Scientific Papers. Series A. Agronomy, Vol. LXVIII, No. 1, 2025
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

STUDIES ON THE INFLUENCE OF GROWTH REGULATORS IN REDUCING THE EFFECTS OF CLIMATE CHANGE ON SOYBEAN CULTIVATION IN CENTRAL MOLDAVIA

Doru STANCIU[1, 2], Oana MÎRZAN[1], Margareta NAIE[1], Alexandra LEONTE[1], Andreea-Sabina PINTILIE[1], Denisia-Mihaela IACOBUȚ[1], Roxana-Georgiana AMARGHIOALEI[1], Cosmin-Alexandru MURARU[1], Carmenica-Doina JITĂREANU[2]

[1]Agricultural Research and Development Station Secuieni, 371 Principala Street, Secuieni, Neamt, Romania
[2]"Ion Ionescu de la Brad" Iași University of Life Sciences, 3 Mihail Sadoveanu Alley, Iasi, Romania

Corresponding author email: georgyana_roxana96@yahoo.com

Abstract

Climatic stress, such as drought and extreme temperatures, represents a major threat to the growth and development of crops, including soybeans, which require a balanced water regime. Water is an essential component of plant life, and its absence is the most crucial abiotic factor negatively affecting the quality and quantity of agricultural production. According to the specialized literature, growth regulators positively influence the morphology, physiology, and quality of soybean production. Recent studies indicate that applying such products at optimal concentrations and growth stages can mitigate abiotic stress. Based on this premise, a study was conducted in the experimental field at ARDS Secuieni, aiming to determine the influence of growth regulators on the productive potential of soybeans. The experiment was bifactorial type, using two soybean varieties created by ARDS Turda and three growth regulators applied during the flowering period. The results highlighted that the tested regulators influenced the adaptability of the soybean varieties to drought.

Key words*: drought, growth regulators, soybean.*

INTRODUCTION

Soy is one of the most important protein and oilseed crops worldwide. At the same time, the importance of soy is also evident in mixed farming systems, making it a key crop both economically and environmentally. In these systems, soybean contributes not only to the diversification of agricultural production but also to the improvement of soil health, having beneficial effects in a cropland, reducing the need for pesticides and chemical fertilizers (Badea et al., 2023; Joița-Păcureanu et al., 2023). However, Europe relies heavily on imports due to the small area devoted to legume cultivation, representing only 1.5% of agricultural land compared to global needs (Watson et al., 2017).

Phytohormones play a key role in regulating the stress response and enhancing plant growth, with a particular focus on soybean. These hormones interact to trigger specific signaling mechanisms that control gene expression and contribute to plant adaptation to adverse conditions. Abiotic stress, particularly drought, negatively affects crop productivity, and in this context, abscisic acid (ABA) acts as a master regulator in the intense responses, causing stomata to close. In the long term, ABA interacts with other hormones such as jasmonic acid (JA), gibberellins (GA), salicylic acid (SA) and brassinositides (BR) to stimulate stomatal closure by regulating gene expression. In contrast, cytokinins (CK) and auxins (IAA) regulate stomatal opening. Abscisic acid (ABA) is present in various organisms and plays a crucial role in regulating cell growth and stress tolerance. Under water stress, endogenous ABA levels increase rapidly, acting as signaling molecules that regulate genes such as DREB proteins and bZIP transcription factors. ABA induces stomatal closure to prevent water loss and improves root architecture to facilitate access to soil water. Exogenous application of phytohormones can enhance drought tolerance of soybean (Shaffique et al., 2023).

Global demand for the soybean crop is increasing due to its economic and nutritional importance, but production is often affected by abiotic stressors such as drought and salinity, which emphasizes the need for innovative strategies, such as the use of plant growth regulators, to improve crop resilience and ensure sustainable yields. The impact of plant growth regulators (PGRs) on soybean productivity highlights how they influence physiology, morphology and stress tolerance. Through exogenous application, PGRs can improve photosynthetic rate, increase chlorophyll content and stimulate translocation of assimilates, which favors biomass accumulation and yield increase. For example, salicylic acid stabilizes photosystem II, improving water use efficiency and antioxidant activity, while cytokinins and gibberellic acid (GA_3) stimulate cell division and stem elongation, contributing to better plant growth. At the morphological level, PGRs such as indolbutyric acid (IBA) promote root development, improving water and nutrient uptake, and ethephon (ETP) increases root surface area, thus increasing resistance to stress conditions. In addition, these compounds play an essential role in ameliorating the effects of abiotic stresses, such as drought and salinity, by activating the plant's defense mechanisms. Application of methyl jasmonate (MeJA) improves drought tolerance by increasing the concentration of soluble sugars and secondary metabolites involved in stress adaptation. Besides yield enhancement, PGR influences seed quality by contributing to higher protein and oil content (Amoanimaa et al., 2022).

The productivity of soybean crop largely depends on the availability of nitrogen, which significantly influences plant growth and development (Salvagiotti et al., 2008), but with its ability to fix atmospheric nitrogen, soybean becomes an important crop in crop rotations, helping to maintain soil fertility and reduce the need for chemical fertilizers. Thus, soybean not only improves agricultural crop yields, but also brings environmental benefits by improving soil structure and nutrient cycling (Ionescu et al., 2022; Moldovan et al., 2022).

Although the application of plant growth regulators (PGRs) has been limited in the past, analysis of the role of the synthetic cytokinin cytokini 6-benzyladenine (6-BAP) in improving drought tolerance of soybean highlights the benefits of exogenous use on plant growth and productivity. Drought adversely affects soybean growth, causing cell dehydration, reduced water potential, accumulation of reactive oxygen species and accelerated senescence, leading to decreased productivity. The 6-BAP molecule contributes to regulating cell division, delaying senescence, improving root architecture and stimulating the translocation of photosynthesis products, thus favoring better adaptation to water stress conditions. In addition, exogenous application of 6-BAP at the end of flowering reduces floral abortion and increases the number of pods and seeds, significantly improving yield. It also plays a key role in plant adaptation to fluctuating water availability, helping to maintain crop vitality (Mangena Phetole, 2022).

Analysis of the effects of the application of a plant growth regulator (PGR) on soybeans at the R2 (beginning of pod formation) and R3 (pod formation) stages, highlights its impact on yield and agronomic characteristics of the crop. Growth regulators are chemicals that influence plant physiological processes such as cell division, stem elongation and stress tolerance. Among the most important PGRs involved in soybean growth are gibberellic acid (GA_3), cytokinins and salicylic acid. Gibberellic acid stimulates stem elongation, fruit development and pod formation, leading to more seeds per plant. Cytokinins, such as kinetin, regulate cell division and delay senescence, having a positive effect on seed weight and quality, in particular by increasing protein content. Salicylic acid plays a key role in stress adaptation, influencing stomatal closure and improving the harvest index, which contributes to increased yield. The study demonstrates that the application of growth regulators in R2-R3 phases can significantly improve the yield and quality of soybean crops, but the efficacy of these products depends on the type of PGR used and the optimal timing of application (Klumpp Geoffrey, 2018).

The impact of plant growth regulators (PGRs) on nitrogen metabolism, yield and quality of the symbiosis between soybean and nitrogen-fixing bacteria was analyzed using various PGRs types (auxins, cytokinins, gibberellins and mepiquat chloride). These were applied to soybean plants following batting to assess the effects on

nitrogen fixation and plant growth. The results showed that the application of these PGRs significantly stimulated the activity of symbiotic batteries, improving the atmospheric nitrogen fixation process, and consequently the growth and development of soybean crop. Treated plants showed higher yield with better nodule development and increased nitrogen concentration. In addition, PGRs positively influenced nitrogen metabolism by stimulating enzyme activity associated with nitrogen assimilation and utilization in plant metabolic processes. Seed quality was also improved, with an increase in protein and lipid content, suggesting a higher efficiency in the utilization of nitrogen resources and a positive impact on the nutritional value of the seeds. Accordingly, the use of growth regulators can optimize the symbiosis between soybean and nitrogen-fixing bacteria, thereby improving the quantity and quality of soybean crops under more sustainable conditions and with less consumption of chemical fertilizers (Chen et al., 2023).

Based on these hypotheses, this paper highlights how commercial products applied on soybean plants have influenced productivity elements in the context of climate change in Central Moldova.

MATERIALS AND METHODS

This paper presents the partial results of an experiment that was located in the experimental field of A.R.D.S. Secuieni, in the year 2023. It aimed to analyze the influence of some growth regulators on some productivity elements of soybean plants. The experiment was bifactorial, where factor A was represented by the soybean variety and factor B by the commercial product. Factor A had 2 gradations, represented by the varieties Onix and Ziana TD, and factor B had 4 gradations, the untreated control and the products Moddus Evo, Ormet and Toprex.

Both Onix and Ziana TD are Romanian varieties created and patented by A.R.D.S. Turda. Varieties are early maturing, falling in the OO maturity group, with Ziana TD being on the borderline between OOO and OO. These varieties have a high yield potential, reaching 4600 kg/ha for Onix and 5000 kg/ha for Ziana TD. Their grains have a protein content of over 40% and a lipid content between 20.9% and 24.6%, ensuring superior nutritional quality. Also, both varieties show very good resistance to lodging, lodging and lodging, and are recommended for the favorable soybean areas of Transylvania, Moldova and the Western Plain.

To fulfill the research objectives set, both soybean varieties were treated with 3 different commercial products with specific growth regulator action.

The physiological action of these products consists in modifying the morpho-physiological characteristics of the plants. They inhibit stem length growth, in particular by reducing internode elongation. At the same time, they accelerate the flowering, fruiting, and fruit ripening processes. At the same time, they contribute to increasing plant tolerance to stress factors such as drought, salinity, diseases, and pests by limiting cell extension and stimulating tissue differentiation (Jităreanu & Toma, 2007).

Moddus Evo is a growth regulator containing 250 g/l trinexapac-ethyl and is applied to control plant elongation, improving plant stability and reducing the risk of plant drop. It is rapidly absorbed through leaves and stems, acting on meristems to inhibit internode elongation. The use of this product results in a more robust plant with a reduced risk of damage in high winds or heavy rain (https://www.syngenta.ro/product/crop-protection/moddus-evo).

Ormet is a growth regulator containing 480 g/l ethephon that regulates the elongation of plants, helping them to become more stable and more resistant to environmental factors such as wind and heavy rain. It is rapidly absorbed and translocated to the meristematic zones, where it inhibits excessive stem elongation and helps to strengthen the straw. It is used in fall and spring wheat and barley crops and is applied from the second internode to the emergence of the spikelets, depending on the phenophyse of the plant. Ormet thus helps to reduce the risk of plant drop and promotes a quality harvest (https://www.adama.com/romania/ro/produse-pentru-protectia-plantelor/regulatori-crestere/ormet).

Toprex is a combined fungicide and growth regulator containing 20 g/l difenoconazole and 125 g/l paclobutrazol, effective in both disease control and improving plant stability. It helps reduce the risk of oilseed rape plants falling by

stimulating a healthy root system and inhibiting excessive stem elongation. It is applied to oilseed rape crops both in the fall (four-leaf to winter) and in the spring (during stem elongation to the green flower bud). In addition, Toprex protects the crop from *Phoma lingam*, a pathogen that causes black rot of oilseed rape (https://www.adama.com/romania/ro/produse-pentru-protectia-plantelor/fungicide/toprex).

The experiment was set up according to the method of plots subdivided into three repetitions, on a faeozoic soil type (typical Cambian chernozemic) characterized by moderate fertility and physico-chemical properties favorable to agricultural crops. The soil has a neutral pH of 7.29 and a loamy texture. The humus level is 2.3%, indicating good fertility. In terms of nutrients, the soil is poorly supplied with total nitrogen (9.4 mg/kg), but very well supplied with mobile phosphorus (189 mg/kg) and mobile potassium (304 mg/kg), thus ensuring optimal conditions for the development of soybean crops.

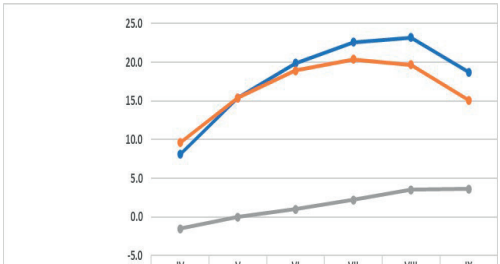
The experiment was set up following all the technological links specific to the soybean crop, the difference being the two treatments applied in the flowering phenophase. The first treatment was applied at the beginning of flowering and the second at full flowering.

In order to highlight the influence of the applied products on the reduction of water stress, determinations were carried out on the number of pods per plant, the number and weight of grains per plant, the thousand kernel weight (TKW), and the yield.

RESULTS AND DISCUSSIONS

The year 2023 was characterized by atypical temperatures for the soybean crop, significantly influencing its development. In April and May, temperatures were at or below the multi-year average (-1.5°C in April and 0°C in May), resulting in slower germination and more difficult initial development. Although soybeans managed to continue their vegetative cycle, this early delay influenced pod formation. Instead, in June, temperatures approached optimal values, favoring vegetative growth and flowering and providing good conditions for further crop development.

However, from July onwards, temperatures deviated significantly above the multi-year average (+2.2°C in July and +3.5°C in August), which caused high heat stress on the plants (Figure 1). Temperatures above 24°C during this period led to flower abortion and poor pod formation, thus limiting yield potential.



	IV	V	VI	VII	VIII	IX
The monthly average (°C)	8.1	15.4	19.9	22.6	23.2	18.7
The multi-year average (°C)	9.6	15.4	18.9	20.4	19.7	15.1
The deviation	-1.5	0.0	1.0	2.2	3.5	3.6

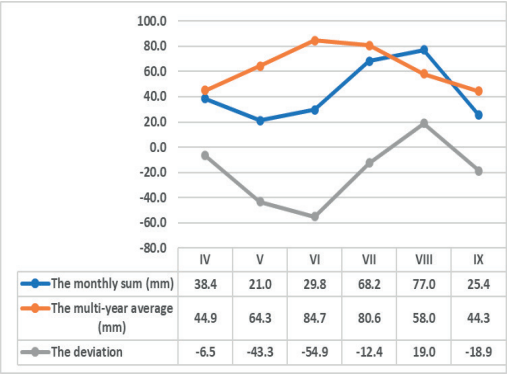
Figure 1. Temperature registrated at A.R.D.S. Secuieni during soybean vegetation period, 2023

In terms of rainfall, 2023 was characterized by a severe rainfall deficit, significantly affecting soybean development. In April, May, and June, rainfall amounts were well below the multi-year average (-6.5 mm, -43.3 mm and -54.9 mm), which created a pronounced water stress in the early growth phases. This shortage hindered the proper development of the root system, limiting the ability of the plants to take up the necessary water during critical periods. In July, the deficit continued (-12.4mm), amplifying the impact of high temperatures and directly affecting pod formation and berry filling. The only month with rainfall above multi-year values was August.

In September, rainfall again fell below the multi-year average (-18.9 mm), accelerating ripening but also contributing to uneven ripening (Figure 2).

Thus, the lack of rainfall, coupled with high temperatures, resulted in a very dry growing season, limiting soybean yield and quality.

The number of pods/plant is a key determinant and is directly related to the ability of the plant to produce seed. This parameter is influenced by environmental conditions, nutrition and applied treatments such as growth regulators. Figure 3 shows that the treatments applied positively influenced pod formation on the plant.



	IV	V	VI	VII	VIII	IX
The monthly sum (mm)	38.4	21.0	29.8	68.2	77.0	25.4
The multi-yeaar average (mm)	44.9	64.3	84.7	80.6	58.0	44.3
The deviation	-6.5	-43.3	-54.9	-12.4	19.0	-18.9

Figure 2. Rainfall registrated at A.R.D.S. Secuieni during soybean vegetation period, 2023

In the case of Onix, the highest average number of pods/plant was recorded in the version with Ormet, followed by Moddus Evo. The control had a similar value with the third growth regulator, about 68 pods/plant.

The Ziana TD variety had lower pod number averages compared to Onix. However, in plots where treatments were performed, higher values were determined than the control sample. This time, the highest average number of pods/plant was influenced by the Toprex product (58.6), followed by Ormet (45.13) and then Moddus Evo (Figure 3).

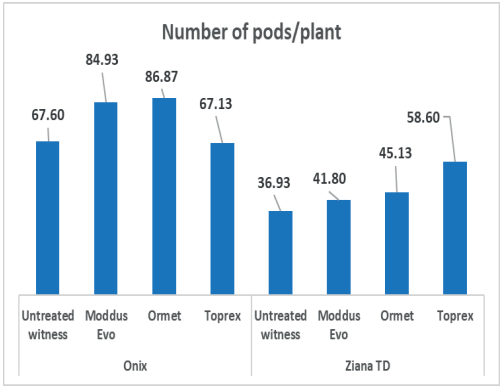


Figure 3. Average number of pods per plant

The number of grains per plant is another important factor in assessing the yield potential of soybeans. It is influenced by the plant's ability to fertilize and develop seeds, a process that can be stimulated or inhibited by growth regulators. More kernels per plant indicate a higher yield, while fewer kernels per plant may signal problems with fertilization and stress conditions.

Directly related to the factor analyzed above, the number of kernels per plant follows a similar trend.

In Onix, average values ranged from 130.73 grains/plant (Toprex) to 181.7 grains/plant (Moddus Evo).

Ziana TD also showed significant differences between treated and control variants. The plot treated with the growth regulator Toprex (114.53) showed the highest average number of grains/plant, while the control plot (76.4) showed the lowest average number of grains/plant (Figure 4).

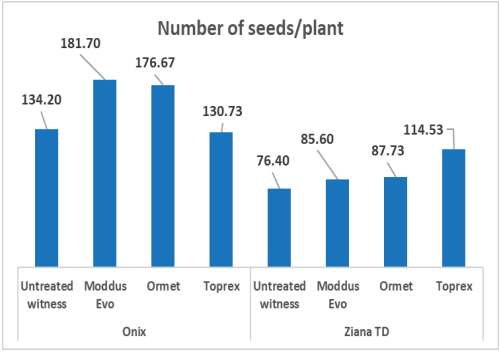


Figure 4. Average number of seeds per plant

The weight of the seeds per plant is an important factor in assessing yield potential, with heavier berries indicating adequate nutrition and optimal plant development.

In the case of Onix, the highest weight of the seeds per plant was 19.52 g (Moddus Evo), followed by the variety with Ormet (17.26 g). The plot sprayed with the Toprex regulator had a slightly lower average weight than the control (14.24 g) and 13.75 g, respectively.

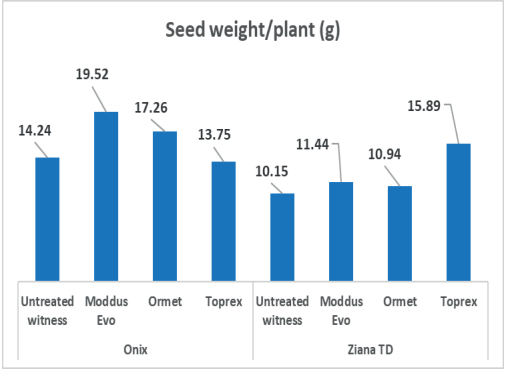


Figure 5. Average seed weight per plant (g)

Ziana TD showed values higher than the control in all the variants treated with the three commercial products. Of these, the one in which the Toprex regulator was applied stands out, with an average grain weight of 15.89 g.

While the highest values for the indices analyzed above were determined for the Onix variety, the thousand kernel weight peaked at 143.73 g for Ziana TD, sprayed with Toprex. In the remaining variants, the thousand kernel weight was lower than the control for both varieties. They ranged from 106.99 g (variety Onix treated with Ormet) to 141.9 g (variety Ziana TD, control var. Ziana TD) (Figure 6).

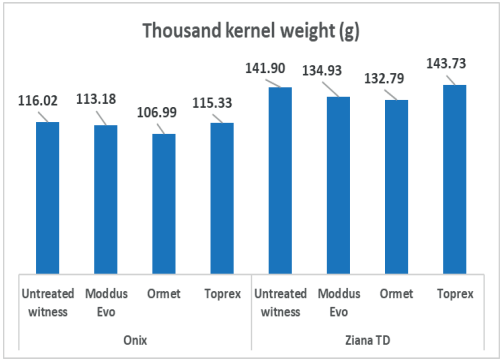


Figure 6. Thousand kernel weight (g) at the soybean, depending on the applied product

In the context of climate change, soybean yield is increasingly affected by extreme weather conditions, such as rainfall deficits and temperature fluctuations. These conditions can significantly reduce the quantity and quality of the harvest, with a direct impact on the availability of soybeans for consumption and industry.

The application of growth regulators can play an important role in plant adaptation to these unfavorable conditions by stimulating physiological processes that help reduce the effects of water stress.

Analyzing Table 1, it can be seen that yields varied both by variety and by product applied.

The highest yield was 1704.33 kg • ha^{-1} for the Onix variety treated with Moddus Evo. This had the highest yield increase of 177.67 kg • ha^{-1} compared to the control sample. At the opposite pole, the Ormet treated variety yielded 1424 kg • ha^{-1}, 102.67 kg • ha^{-1} less than the untreated plot.

In the case of Ziana TD, yields were higher than in the Onix variety. This time, the Toprex-treated variety was more productive than the control, with 1937.33 kg • ha^{-1}. In comparison with the untreated control, the yield increase was 135.67 kg • ha^{-1} (Toprex) and 123 kg • ha^{-1} (Ormet). While the influence of the growth regulator Moddus Evo resulted in a yield increase in Onix, Ziana TD yield was 1746.67 kg • ha^{-1}, 55 kg • ha^{-1} less than the untreated sample. The yield was statistically interpreted, but the differences recorded are not statistically assured (Table 1).

Table 1. Soybean grain production (kg • ha^{-1})

Variety	Treatment	Production (kg/ha)	% compared to control	Difference (kg/ha)	Significance
Onix	Untreated witness	1526.67	100	-	
	Moddus Evo	1704.33	112	177.67	
	Ormet	1424.00	93	-102.67	
	Toprex	1541.67	101	15.00	
Ziana TD	Untreated witness	1801.67	100	-	
	Moddus Evo	1746.67	97	-55.00	
	Ormet	1924.67	107	123.00	
	Toprex	1937.33	108	135.67	
DL kg/ha			5% =	335.8	
			1% =	471.3	
			0.1% =	665.3	

CONCLUSIONS

In climatic terms, the soybean growing season was marked by a precipitation deficit of -117.00 mm, against a 1.5°C increase in temperature compared to multi-year averages. The soybean growing season is characterized as hot and very dry.

Growth regulators had a positive impact on the analyzed productivity indices. They influenced the morpho-physiological processes of the two varieties differently.

The variants in which the commercial product Toprex was applied recorded the highest average values of pod number/plant, number of grains/plant and grain weight/plant for Ziana TD and the lowest for Onix.

Additionally, the highest thousand kernel weight was recorded for the Ziana TD variety treated with Toprex, reaching 143.73 g.

The yield ranged from 1424 kg • ha^{-1}(Onix treated with Ormet) to 1937.33 kg • ha^{-1} (Ziana TD treated with Toprex). Differences in yield compared to the control ranged from -102.67 kg • ha^{-1} (Onix treated with Ormet) to 177.67 kg • ha^{-1} (Onix treated with Moddus Evo).

REFERENCES

Amoanimaa-Dede Hanna, Su C., Yeboah A., Zhou H., Zheng D., Zhu H. (2022). Growth regulators promote soybean productivity: a review. *Peerj Life and Evironment,Volume 10, Section Plant Biology.*

Badea, O.D., Popescu, D. M., Ionescu, N., Nicolae, C.M. (2023). Influence of $CaCo_3$ wordings by np doses on soybean yields. *Scientific Papers. Series A. Agronomy, Vol. LXVI*, No. 1, 212–219.

Chen, W., Li, J., Yuan, H., You, L., Wei, Q., Feng, R., Jiang, S., Zhao, X. (2023). Plant growth regulators improve nitrogen metabolism, yield, and quality of soybean–rhizobia symbiosis*. Annals of Microbiology, Volumue 73*, no. 15.

Geoffrey, K. (2018). Effects of a Plant Growth Regulator Product on Soybean at R2-R3. *Iowa State University, Department of Agronomy.*

Ionescu, N., Badea, O. D., Popescu, D. M., Nicola, M.C. (2022). New soybean varieties variability by plants morphology from ecological white luvic soil conditions. *Scientific Papers. Series A. Agronomy, Vol. LXV,* No. 1, 368-373.

Jităreanu, C. D., Toma, L. D. (2007). *Plant Physiology*. Iasi, RO: Ion Ionescu from Brad Publishing House.

Joiţa-Păcureanu, M., Popescu, G., Rîşnoveanu, L., Ciornei, L., Bărbieru, A., Oprea, D., Anton, G.F., Dunăreanu, C., Petcu V. (2023). Sunflower and soybean crops cultivated in a mixed intercropping system, in the 2022. *Scientific Papers. Series A. Agronomy, Vol. LXVI,* No. 2, 550-554.

Mangena P. (2022). Evolving role of synthetic cytokinin 6-benzyl adenine for drought stress tolerance in soybean (*Glycine max* L. Merr*.). Frontiers in Sustainable Food Systems, Section Crop Biology and Sustainability, Volume 6.*

Moldovan, C., Florian, V., Suciu, L., Morea, A., Tărău, A., Urdă, C, (2022). Influence of seed age on quality, germination and seed health in soybeans. *Scientific Papers. Series A, Agronomy, Vol. LXV,* No. 2, 270274.

Salvagiotti, F., Cassman, K.G., Specht, J.E., Walters, D.T., Weiss, A., Dobermann, A. (2008). Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. *Field Crops Res., 108,* 1–13.

Shaffique, S., Hussain, S., Kang, Sang-Mo, Imran Muhamad, Injamum-Ul-Hoque Md., Khan Muhammad Aaqil, Lee In-Jung (2023). Phytohormonal modulation of the drought stress in soybean: outlook, research progress, and cross-talk. *Frontier in Plant Science. Section Plant Physiology, Volume 14*.

Watson, C.A., Reckling, M., Preissel, S., Bachinger, J., Bergkvist, G., Kuhlman, T., Lindström, K., Nemecek, T., Topp, C.F.E., Vanhatalo, A. (2017). Chapter Four - Grain legume production and use in European agricultural systems. *Advances in Agronomy, Volume 144,* pp. 235–303.

https://www.adama.com/romania/ro/produse-pentru-protectia-plantelor/regulatori-crestere/ormet.

https://www.adama.com/romania/ro/produse-pentru-protectia-plantelor/fungicide/toprex

https://www.syngenta.ro/product/crop-protection/moddus-evo.