Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development
Vol. 23, Issue 1, 2023
PRINT ISSN 2284-7995, E-ISSN 2285-3952

NATURAL EXTRACTS AS ALTERNATIVE ELEMENTS IN PLANT CULTIVATION TECHNOLOGIES. CASE STUDY IN OATS

Ovidiu EREMI, Florin SALA

University of Life Sciences "King Mihai I" from Timisoara, Timișoara, 300645, Romania
Emails: eremiovidiu@gmail.com; florin_sala@usab-tm.ro

Corresponding author: florin_sala@usab-tm.ro

Abstract

The study evaluated the possibility of using a plant extract in the perspective of alternative plant cultivation technologies. An extract based on the herba (Urtica dioica L.) was used in aqueous solution, in a ratio of 1:10. Foliar treatment solutions were prepared from the base solution (UdE) with concentrations of 25% (V2), 50% (V3), 75% (V4) and 100% (V5), which were tested together with a control variant (V1). The biological material was represented by the Mureșana oat variety. The prepared solutions were applied in four treatments, on consecutive days, the first treatment at the stage of 4-5 leaves (15-19 BBCH code). The effect of the treatments on some biometric and plant productivity parameters was evaluated: plant height (PH), stem diameter (SD), root length (RL), plant weight (PW), root weight (RW), panicle length (PL), number of branching levels (NBL), and distance between branching levels (DbBL). Very strong correlations were recorded between SD and UdE (r=0.969), between PW and UdE (r=0.947), between RW and UdE (r=0.976), between PH and RL (r=0.961), between PW and SD (r=0.974), between RW and SD (r=0.945) and between PW and RW (r=0.951). Biometric parameters of the plants were taken into account, and based on the regression analysis it was possible to estimate with high precision the panicle length (PL) depending on the biometric parameters RL, PW and RW (p=0.0042, RMSE=1.85750), parameters which showed a close correlation with the extract concentration (UdE) applied (r=0.707 in the case of RL; r=0.947 in the case of PW; r=0.976 in the case of RW).

Key words: *agricultural technologies, alternative inputs, natural extracts, oats, prediction models*

INTRODUCTION

The innovative plant cultivation technologies are always analysed, adapted and improved, in relation to the crop plants and the agricultural production system, the climatic conditions, the level of harvests and quality indices, aspects of the product market, costs and benefits [1, 9, 19, 21, 23, 28, 34].

In the category of agricultural inputs, respectively agricultural technologies, fertilizers, biostimulators and different bioactive products occupy an important place, in the context of sustainable agriculture, and integrated agricultural practices [10, 26, 31].

In relation to the purpose of sustainable agricultural systems, the significant reduction of synthetic agrochemical products, environmentally friendly technologies, as well as from the perspective of environmental protection, there are more and more concerns, studies and research for the use of natural biostimulatory substances (plant bioactive substances, different plant extracts), which improve certain metabolic and physiological processes in crop plants (rooting, flowering, plant growth, fruiting, etc.) or production quality indices [4, 6, 7, 14, 15].

Different methods and techniques for obtaining plant extracts and bioactive compounds have been studied and developed in relation to the plant source (species), the plant part used, the category of active principles, their properties in relation to stability and bioactive effect [2, 8, 15, 17, 29].

Extracts from different plant species were studied, tested and used in order to evaluate the effectiveness of plants of economic interest (field crops, vegetables, ornamentals, etc.) [5, 24, 25, 36].

The mode of action of plant biostimulators has been studied in different plants in order to develop new biostimulators, but also to effectively integrate these products into culture technologies [29].

This study aimed to evaluate the influence of a natural extract based on the herba, *Urtica dioica* L., on some elements and parameters of productivity in crops from the grasses group (oats) and to develop some models for estimating panicle sizes, as the main element of productivity, under the influence of applied treatments.

MATERIALS AND METHODS

The study evaluated the influence of a plant extract based on the herba, *Urtica dioica* L. (UdE) on some plants of economic interest. The study took place under controlled conditions, during the 2021-2022 agricultural year.

To make the extract, plant material (herba) from the species *Urtica dioica* L. was used, harvested during the flowering phase of the plants, according to a studied methodology [25]. The extract was made in water (herba:water ratio, 1:10), from plant material (herba) collected from the species *Urtica dioica* L., figure 1. The obtained *U. dioica* extract (UdE) was used in four concentrations in aqueous solutions, 25% (V2), 50% (V3), 75% (V4) and 100% (V5), along with a control variant (V1).

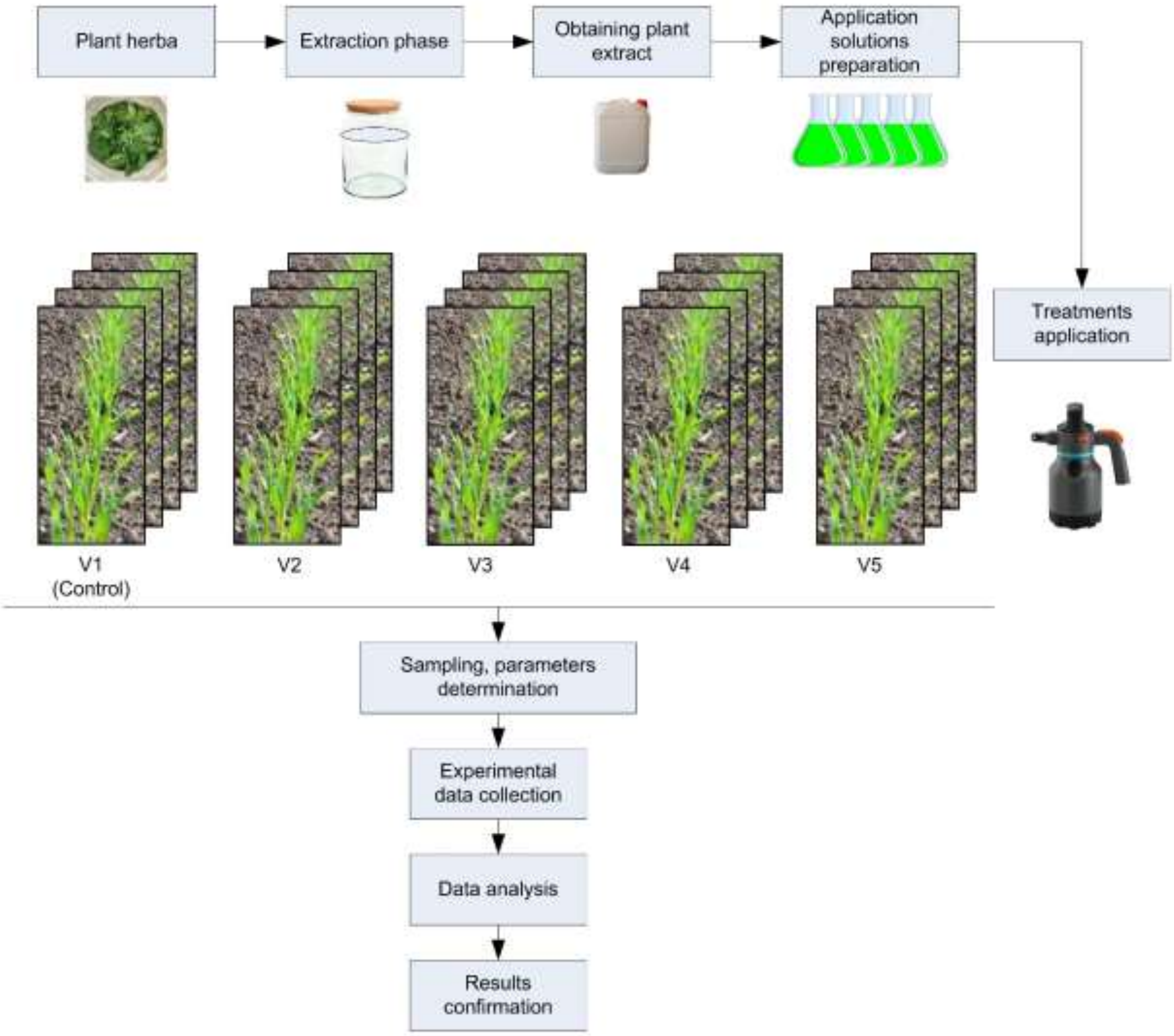

Fig. 1. The logical scheme of the experiment with plant extracts (UdE) at oats, the Mureșana variety
Source: original figure.

Oats were used as the test plant, the biological material being represented by the Mureșana oat variety. The plants were grown experimentally in pots measuring 70 × 20 × 15 cm (L × W × H). A growth substrate consisting of garden soil and compost (ratio 1:1) was used.

The treatments were applied at the 4-5 leaf stage of the plants (15-19 BBCH code, Principal growth stage 1; Leaf development)

[27]. Four treatments were applied, on consecutive days, in the mentioned concentrations and equal amounts of solutions (150 ml solution/variant). The application of the treatments was done with a manual sprayer (Figure 1).
In order to record the influence of the used extract (UdE), biometric and physiological parameters and indices were determined for the oat plants, regarding plant growth and development, biomass accumulation and productivity elements. Thus, the following parameters were determined: plant height (PH), stem diameter (SD), root length (RL), plant weight (PW), root weight (RW), panicle inflorescence length (PL), number of branching levels (NBL) and distance between branching levels (DbBL). Seven plant samples were determined on each variant.
The experimental data were analyzed according to the processing methodology and statistical interpretation of the results. ANOVA test, Correlation analysis, Regression analysis, Clusters analysis were used, and appropriate statistical safety parameters were used for the statistical safety of the results. Appropriate software applications [16, 18], and the statistical calculation module in EXCEL were used for data analysis and processing.

RESULTS AND DISCUSSIONS

The treatments with extracts of *Urtica dioica* L. (UdE, %) applied in different concentrations to the oat plants influenced the vegetation state of the plants, the rate of growth and development, aspects highlighted by parameters and physiological indices determined and the average biomass production recorded. The data set, average values, is presented in Table 1.
In relation to the experimental variants, given the extract concentrations (UdE, %), the variation in plant height was recorded between PH=97.71±1.59 cm (V1, control) and PH=108.71±3.11 cm (V4), the biomass variation between PW=9.43±1.81g (V1) and PW=21.14±1.99 g (V4), respectively of the panicle length between PL=15.00±1.02 cm and PL=18.86±0.70 cm (V4), with a number of branches BLN=3.29±0.18 and BLN= 4.00±0.22 (V3).
The ANOVA test confirmed the safety of the data and the presence of variance within the experimentally recorded value series, table 2.

Table 1. Parameter values for oat plants, depending on the foliar treatment (UdE, %) applied

Experimental variants	UdE	PH	SD	RL	PW	RW	PL	BLN	DbBL
	(%)	(cm)	(mm)	(cm)	(g)	(g)	(cm)	(no)	(cm)
V1	0	97.71±1.59	3.31±0.10	13.86±3.54	9.43±1.81	2.71±0.52	17.43±1.49	3.57±0.20	5.29±0.36
V2	25	99.00±1.00	3.69±0.20	15.93±1.68	11.86±1.91	4.14±0.63	15.00±1.02	3.29±0.18	4.14±0.34
V3	50	104.29±3.57	3.89±0.06	18.29±1.25	13.57±1.02	4.29±0.28	18.14±0.63	4.00±0.22	4.86±0.32
V4	75	108.71±3.11	4.32±0.17	19.86±1.62	21.14±1.99	6.29±0.64	18.86±0.70	3.29±0.18	5.51±0.24
V5	100	101.14±3.57	4.31±0.20	17.00±1.94	20.57±4.51	7.70±2.06	17.71±0.78	3.43±0.20	5.37±0.47

Source: original data recorded from the experiment.

Table 2. ANOVA test

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	148.2237	15	9.881578	17.2972	1.33E-22	2.8035
Within Groups	63.98347	112	0.571281			
Total	212.2071	127				

Source: original calculated data

A normal distribution of values was recorded within each series of data, on parameters determined for oat plants, under the influence of foliar treatments with plant extracts (UdE, %), under statistical safety conditions (r=0.942 for PH, r= 0.994 for SD, r=0.985 for RL, r=0.961 for PW, r=0.913 for RW, r=0.957 for PL, r=0.843 for BLN and r=0.966 for DbBL). The graphic representation of the values series distribution, for each analyzed parameter, is given in Figure 2, as a normal probability plot.

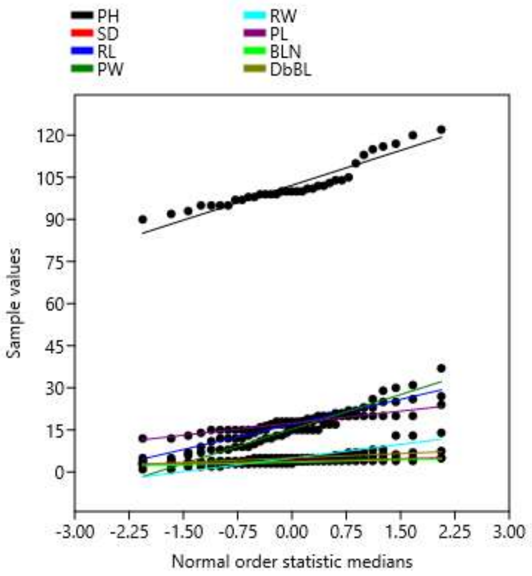

Fig. 2. The graphic distribution of the series of values within the parameters analyzed for oats
Source: original figure.

The correlation analysis highlighted the level of correlations (Figure 3) between the parameters analyzed for oats (average values), in relation to the treatments applied with plant extracts (UdE) in different concentrations. Very strong correlations were recorded between SD and UdE (r=0.969), between PW and UdE (r=0.947), between RW and UdE (r=0.976), between PH and RL (r=0.961), between PW and SD (r=0.974), between RW and SD (r=0.945), and between PW and RW (r=0.951).

Strong correlations were recorded between RL and SD (r=0.833) and between DbBL and PL (r=0.870). Other levels of correlations were also recorded, and the entire set of values of the correlation coefficient (r) is presented in Figure 3.

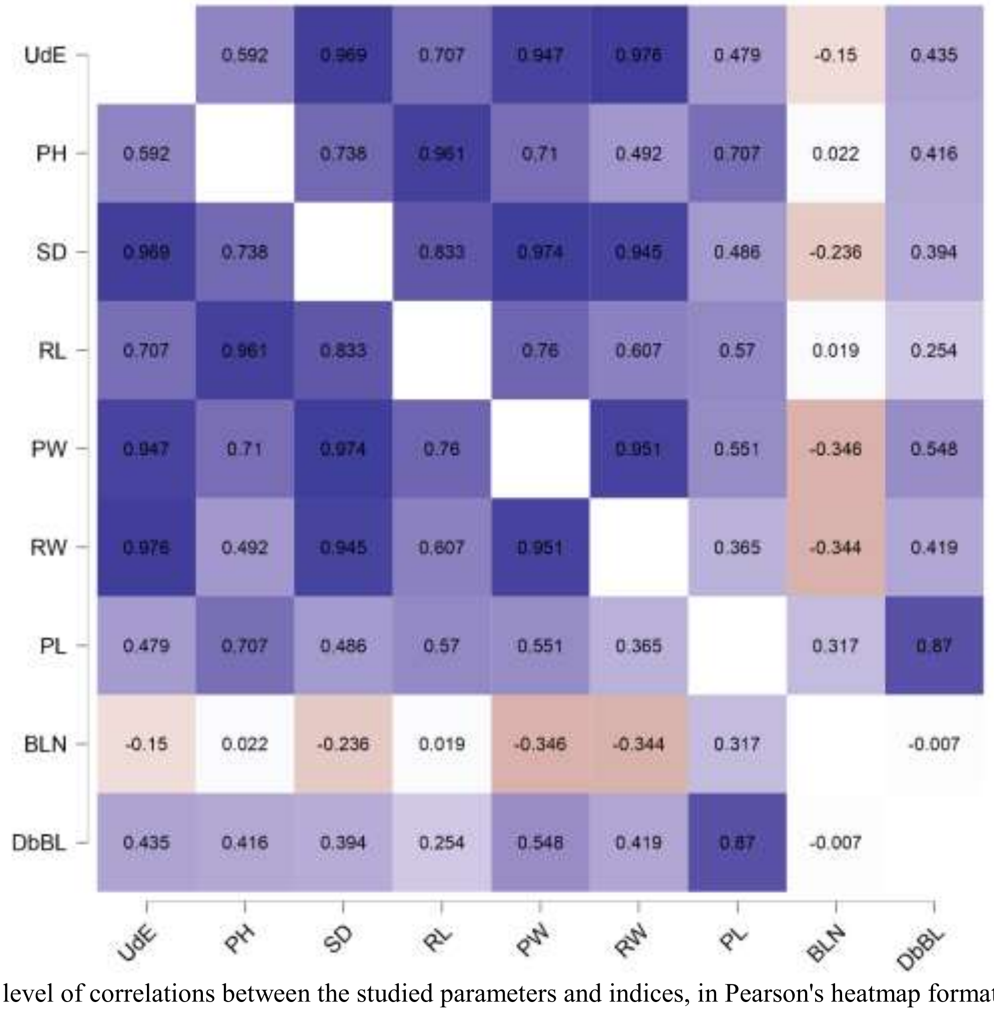

Fig. 3. The level of correlations between the studied parameters and indices, in Pearson's heatmap format
Source: original data, results by calculation.

The level of variability within the data series, for each parameter, was analyzed and quantified based on the coefficient of variation (CV). High level of variability resulted in the case of the RW parameter (CV_{RW}=62.51226), followed by the PW parameter (CV_{PW}=51.72667). The lowest level of variation was recorded for the PH parameter (CV_{PH}=7.83172). In the other parameters, intermediate values of the coefficient of variation were recorded, in descending order, CV_{RL}=33.91392, CV_{DbDL}= 20.23965, CV_{BLN}=15.99497, CV_{PL}=15.88408, and respectively CV_{SD}=14.24221.

The variation of some plant parameters and indices was evaluated in relation to the plant extract concentration (UdE, %) used.

The root system of the oat plants responded favourably to the applied treatments, so that the variation of the root length (RL) in relation to UdE was described by equation (1) under conditions of R^2=0.995, p=0.085, and the root weight (RW) was described by equation (2) under conditions of R^2=0.968, p=0.0317.

The graphic distribution of RL and RW values in relation to UdE is presented in Figure 4, respectively in Figure 5.

$$RL = -2.517E-05x^3 + 0.002559x^2 + 0.02725x + 13.9 \quad (1)$$
$$RW = 0.0002069x^2 + 0.02783x + 2.859 \quad (2)$$

where, x – UdE (%)

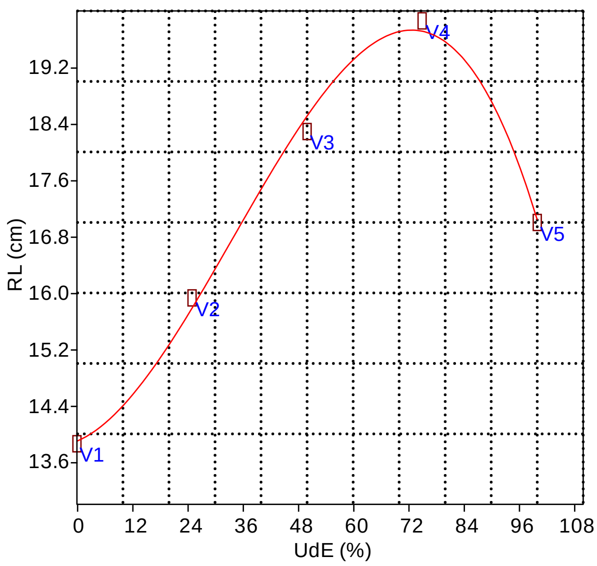

Fig. 4. RL variation depending on UdE concentration, Mureşana oat variety
Source: original figure.

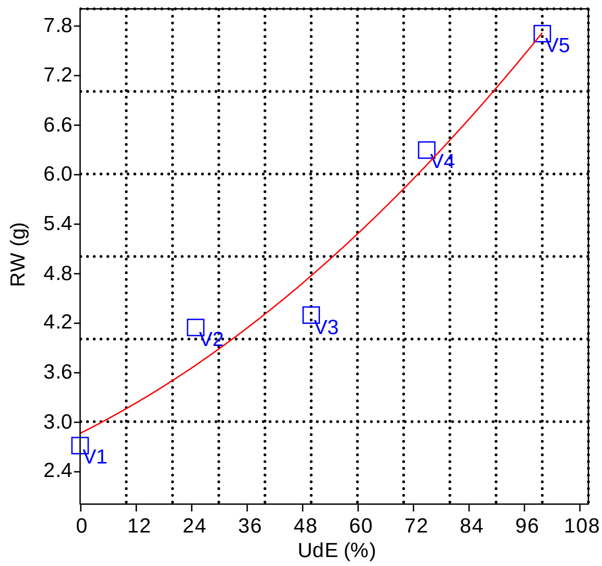

Fig. 5. RW variation according to UdE concentration, Mureşana oat variety
Source: original figure.

The variation of the SD parameter according to the concentration of UdE used was described by equation (3), under conditions of R^2=0.977, p=0.190, and the variation of plant weight according to UdE (%) was described by equation (4) in conditions of R^2=0.945, p=0.294. The graphic distribution of the SD and PW values depending on the UdE concentrations is shown in Figures 6 and 7.

$$SD = -1.387E-06x^3 + 0.0001451x^2 + 0.009352x + 3.325 \quad (3)$$
$$PW = -3.957E-05x^3 + 0.00592x^2 - 0.08487x + 9.724 \quad (4)$$

where: x – UdE (%)

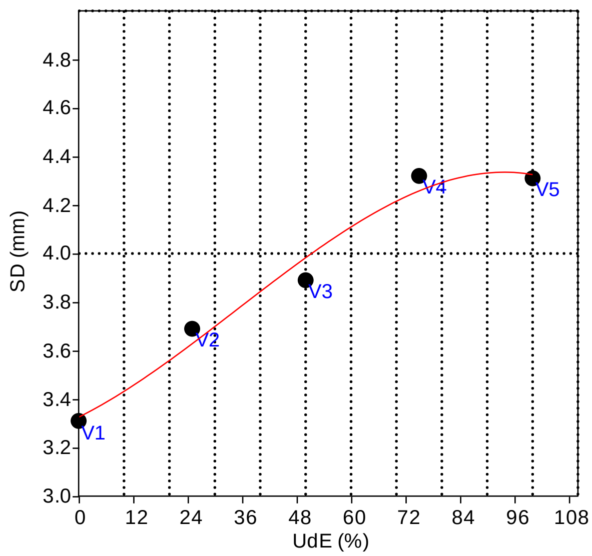

Fig. 6. SD variation according to UdE concentration, Mureşana oat variety
Source: original figure.

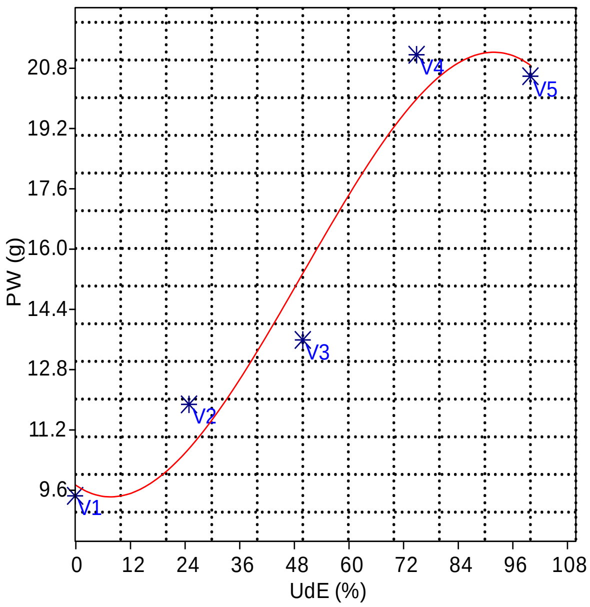

Fig. 7. PW variation according to UdE concentration, Mureşana oat variety
Source: original figure.

The oat inflorescence is of the panicle type, and the length of the panicle is a main criterion that underlies productivity and production, through length (PL), number of branching levels (BLN), distance between branching levels (DbBL), number of seeds (SN), and their weight (SW).

Based on the recorded experimental data, the variation of the panicle size (PL), in relation to the biometric parameters of the plants, under the influence of the treatments applied with plant extracts (UdE, %) was estimated, through the quadratic regression analysis. The results obtained based on the morphological parameters of the plants (PH, SD, PW, RL and RW) in different combinations, and the equation coefficients and statistical safety parameters (p, R, F test, RMSEP) are presented in Table 3.

Table 3. Panicle length estimation based on plants parameters in relation to UdE treatment, Mureşana oat variety

Statistical categories	Model code used to estimate petiole length (PL)									
	PL E1	PL E2	PL E3	PL E4	PL E5	PL E6	PL E7	PL E8	PL E9	PL E10
	Parameters and indices considered									
x	PH	PH	PH	PH	PH	PH	SD	SD	SD	RL
y	SD	SD	SD	PW	PW	RL	RL	RL	PW	PW
z	PW	RL	RW	RW	RL	RW	PW	RW	RW	RW
	Values of statistical safety coefficients									
Multiple R	0.618	0.532	0.510	0.705	0.645	0.488	0.640	0.535	0.709	0.732
R Square	0.382	0.283	0.260	0.498	0.416	0.238	0.410	0.286	0.502	0.537
Adjusted R Square	0.154	0.024	-0.006	0.305	0.206	-0.035	0.190	0.028	0.310	0.355
Observation	35	35	35	35	35	35	35	35	35	35
F	2.0117	1.2829	1.1442	3.2187	1.9775	1.0154	2.2579	1.3029	3.2772	3.7622
p	0.0810	0.2941	0.3705	0.0099	0.0861	0.4543	0.0522	0.2843	0.0090	0.0042
RMSEP	2.14439	2.31036	2.34656	1.93400	14.04880	2.38170	2.09590	2.30520	1.92530	1.85750
	Values of the coefficients of the equation									
Intercept	87.200742	-84.957308	17.827862	10.559692	32.0000000	23.5537518	-3.2092194	-20.5447880	-7.6981447	13.4422538
x^2	0.0035284	-0.0126794	-0.0005674	-0.0017037	0.0018576	-0.0015701	-0.3040822	-2.5927415	-1.9768483	0.0077124
y^2	-0.8707363	-2.3260131	-3.3456918	-0.0283810	-0.0126461	0.0001024	0.0069172	0.0146503	-0.0026943	-0.0392965
z^2	0.7093195	-0.7224707	1.3470472	2.8880152	-5.56E+15	1.7598494	0.5161569	0.3755704	-2.5029394	0.1510441
xy	0.1491629	0.1539415	0.2009427	0.0322145	0.0001576	0.0237679	-0.0885063	0.1086374	-0.1867650	0.0450109
xz	-0.0043452	0.0199062	-0.0351867	-0.0744669	-0.0008165	-0.0200645	-0.1676011	0.1573323	1.1383155	-0.1514663
yz	-0.1782185	-0.1707053	0.2511219	0.0547829	0.0010009	-0.0586626	-0.0045808	-0.0655436	-0.0291711	0.0928092
x	-1.3034940	1.8054678	-0.4518278	0.1785011	-0.3829435	0.0389372	6.1707411	19.4696865	12.654958 0	-0.2259743
y	-6.0123569	6.7792460	5.8618700	-2.0853626	0.6593543	-2.1816505	0.0629362	-0.6275692	1.5275039	0.5074138
z	0	0	0	0	1.112E+16	0	0	0	0	0

Source: original data resulting from calculation based on experimental data.

Based on the considered biometric parameters, 10 series of analyzes (PW E1 to PW E10) were made to estimate PL values, as an important parameter in the formation of useful agricultural production.

By analysis of p parameter values, it was found statistically safety in the case of PL E4 estimation (p=0.0099; PH, PW and RW parameters were used); in the case of PL E9 estimation (p=0.0090; SD, PW and RW parameters were used); in the case of PL E10 estimation (p=0.0042; RL, PW, RW parameters were used).

According to RMSEP parameter, equation (5), and based on the recorded values (better the lower RMSEP value), it was found that in the case of PL E10 estimation (based on the RL, PW, RW parameter) were registered the highest level of statistical safety (RMSEP=1.85750), from the entire series of estimates made.

$$RMSEP = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(y_j - \hat{y}_j\right)^2} \quad (5)$$

In the respective estimation (PL E10), the root length (RL), plant weight (RW) and root weight (RW) parameters were used, important parameters in defining the level of plant development, the fruiting capacity and the formation of agricultural production.

From the correlation analysis, Figure 3, it was found that the three parameters (RL, PW, RW) used to estimate the petiole length (PL) showed very strong, positive correlations with UdE, a fact that confirms the positive influence of the treatment applied on some parameters and physiological indices of the plants, and based on these indices the size of the panicle (PL) was built, as a functional determination of the plants.

The panicle length values estimated by the 10 models (PL E1 to PL E10) were used in the cluster analysis and resulted the dendrogram presented in Figure 8, under statistical safety conditions (Coph.corr.=0.999).

The independent positioning of the PL E5 model with the highest estimation error and the grouping of the other models into two sub clusters, according to the similarity level for the productivity parameters estimated, were found.

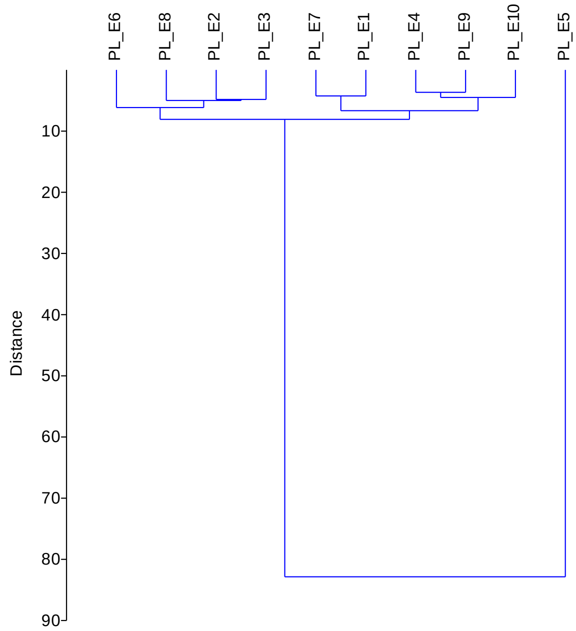

Fig. 8. Dendrogram of the models used for estimation of a productivity parameter for oats, the Mureșana variety
Source: original figure.

Based on analysis of the models grouping (Figure 8), as well as based on the SDI values (Table 4) and the statistical safety results (Table 3), it was found that the highest level of safety in the estimation of panicle size (PL) was provided by the PL E10 model. The highest level of similarity was between the models PL E4 and PL E9 (SDI=3.6572) with which it was associated (SDI=4.2399 between PL E10 and PL E9, and SDI=4.7529 between PL E10 and PL E4, respectively).

The use of bioactive substances and biostimulators in plant cultivation technologies is of great interest for the purpose of regulating plant growth, stimulating metabolic processes, alleviating effects generated by different stress factors, with favourable effects on agricultural production (quantitative and qualitative) and of the environment [20, 22, 30, 32, 35].

As a result of the bioactive compounds, *Urtica dioica* L. showed interest for pharmacy, medicine and therapeutic applications, for food (functional foods), but also for plant culture techniques [3, 8, 33].

Table. 4. SDI values in relation to PL prediction certainty based on plant parameters

	PL E1	PL E2	PL E3	PL E4	PL E5	PL E6	PL E7	PL E8	PL E9	PL E10
PL E1	0	7.2193	5.8394	6.3349	82.6970	7.4850	4.2471	6.7846	5.9423	7.2855
PL E2	7.2193	0	4.8252	8.9668	82.6500	6.2315	7.1651	5.0284	8.9695	8.9176
PL E3	5.8394	4.8252	0	8.2257	82.5640	6.7379	7.3014	4.9674	8.3625	9.2862
PL E4	6.3349	8.9668	8.2257	0	83.8710	9.6812	6.8662	8.6674	3.6572	4.7529
PL E5	82.6970	82.6500	82.5640	83.8710	0	81.7730	82.3310	83.3150	83.4480	82.9700
PL E6	7.4850	6.2315	6.7379	9.6812	81.7730	0	6.9762	5.4560	9.7223	9.0942
PL E7	4.2471	7.1651	7.3014	6.8662	82.3310	6.9762	0	6.0550	6.4433	7.0734
PL E8	6.7846	5.0284	4.9674	8.6674	83.3150	5.4560	6.0550	0	8.5816	8.2929
PL E9	5.9423	8.9695	8.3625	3.6572	83.4480	9.7223	6.4433	8.5816	0	4.2399
PL E10	7.2855	8.9176	9.2862	4.7529	82.9700	9.0942	7.0734	8.2929	4.2399	0

Source: Original data calculated based on experimental results.

Plant extracts based on nettle (*Urtica dioica* L.), applied alone or in association with extracts from other species (*Taraxacum*, *Artemisia*, *Polygonum*, *Equisetum*) exerted biostimulating activity on cabbage seedlings [11, 12]. The authors communicated the favourable influence of the treatments on the root system (length and weight), a similar effect was also recorded in this study, based on tests on oats, Muresana variety.

Favourable effects of the *Urtica dioica* extracts, along with other plants species, were also recorded and communicated regarding to leaves chlorophyll content (a+b), some root properties, the production of leaves, and some vitamin content in celery [13].

The results registered in this study, regarding the effects of *Urtica dioica* extracts in the concentrations applied to oats and under the studied conditions, are in agreement with other results communicated regarding the favourable influence of *Urtica dioica* extracts, applied alone or associated with other plant extracts, to different species of cultivated plants. The communicated results contribute to the completion of the information base regarding the effects of plant extracts in the controlling of plant vegetation, for sustainable technolo-gies, quality products and environmental protection.

CONCLUSIONS

The extracts of *Urtica dioica* L., in the concentrations used for oats, the Mureșana variety, had favourable effects on the root system, the dimensional parameters of the plants, and the size and structure of the inflorescence. At the root level, there were favourable effects on root length (RL) and root weight (RW), with increases between 14.95-43.30% in the case of RL, and 52.63-183.68% in the case of RW, respectively.

At the plants level, the applied treatments (UdE) generated different response in plant height (PH), in stem diameter (SD), and in plant weight (PW), with increases of 1.32 - 11.26% in the case of PH parameter; increases of 11.71 - 30.58% in the case of SD parameter; and increases of 25.76 – 124.24% in the case of PW parameter. At the level of the panicle-type inflorescence, there was an increase in length (PL), a positive variation in the number of branches (BLN), with increases of 1.64 - 8.20% in the case of PL parameter, and 12% in the case of BLN parameter.

Based on the regression analysis, it was possible to estimate with high precision the length of the panicle (PL) according to the biometric parameters RL, PW and RW, as determining elements in the formation of PL, and the correlation analysis confirmed the close connection of RL, PW and RW with the applied extract concentration (UdE) (r=0.707 in the case of RL parameter; r=0.947 in the case of PW parameter; r=0.976 in the case of RWparameter).

REFERENCES

[1]Adamides, G., Kalatzis, N., Stylianou, A., Marianos, N., Chatzipapadopoulos, F., Giannakopoulou, M., Papadavid, G., Vassiliou, V., Neocleous, D., 2020, Smart farming techniques for climate change adaptation in Cyprus, Atmosphere, 11:557.

[2]Azmir, J., Zaidul, I.S.M., Rahman, M.M., Sharif, K.M., Mohamed, A., Sahena, F., Jahurul, M.H.A., Ghafoor, K., Norulaini, N.A.N., Omar, A.K.M., 2013, Techniques for extraction of bioactive compounds from plant materials: A review, Journal of Food Engineering, 117(4):426-436.

[3]Belščak-Cvitanović, A., Komes, D., Durgo, K., Vojvodić, A., Bušić, A., 2015, Nettle (*Urtica dioica* L.) extracts as functional ingredients for production of chocolates with improved bioactive composition and sensory properties, Journal of Food Science and Technology, 52(12):7723-34.

[4]Caradonia, F., Battaglia, V., Righi, L., Pascali, G., La Torre, A., 2019, Plant biostimulant regulatory framework: prospects in Europe and current situation at international level, Journal of Plant Growth Regulation 38:438-448.

[5]Carmody, N., Goñi, O., Łangowski, Ł., O'Connell, S., 2020, *Ascophyllum nodosum* extract biostimulant processing and its impact on enhancing heat stress tolerance during tomato fruit set, Frontiers in Plant Science, 11:807.

[6]Colla, G., Rouphael, Y., 2015, Biostimulants in horticulture, Scientia Horticulturae, 196:1-2.

[7]El-Nakhel, C., Cozzolino, E., Ottaiano, L., Petropoulos, S.A., Nocerino, S., Pelosi, M.E., Rouphael, Y., Mori, M., Di Mola, I., 2022, Effect of biostimulant application on plant growth, chlorophylls and hydrophilic antioxidant activity of spinach (*Spinacia oleracea* L.) grown under saline stress, Horticulturae, 8:971.

[8]Flórez, M., Cazón, P., Vázquez, M., 2022, Antioxidant extracts of nettle (*Urtica dioica*) leaves: Evaluation of extraction techniques and solvents, Molecules, 27:6015.

[9]Fussy, A., Papenbrock, J., 2022, An overview of soil and soilless cultivation techniques-chances, challenges and the neglected question of sustainability, Plants, 11:1153.

[10]García-Mier, L., Guevara-González, R.G., Mondragón-Olguín, V.M., Del Rocío Verduzco-Cuellar, B., Torres-Pacheco, I., 2013, Agriculture and bioactives: achieving both crop yield and phytochemicals, International Journal of Molecular Sciences, 14(2):4203-22.

[11]Godlewska, K., Biesiada, A., Michalak, I., Pacyga, P., 2019, The effect of plant-derived biostimulants on white head cabbage seedlings grown under controlled conditions, Sustainability, 11(9):5317.

[12]Godlewska, K., Biesiada, A., Michalak, I., Pacyga, P., 2020a, The effect of botanical extracts obtained through ultrasound-assisted extraction on white head cabbage (*Brassica oleracea* L. Var. *capitata* L.) seedlings grown under controlled conditions, Sustainability, 12(5):1871.

[13]Godlewska, K., Pacyga, P., Michalak, I., Biesiada, A., Szumny, A., Pachura, N., Piszcz, U., 2020b, Field-scale evaluation of botanical extracts effect on the yield, chemical composition and antioxidant activity of celeriac (*Apium graveolens* L. Var. *rapaceum*), Molecules, 25(18):4212.

[14]Godlewska, K., Ronga, D., Michalak, I., 2021a, Plant extracts - importance in sustainable agriculture, Italian Journal of Agronomy, 16(2):1851.

[15]Godlewska, K., Pacyga, P., Michalak, I., Biesiada, A., Szumny, A., Pachura, N., Piszcz, U., 2021b, Systematic investigation of the effects of seven plant extracts on the physiological parameters, yield, and nutritional quality of radish (*Raphanus sativus* var. *sativus*), Frontiers in Plant Science, 12:651152.

[16]Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001, PAST: Paleontological statistics software package for education and data analysis, Palaeontologia Electronica, 4(1):1-9.

[17]Han, S., Park, JS., Umanzor, S., Yarish, C., Kim J.K., 2022, Effects of extraction methods for a new source of biostimulant from *Sargassum horneri* on the growth of economically important red algae, *Neopyropia yezoensis*, Scientific Reports, 12:11878.

[18]JASP Team (2022). JASP (Version 0.16.2) [Computer software].

[19]Khan, N., Ray, R.L., Sargani, G.R., Ihtisham, M., Khayyam, M., Ismail, S., 2021, Current progress and future prospects of agriculture technology: Gateway to sustainable agriculture, Sustainability, 13:4883.

[20]Kisvarga, S., Farkas, D., Boronkay, G., Neményi, A., Orlóci, L., 2022, Effects of biostimulants in horticulture, with emphasis on ornamental plant production, Agronomy, 12:1043.

[21]Lew, T.T.S., Sarojam, R., Jang, IC., Park B.S., Naqvi, N.I., Wong, M.H., Singh G.P., Ram, R.J., Shoseyov, O., Saito, K., Chua N.-H., Strano, M.S., 2020, Species-independent analytical tools for next-generation agriculture, Nature Plants, 6:1408-1417.

[22]Li, J., Van Gerrewey, T., Geelen, D., 2022, A meta-analysis of biostimulant yield effectiveness in field trials, Frontiers in Plant Science, 13:836702.

[23]Lieder, S., Schröter-Schlaack, C., 2021, Smart farming technologies in arable farming: Towards a holistic assessment of opportunities and risks, Sustainability, 13:6783.

[24]Macra, G., Sala, F., 2022, Wheat biological yield variation in relation to nitrogen and foliar biostimulator treatment, AgroLife Scientific Journal, 11(1):104-110.

[25]Maričić, B., Radman, S., Romić, M., Perković, J., Major, N., Urlić, B., Palčić, I., Ban, D., Zorić, Z., Ban, S.G., 2021, Stinging nettle (*Urtica dioica* L.) as an aqueous plant-based extract fertilizer in green bean (*Phaseolus vulgaris* L.) sustainable agriculture, Sustainability, 13:4042.

[26]McArthur, J.W., McCord, G.C., 2017, Fertilizing growth: Agricultural inputs and their effects in economic development, Journal of Development Economics, 127:133-152.

[27]Meier, U., 2001, Growth stages of mono-and dicotyledonous plants BBCH monograph. 2. Edition, Federal Biological Research Centre for Agriculture and Forestry, 158 pp.

[28]Munz, J., Schuele, H., 2022, Influencing the success of precision farming technology adoption-A model-based investigation of economic success factors in small-scale agriculture, Agriculture, 12:1773.

[29]Paul, K., Sorrentino, M., Lucini, L., Rouphael, Y., Cardarelli, M., Bonini, P., Reynaud, H., Canaguier, R.,

Trtílek, M., Panzarová, K., Colla, G., 2019, Understanding the biostimulant action of vegetal-derived protein hydrolysates by high-throughput plant phenotyping and metabolomics: A case study on tomato, Frontiers in Plant Science, 10:47.

[30]Pîrvulescu, A., Sala, F., Boldea, M., 2015, Variation of chlorophyll content in sunflower under the influence of magnetic nanofluids, AIP Conference Proceedings, 1648: 670009-1 - 670009-4.

[31]Rouphael, Y., Colla, G., 2020, Editorial: Biostimulants in agriculture, Frontiers in Plant Science, 11:40.

[32]Sala, F., 1999, Magnetic fluids effect upon growth processes in plants, Journal of Magnetism and Magnetic Materials, 201(1-3):440-442.

[33]Taheri, Y., Quispe, C., Herrera-Bravo, J., Sharifi-Rad, J., Ezzat, S.M., Merghany, R.M., Shaheen, S., Azmi, L., Prakash Mishra, A., Sener, B., Kılıç, M., Sen, S., Acharya, K., Nasiri, A., Cruz-Martins, N., Tsouh Fokou, P.V., Ydyrys, A., Bassygarayev, Z., Daştan, S.D., Alshehri, M.M., Calina, D., Cho, W.C., 2022, *Urtica dioica*-derived phytochemicals for pharmacological and therapeutic applications, Evidence-Based Complementary and Alternative Medicine, 2022:4024331.

[34]Uyeh, D.D., Mallipeddi, R., Park, T., Woo, S., Ha, Y., 2022, Technological advancements and economics in plant production systems: How to retrofit? Frontiers in Plant Science, 13:929672.

[35]Yakhin, O.I., Lubyanov, A.A., Yakhin, I.A., Brown, P.H., 2017, Biostimulants in plant science: A global perspective, Frontiers in Plant Science, 7:2049.

[36]Yuniati, N., Kusumiyati, K., Mubarok, S., Nurhadi, B., 2022, The role of moringa leaf extract as a plant biostimulant in improving the quality of agricultural products, Plants, 11:2186.