The main weather conditions of the research years in comparison with the long-term average data are shown in Figure 2.

While analyzing the weather conditions of 2019–2021, it was found that during the growing season of sunflower cultivation, 235–364 mm of precipitation was recorded, i.e. 106–120% of the long – term average, but their distribution was uneven. The most favorable year for sunflower cultivation was 2021, during the growing season precipitation amounted to 364 mm, which was

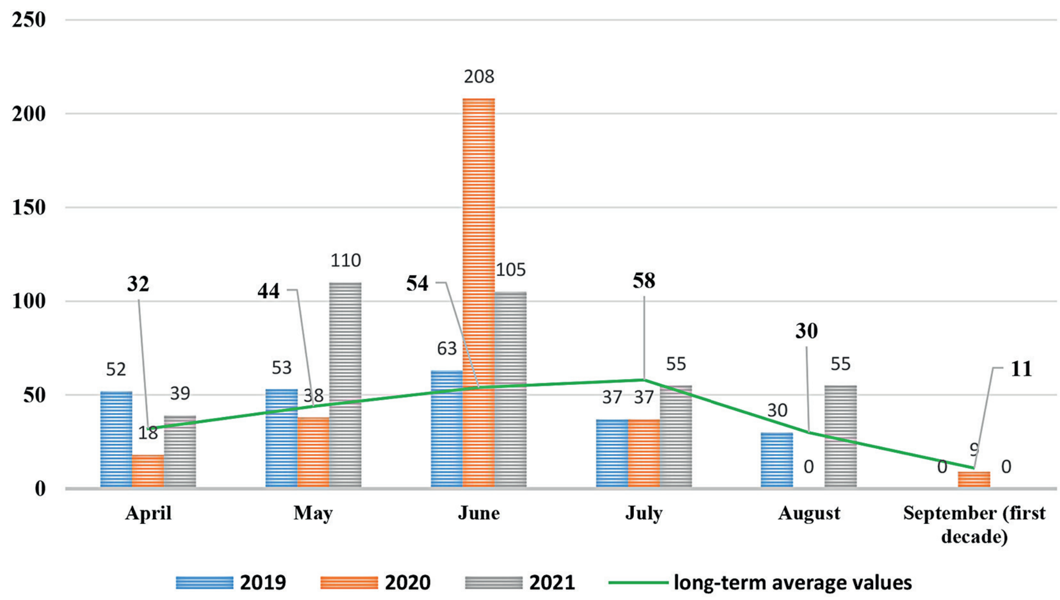

Figure 2. Precipitation during the growing season of sunflower cultivation, 2019–2021 yrs (mm)

159% of the norm, relative to the spring moisture reserves in the meter layer of soil in the years of research, they differed almost twice, so in 2019 the moisture reserves were 69 mm, in 2020 they were 41 mm and they were 89 mm in 2021. It should also be noted that in 2021, precipitation occurred during critical phases of plant development, namely during budding and flowering. Accordingly, in the generative phase of development, sunflower plants did not suffer from a lack of moisture, in the future all the processes from flowering and seed filling occurred without the manifestation of stressful conditions.

The results of observations showed that in 2019 and 2020, the second half of the growing season of sunflower agrocenosis occurred with a severe shortage of soil and air moisture. The development of plants during this period took place under conditions of constant stress from lack of moisture and under the influence of high air temperatures (Figure 3).

The weather conditions in 2020 for sunflower development were difficult throughout the entire growing season of the crop. High temperature conditions against the background of insufficient moisture led to a reduction in interphase

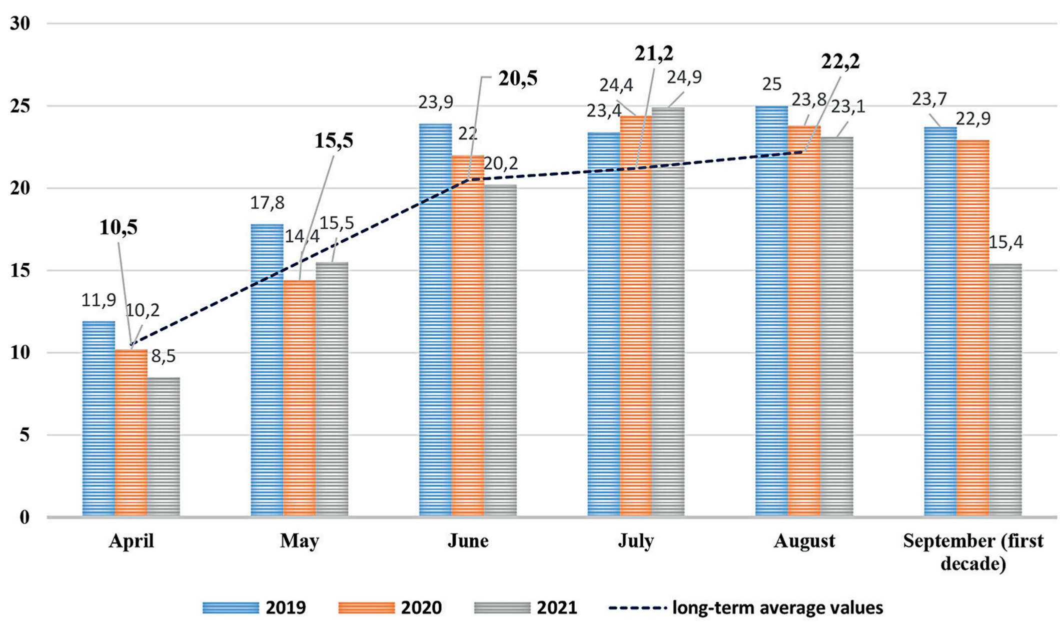

Figure 3. Average monthly air temperature for the growing season of sunflower cultivation for 2019–2021 (°C)

periods of plant development. This phenomenon is not a positive factor, especially combined with extremely low moisture supply (41 mm) of the meter-long soil layer before sowing in 2020. The high temperature regime in the future and low humidity caused an intensive consumption of soil moisture for transpiration and evaporation.

As for the temperature indicators for 2019 and 2020, the average monthly air temperature was higher than the corresponding long-term average data. In 2021, the temperature regime of the growing season of sunflower plants was generally lower compared to the long-term average values, with the exception of July 2021. Good humidification conditions in 2021 against the background of a satisfactory temperature regime (without extremely high indicators) had a positive impact on the course of interphase periods of plants. The growing season of sunflower tended to prolong the photosynthetic activity, which had a positive effect on the productivity of agrocenosis in general.

Under the arid conditions of the Southern steppe of Ukraine, the level of soil moisture supply is one of the decisive factors in the formation of agrocenosis productivity. All agricultural activities aimed at preserving moisture are the main ones in the agriculture of the steppe zone (He et al., 2021; Xu et al., 2021).

The level of crop yield is the main indicator of the effectiveness of crop cultivation; it can also depend on the genetic characteristics of hybrids, reactions to soil and climatic conditions of cultivation and elements of varietal agricultural technology (Flagella et al., 2002; Ibrahim, 2012). The results of the research proved that the introduction of various growth-regulating drugs is an effective and efficient way to improve the development conditions of sunflower plants (Table 1).

Indeed, in 2019–2021 there is a steady increase in the yield from the use of growth – regulating substances. The Oplot and P64GE133 sunflower hybrids, on average for the experiment, formed the highest productivity over the years of research under the influence of growth-regulating substances. As for the DSL 403 and 8X477KL hybrids, they were slightly inferior in yield to the above-mentioned hybrids, and Hector was generally inferior in productivity to all the hybrids studied. The studied hybrids formed the highest productivity in favorable 2021, and under extreme weather conditions in 2020, all hybrids tended to reduce yields by almost 30%.

Analysis of the presented experimental data in Table 1 made it possible to state that foliar treatment with combined growth-regulating drugs had a positive effect on increasing the productivity of all studied sunflower hybrids. Thus, the highest

Table 1. Sunflower yield depending on foliar treatment with growth-regulating drugs over the years of research, t/ha

Hybrids (A)	Preparation (B)	Years			Average for 3 yrs.
		2019	2020	2021	
Oplot	Without preparations (control)	2.82	1.98	2.88	2.56
	Architect[tm]	3.07	2.01	3.12	2.73
	Helafit Combi	3.10	2.04	3.11	2.75
Hector	Without preparations (control)	1.92	1.54	2.04	1.83
	Architect[tm]	2.14	1.68	2.23	2.02
	Helafit Combi	2.10	1.72	2.22	2.01
DSL 403	Without preparations (control)	2.44	1.83	2.54	2.27
	Architect[tm]	2.55	1.88	2.86	2.43
	Helafit Combi	2.60	1.93	2.90	2.48
P64GE133	Without preparations (control)	2.71	1.90	2.92	2.51
	Architect[tm]	2.88	1.95	3.05	2.63
	Helafit Combi	2.89	2.02	3.10	2.67
8X477KL	Without preparations (control)	2.22	1.68	2.41	2.10
	Architect[tm]	2.37	1.71	2.96	2.35
	Helafit Combi	2.37	1.74	3.09	2.40
HIP05, t/ha	A	0.09	0.07	0.09	-
	B	0.12	0.11	0.10	-
	AB	0.25	0.21	0.24	-

yield according to the experiment on average over the years of research was formed by the Oplot sunflower hybrid as 2.75 t/ha in the variant of plant treatment with Helafit Combi. The P64GE133 hybrid was slightly inferior in yield, forming a yield of 2.67 t/ha under such conditions.

The conditions of the southern steppe zone of Ukraine are characterized by unstable and uneven moisture. It is a zone of risky farming. Under such conditions, the main task is to maximize the use of moisture reserves in the soil during sowing and precipitation during the growing season. Observations of the dynamics of moisture in the meter-long soil layer during the growing season of plants showed that hybrids used it differently. This is due to the genetic characteristics of a particular hybrid, as well as the influence of foliar treatment of plants with growth-regulating drugs (Table 2).

Productive moisture reserves at the beginning of sowing can be classified as satisfactory. At the end of the sunflower growing season, in the phase of full ripeness, the moisture reserves of the meter layer acquired minimal values. The water consumption coefficient is an integral expression of all components of the water regime. Analysis of the water balance results indicated that under the conditions of using combined preparations, the water consumption coefficient of all the studied hybrids tended to decrease compared to the control variants, where foliar treatment of sunflower plants was not carried out. Thus, the lowest level of water consumption coefficient (1283 m^3/t) was recorded in the P64GE133 hybrid under the conditions of processing sunflower plants with a Helafit Combi combined preparation of biological origin, and it was the highest in the Hector hybrid (1860 m^3/ha) in the control variant. Such a decrease in the water consumption coefficient in all the studied hybrids under the influence of processing sunflower plants with multifunctional preparations indicates a more economical use of soil moisture for the formation of a unit of yield.

CONCLUSIONS

The results of field studies proved that foliar treatments of sunflower hybrids of high-oleic type with Architect^{tm} and Helafit Combi multifunctional preparations had a positive effect on the productivity of agrocenosis of all the studied hybrids. The highest yield of 2.75 t/ha over the years of research on the experiment was formed in the Oplot hybrid in the variant of foliar treatment of plants with Helafit Combi. The introduction of

Table 2. Sunflower water balance depending on foliar treatment with growth – regulating drugs, average for 2019–2021

Hybrids	Preparation	Reserve of moisture in lay 0–100 cm, m^3/ha		Sum of precipitations for vegetation, m^3/ha	Total water consumption, m^3/ha	Yield, t/ha	Coefficient of water consumption, m^3/t
		Beginning of sowing	Full ripeness				
Oplot	Without preparations (control)	663	288	3030	3405	2.56	1330
	Architect^{tm}	663	280	3030	3413	2.73	1250
	Helafit Combi	663	274	3030	3419	2.75	1243
Hector	Without preparations (control)	663	288	3030	3405	1.83	1860
	Architect^{tm}	663	277	3030	3416	2.02	1691
	Helafit Combi	663	272	3030	3421	2.01	1702
DSL 403	Without preparations (control)	663	288	3030	3405	2.27	1500
	Architect^{tm}	663	274	3030	3419	2.43	1406
	Helafit Combi	663	275	3030	3418	2.48	1378
P64GE133	Without preparations (control)	663	288	3030	3405	2.51	1357
	Architect^{tm}	663	270	3030	3423	2.63	1301
	Helafit Combi	663	268	3030	3425	2.67	1283
8X477KL	Without preparations (control)	663	288	3030	3405	2.10	1621
	Architect^{tm}	663	273	3030	3420	2.35	1455
	Helafit Combi	663	283	3030	3410	2.40	1421

growth-regulating preparations at the initial stages of sunflower growth and development leads to improved growing conditions and increased plant resistance to stress from high temperatures and lack of moisture. The study preparations contribute to a more economical use of soil moisture for the formation of a crop unit, as evidenced by a decrease in the water consumption coefficient for all the studied hybrids. The lowest water consumption coefficient of 1283 m^3/t was found in the P64GE133 hybrid under the conditions of treatment of sunflower plants with a Helafit Combi combined preparation of biological origin. Foliar treatment of plants with combined growth-regulating preparations led to optimization of water consumption of agrocenosis in general.

REFERENCES

1. AbdAllah A.M., Burkey K.O. and Mashaheet A.M. 2018. Reduction of plant water consumption through anti-transpirants foliar application in tomato plants (Solanum lycopersicum L). Scientia Horticulturae, 235, 373–381.
2. Anfang M. and Shani E. 2021. Transport mechanisms of plant hormones. Current Opinion in Plant Biology, 63, 102055.
3. Bhattacharya A. 2019. Chapter 6 - Effect of High-Temperature Stress on the Metabolism of Plant Growth Regulators. Effect of High Temperature on Crop Productivity and Metabolism of Macro Molecules, 485–591.
4. Deepika P. and Ali D.M. 2020. Production and assessment of microalgal liquid fertilizer for the enhanced growth of four crop plants. Biocatalysis and Agricultural Biotechnology, 28, 101701.
5. Domaratskiy E.O., Zhuykov O.G., Ivaniv M.O. 2018. Influence of Sowing Periods and Seeding Rates on Yield of Grain Sorghum Hybrids under Regional Climatic Transformations. Indian Journal of Ecology, 45(4), 785–789.
6. Domaratskyi Ye., Kozlova O., Domaratskyi O., Lavrynenko Iu., Bazaliy V. 2020. Effect of nitrogen nutrition and environmentally friendly combined chemicals on productivity of winter rapeseed under global climate change. Indian Journal of Ecology, 47(2), 330–336.
7. Domaratskiy Ye., Kozlova O. and Kaplina A. 2020. Economic Efficiency of Applying Environmentally Friendly Fertilizers in Production Technologies in the South of Ukraine. Indian Journal of Ecology, 47 (3), 624–629.
8. Domaratskiy Ye. 2021. Leaf Area Formation and Photosyntetic Activity of Sunflower Plents Depending on Fertilizers and Growth Regulators. Journal of Ecological Engineering, 22(6), 99–105.
9. Dudiak N.V., Potravka L. A., Stroganov A. A. 2019. Soil and Climatic Bonitation of Agricultural Lands of the Steppe Zone of Ukraine. Indian Journal of Ecology, 46 (3), 534–540.
10. Flagella Z., Rotunno T., Tarantano E., Caterina R.D. and Caro A.D. 2002. Changes in seed yield and oil fatty acid composition of high oleic sunflower (Helianthus annuus L.) hybrids in relation to the sowing date and the water regime. European Journal of Agronomy, 17(3), 221–230.
11. Giannini V., Mula L., Carta M., Patteri G. and Roggero P.P. 2022. Interplay of irrigation strategies and sowing dates on sunflower yield in semi-arid Mediterranean areas. Agricultural Water Management, 260, 107287.
12. He K., Huang Yo., Qi Yu, Sheng Zh. and Chen Hu. 2021. Effects of nitrogen addition on vegetation and soil and its linkages to plant diversity and productivity in a semi-arid steppe. Science of The Total Environment, 778, 146299.
13. Howell T.A., Evett S.R., Tolk J.A., Copeland K.S. and Marek Th.H. 2015. Evapotranspiration, water productivity and crop coefficients for irrigated sunflower in the U.S. Southern High Plains. Agricultural Water Management, 162, 33–46.
14. Ibrahim H.M. 2012. Response of Some Sunflower Hybrids to Different Levels
15. Jan A.U., Hadi F., Ditta A., Suleman M. and Ullah M. 2022. Zinc-induced anti-oxidative defense and osmotic adjustments to enhance drought stress tolerance in sunflower (Helianthus annuus L.). Environmental and Experimental Botany, 193, 104682.
16. Kondhare K.R., Patil A.B. and Giri A.P. 2021. Auxin: An emerging regulator of tuber and storage root development. Plant Science, 306, 110854.
17. Kotova N. and Makhortykh S. 2010. Human adaptation to past climate changes in the northern Pontic steppe. Quaternary International, 220(1–2), 88–94.
18. Koutroubas S.D., Antoniadis V., Damalas Ch.A. and Fotiadis S. 2020. Sunflower growth and yield response to sewage sludge application under contrasting water availability conditions. Industrial Crops and Products, 154, 112670.
19. Melino V.J., Tester M.A. and Okamoto M. 2022. Strategies for engineering improved nitrogen use efficiency in crop plants via redistribution and recycling of organic nitrogen.Current Opinion in Biotechnology, 73, 263–269.
20. Mu Xi., Chen Q., Wu Xi., Chen F., Yuan Li. and Mi G. 2018. Gibberellins synthesis is involved in the reduction of cell flux and elemental growth rate in maize leaf under low nitrogen supply. Environmental and Experimental Botany, 150, 198–208.

21. Pichura V.I., Potravka L.A., Skrypchuk P.M., Stratichuk N.V. 2020. Anthropogenic and climatic causality of changes in the hydrological regime of the Dnieper river. Journal of Ecological Engineering, 21(4), 1–10.
22. Pichura V., Potravka L., Dudiak N., Vdovenko N. 2021. Space-Time Modeling of Climate Change and Bioclimatic Potential of Steppe Soil. Indian Journal of Ecology, 48(3), 671–680.
23. Pichura V., Potravka L., Dudiak N., Stroganov A., Dyudyaeva O. 2021. Spatial differentiation of regulatory monetary valuation of agricultural land in conditions of widespread irrigation of steppe soils. Journal of water and land development, 48(I–III), 182–196.
24. Shourbalal S.K.S., Soleymani A. and Javanmard H.R. 2019. Shortening vernalization in winter wheat (Triticum aestivum L.) using plant growth regulators and cold stratification. Journal of Cleaner Production, 219, 443–450.
25. Small C.C. and Degenhardt D. 2018. Plant growth regulators for enhancing revegetation success in reclamation: A review. Ecological Engineering, 118, 43–51.
26. Török P., Neuffer B., Heilmeier H., Bernhardt K.-G., Wesche K. 2020. Climate, landscape history and management drive Eurasian steppe biodiversity. Flora, 271, 151685.
27. Xu T., Zhu L., Ma Q., Wang J., Lü X. and Tang L. 2021. Moisture and vegetation variations in the extremely cold-dry area of the Tibetan Plateau during the past 5000 years. Catena, 204, 105381.
28. Wang J.Yo., Lin P.-Yu and Al-Babili S. 2021. On the biosynthesis and evolution of apocarotenoid plant growth regulators. Seminars in Cell & Developmental Biology, 109, 3–11.
29. Zhang H., Sun Xi. and Dai M. 2022. Improving crop drought resistance with plant growth regulators and rhizobacteria: Mechanisms, applications, and perspectives. Plant Communications, 3(1), 100228.