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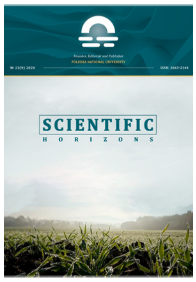

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Modelling *Salvia sclarea* L. yields depending on plants spacing, mineral fertilisers and depth of ploughing in the irrigated conditions of cold Steppe zone

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Abstract. Ukraine has favourable natural conditions for the cultivation of medicinal and aromatic plants, but there is a lack of scientific knowledge and practical guidelines for their cultivation. Clary sage is a valuable and prospective crop for the South of Ukraine and deserves special attention. This study is aimed to investigate theoretical mechanisms of clary sage productivity formation on the irrigated lands of the Southern Ukraine. The experimental basis for the study is the data on crop inflorescence yields, collected during field investigation of clary sage cultivation technology in the drip-irrigated lands of the Kherson Oblast during 2013-2018. Theoretical study on the yield formation depending on the cultivation technology elements was performed through rank correlation and heteroscedasticity analyses, while the mathematical model for the crop yield prediction was developed using multiple regression. As a result, the null hypothesis about the influence of the factors studied on crop yields was denied according to the Breusch-Pagan and Glejser tests, although the results of the analysis of variances revealed no significant effect of the depth of the plough and the spacing of the crop on the yields. Rank correlation analysis revealed that the highest influence on crop yield is attributed to phosphorus fertilisers. In addition, information on the influence of each agrotechnological factor on the yield of clary sage was determined, namely: 1 kg of nitrogen fertilisers applied per ha reduces the yield by 6.34 kg; 1 kg

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of phosphorus fertilisers applied per ha increases the yield by 156.44 kg; 1 extra cm of row spacing reduces the yield by 3.33 kg; 1 cm deeper ploughing improves the yield by 56.56 kg. The model has moderate fitting quality (correlation coefficient 0.5885) and reasonably good yield prediction accuracy (mean absolute percentage error 24.12%). The study has no analogues in Ukraine or in the world and provides novel theoretical and practical insights on the formation of clary sage productivity in the cold Steppe zone

Keywords: variance analysis; drip irrigation; medicinal plants; multiple regression analysis; rank correlation; South of Ukraine; yield prediction

INTRODUCTION

Crop yields modelling and prediction is an important task of modern agricultural science. Yield predictions and forecasts are necessary for rational adjustment of the agrotechnological aspects of crops cultivation, as well as economic planning, agricultural market policy formation, making decisions on food export and import, etc. (Lykhovyd *et al.*, 2023). Currently, various crop yield prediction models are deeply integrated in decision support systems; for example, DSSAT, used by agricultural practitioners and stakeholders to improve water, land, soil, and crop management through empirical modelling of some major crop responses to changing environmental and agrotechnological parameters, entered the system.

Empirical and statistical crop modelling is impossible without previous in-field or *in vitro* studies. Therefore, field research is the basis for mathematical and theoretical work. Modelling the yields of medicinal plants is not widespread, although it is important to better understand the processes of their productivity formation. As far as Ukraine possesses favourable soil and climate conditions for cultivation of most medicinal and aromatic plants, it is necessary both to develop regional cultivation technologies and deepen theoretical knowledge on the crops' productivity formation.

Clary sage is a valuable medicinal plant, which is in high demand on the global market due to the unique content of volatile compounds in its raw material (Acimovic *et al.*, 2022). The essential oil of this crop is used in the pharmaceutical and perfumery industries. Currently, the main producers of the raw material of clary sage are France, Bulgaria, and Hungary (Fopa-Fomeju *et al.*, 2020). To improve the production of clary sage in Ukraine, it is important to develop regional cultivation technology and provide theoretical substantiation of its elements.

Clary sage cultivation is not sufficiently investigated in Ukraine and abroad. Besides, in-field studies on clary sage productivity are limited in the studied factors. For example, Elgaml *et al.* (2022) considered the effects of different irrigation modes (100% and 50% ETo) on the yield, essential oil output, and physiological aspects of clary sage growth and development in Egypt. Verma *et al.* (2023) studied the effects of different temperature regimes on crop emergence and germination rates, which is quite a specific and narrow subject. Koul *et al.* (2017) established some patterns of clary sage reaction to different altitudes and climate patterns (subtropical or temperate climate). At the same time, some scientific groups studied clary sage from the phytoremediation standpoint, for example, Dobrikova *et al.* (2021) proved that the crop is prospective for sanitation of Zn-polluted lands.

Most scientific research on the cultivation technology and productivity assessment describe the results, devoted to the related species *Salvia officinalis* L., or common sage. For example, Ukrainian researchers Panfilova & Fedorchuk (2022) investigated the efficiency of biological preparations and mineral fertilisers application on the crops of *Salvia officinalis* L. under the conditions of the Southern Steppe zone of Ukraine, while their colleagues Svydenko *et al.* (2022) performed robust investigations on the best genotypes for sage cultivation in the above-mentioned agro-climatic zone. Kotyuk *et al.* (2022) conducted one of the most prospective and valuable studies on the cultivation of *Salvia sclarea* L. to establish the possibilities of the introduction and productivity of clary sage in the conditions of the Central Polissia zone. As a result, researchers found that the crop is prospective and deserves the attention of Ukrainian farmers. The main drawback of the quoted studies is absence of theoretical mathematical substantiation of the crop productivity depending on the environmental, genetic, and agrotechnological factors.

The goals of current study are: 1) to determine the crop's productivity depending on tillage, spacing, and fertilisation options; 2) to derive theoretical mathematical model of clary sage yield formation in the drip-irrigated conditions of the South of Ukraine depending on selected agrotechnological factors using multiple regression analysis.

MATERIALS AND METHODS

The study, described in the paper, was performed in two separate stages. The first stage included carrying out field experiments on the influence of agrotechnology on the yields of clary sage. The second stage included statistical processing of the data collected in field trials and drawing conclusions about crop yield modelling and the influence of each agrotechnological factor on the yield of clary sage.

Stage 1

The experimental study on the influence of cultivation technology on the yields of clary sage inflorescences was carried out in the experimental field, located on the territory of the 'Dodola' agricultural farm (Beryslav district, Kherson Oblast, Ukraine). The study was conducted during 2013-2018 and included the estimation of such agrotechnological elements as follows:

- Factor A – mineral fertiliser application rates – $N_0 P_0$ (0 kg ha^{-1} in total), $N_{60} P_{30}$ (90 kg ha^{-1} in total), $N_{60} P_{60}$ (120 kg ha^{-1} in total), $N_{60} P_{90}$ (150 kg ha^{-1} in total);
- Factor B – spacing of the plants (the distance between the rows) – 45 cm, 70 cm;
- Factor C – depth of ploughing – 20-22 cm, 28-30 cm.

The study was performed in four replications using split plot randomised design method. The average area of the sown plot was 105 m^2, the accounting area was 50 m^2.

The soil of the experimental field was represented by dark-chestnut, slightly saline, middle-loamy soil with the bulk density of 1.43 g cm^{-3}, field water capacity of 21.5%, wilting point of 9.1%, humus content of 2.18%, available nitrogen, phosphorus, and potassium content of 12.5-24.8, 16.8-39.5, 325-380 mg kg^{-1}, respectively. Weather conditions in the study period were typical for the climatic zone of the southern steppe of Ukraine.

Clary sage of Taihan variety was used in the trials. The predecessor was winter wheat. In the pre-ploughing period, double harrowing was conducted to the depth of 6-8 cm. Mouldboard ploughing was conducted in late autumn strictly with accordance to the study design. Mineral fertilisers were applied in the form of super phosphate and ammonium nitrate as foreseen by the scheme of the experiment. Clary sage was sown after pre-sowing soil tillage using standard sowing machine with accordance to plant spacing, stipulated by the study design. Plant care included drip irrigation, which was carried out according to weather conditions and available soil moisture (2-4 waterings were generally carried out per growing season) to maintain it at the level of 70-75% of the field water capacity in the layer 0-50 cm, and cultivating the space between the crop rows to a depth of 6-8 cm. Harvesting of clary sage inflorescences was conducted manually in the first year of the crop use, and with the harvesting machine "Ros-2" in the second-fourth years of the crop use, with immediate weighing of the harvest. In total, clary sage was harvested four times (four years of crop use). The cumulative yield of the crop was calculated as the sum of the yields for each year. The yields were statistically analysed using standard three-way analyses of variance (ANOVA) procedure, explained by Schmuller (2021), within the framework of BioStat v.7 to determine the significance of the differences between the variants by the values of the Fisher's least significant difference at $p<0.05$ (LSD_{05}). Standard deviations in crop yields were calculated according to Shi *et al.* (2020).

Stage 2

Statistical analysis was performed using the standard procedure for linear multiple regression and rank correlation in BioStat v.7 software (Fieller *et al.*, 1957; Uyanık & Güler, 2013). The strength of the relationship between the yields of clary sage and the agrotechnological factors studied was established using the classification proposed by Evans (1996). The influence of the elements of the cultivation technology on crop productivity was also assessed by the values of the regression coefficients. The quality of the fitting of the model for the prediction of clary sage yield was evaluated by the Pearson correlation coefficient values, while the accuracy was judged by the mean absolute percentage error (MAPE) using the guidelines of Blasco *et al.* (2013). The calculations of MAPE were performed according to De Myttenaere *et al.* (2016). Heteroscedasticity of the data was also checked by Breusch-Pagan test (Breusch & Pagan, 1979) and Glejser test (Glejser, 1969) to accept or deny the null hypothesis for the relationship between the cultivation technology options and clary sage yields. The visual approximation of the multiple regression model was performed using the Microsoft Excel 365 graphical toolkit to depict the fitting quality of the developed equation.

RESULTS AND DISCUSSION

The results of the first stage of the study revealed some key features of clary sage productivity formation under the impact of agrotechnological factors, namely, that the yield of clary sage inflorescences is not statistically significant effected by ploughing or spacing (Table 1 and Table 2). The highest yield was recorded in the variant of ploughing on 28-30 cm, plant spacing of 45 cm, and mineral fertiliser applications rates of $N_{60}P_{90}$. The lowest productivity was recorded when the crop was cultivated in ploughing 20-22 cm with a spacing of 45 cm and no fertilisers were applied. Significant effect on the yield is attributed to the total dose of mineral fertilisers applied, where the pairs of 0 vs 120, 0 vs 150, and 90 vs 150 are significantly different in productivity. Thus, it was established that the depth of tillage and the spacing of the crops are not of great importance for the formation of the productivity of clary sage under irrigated conditions. Moreover, Giannoulis *et al.* (2021) proved that plant density had negative effect on the yields of a related species *Salvia officinalis* L., while their results support the claim of better crop productivity under mineral fertilisation. Katar *et al.* (2022) also supports the statement that salvia productivity benefits from fertiliser application; however, essential oil yields could be decreased at higher rates of mineral nitrogen. There is a gap in scientific literature about the effects of tillage on the productivity of clary sage, therefore, current study provides a breakthrough in this subject.

As the cumulative yields of the clary sage inflorescences for four years of crop use were calculated and generalised with correspondence to the options of cultivation technology and their combinations, Table 3 was created to represent the inputs, used to perform the modelling and statistical investigation of the yields. There were 64 data pairs in total.

Table 1. *Yields of clary sage inflorescences depending on the depth of ploughing, crop spacing, and fertilisers application rates (average for four years of the crop use)*

Factor A (total rates of NP fertiliser applied, kg×ha^{-1})	Factor B (crop spacing, cm)	Factor C (depth of ploughing, cm)	Clary sage inflorescences yield, t×ha^{-1}±standard deviation
0	45	20-22	19.07±2.57
			17.74±2.40
			14.28±1.93
			12.81±1.74
	70		19.16±2.58
			18.40±2.49
			14.28±1.94
			14.25±1.93
	45	28-30	20.08±3.83
			17.72±2.64
			14.31±2.52
			14.46±2.13
	70		21.06±3.90
			17.98±2.77
			14.94±2.61
			14.22±2.08
90	45	20-22	28.08±5.08
			19.35±3.95
			18.59±2.68
			15.21±2.10
	70		28.56±5.32
			20.36±3.98
			19.13±2.82
			15.69±2.22
	45	28-30	28.56±6.15
			20.07±4.59
			19.52±3.22
			14.55±2.34
	70		25.67±5.89
			21.01±4.19
			20.30±3.50
			14.78±2.40
120	45	20-22	37.93±2.73
			29.11±2.37
			19.57±1.93
			15.77±1.96
	70		38.84±2.90
			29.24±2.43
			20.61±1.99
			16.33±1.93
	45	28-30	40.52±3.85
			29.55±2.75
			23.12±2.66
			15.91±1.97
120	70	28-30	30.21±3.44
			29.98±2.86
			24.16±2.77
			16.67±1.97

Table 1, Continued

Factor A (total rates of NP fertiliser applied, kg×ha^{-1})	Factor B (crop spacing, cm)	Factor C (depth of ploughing, cm)	Clary sage inflorescences yield, t×ha^{-1}±standard deviation
150	45	20-22	45.51±5.52
			33.82±3.96
			23.55±3.15
			17.46±2.16
	70		42.47±3.86
			30.58±4.08
			24.97±3.30
			17.70±2.25
	45	28-30	46.29±6.28
			33.74±4.57
			23.68±3.22
			17.06±2.32
	70		45.24±6.14
			32.34±4.38
			27.77±3.78
			17.43±2.35

Source: *compiled by the authors*

Table 2. *Average yield of clary sage inflorescences by the studied agrotechnological factors, and the results of three-way analysis of variance*

Factor A gradations	Yield, t ha^{-1}	Factor B gradations	Yield, t ha^{-1}	Factor C gradations	Yield, t ha^{-1}
0	16.55	45	23.34	20-22	23.08
90	20.59	70	23.26	28-30	23.53
120	26.10	LSD_{05}	0.75, not significant	LSD_{05}	4.06, not significant
150	29.98				
LSD_{05}	8.43, significant				

Source: *compiled by the authors*

Table 3. *Inputs for the modelling and statistical analysis of cumulative clary sage yields*

Fertilisers, kg ha^{-1}		Spacing, cm	Ploughing depth, cm	Cumulative clary sage yield
Nitrogen (N)	Phosphorus (P)			
0	0	45	21	19.07
0	0	45	21	17.74
0	0	45	21	14.28
0	0	45	21	12.81
0	0	70	21	19.16
0	0	70	21	18.40
0	0	70	21	14.28
0	0	70	21	14.25
60	30	45	21	28.08
60	30	45	21	19.35
60	30	45	21	18.59
60	30	45	21	15.21
60	30	70	21	28.56
60	30	70	21	20.36
60	30	70	21	19.13
60	30	70	21	15.69
60	60	45	21	37.93
60	60	45	21	29.11

Table 3, Continued

Fertilisers, kg ha^{-1}		Spacing, cm	Ploughing depth, cm	Cumulative clary sage yield
Nitrogen (N)	Phosphorus (P)			
60	60	45	21	19.57
60	60	45	21	15.77
60	60	70	21	38.84
60	60	70	21	29.24
60	60	70	21	20.61
60	60	70	21	16.33
60	90	45	21	45.51
60	90	45	21	33.82
60	90	45	21	23.55
60	90	45	21	17.46
60	90	70	21	42.47
60	90	70	21	30.58
60	90	70	21	24.97
60	90	70	21	17.70
0	0	45	29	20.08
0	0	45	29	17.72
0	0	45	29	14.31
0	0	45	29	14.46
0	0	70	29	21.06
0	0	70	29	17.98
0	0	70	29	14.94
0	0	70	29	14.22
60	30	45	29	28.56
60	30	45	29	20.07
60	30	45	29	19.52
60	30	45	29	14.55
60	30	70	29	25.67
60	30	70	29	21.01
60	30	70	29	20.30
60	30	70	29	14.78
60	60	45	29	40.52
60	60	45	29	29.55
60	60	45	29	23.12
60	60	45	29	15.91
60	60	70	29	30.21
60	60	70	29	29.98
60	60	70	29	24.16
60	60	70	29	16.67
60	90	45	29	46.29
60	90	45	29	33.74
60	90	45	29	23.68
60	90	45	29	17.06
60	90	70	29	45.24
60	90	70	29	32.34
60	90	70	29	27.77
60	90	70	29	17.43

Source: *compiled by the authors*

First, data were used to determine the strength of the relationship between each agrotechnological option studied and the yield of clary sage by rank correlation analysis. The correlation coefficients of Spearman (ρ), Kendall (τ), Pearson (r), Goodman and Kruskal (γ) were calculated and presented in Table 4.

Table 4. Rank correlations for the relationship between the elements of cultivation technology and the yields of clary sage

Cultivation technology element	Correlation coefficients			
	Spearman (ρ)	Kendall (τ)	Goodman and Kruskal (γ)	Pearson (r)
Nitrogen (N)	0.52	0.43	0.70	0.45
Phosphorus (P)	0.59	0.48	0.55	0.59
Spacing, cm	0.03	0.03	0.04	0.01
Ploughing depth, cm	0.04	0.04	0.05	0.03

Source: *prepared on the basis of the authors' genuine research*

According to the results of the rank correlation analysis, the strongest relationship (and the greatest impact on clary sage yields) is attributed to phosphorus fertilisers, while the slightest relationship (almost absent) is attributed to the spacing of the plants and the depth of ploughing. Therefore, fertilisation has a decisive role in the determination of drip-irrigated clary sage yields. The results of Breusch-Pagan and Glejser tests are provided in Table 5. The tests confirm that the null hypothesis is denied, so it could be assured that the factors studied had a statistically significant influence on the yields of the studied crop.

Table 5. Results of heteroskedasticity tests for the input data set

Statistical index	Value
Breusch-Pagan test	
Statistics of the test	2.0720
P-value	0.0004
Degrees of freedom	4
Critical value	9.4877
Null hypothesis	Denied
Glejser test	
Statistics of the test	22.1300
P-value	0.0002
Degrees of freedom	4
Critical value	9.4877
Null hypothesis	Denied

Source: *compiled by the authors*

Further, linear multiple regression analysis was performed. The statistics for the analysis and the developed model are provided in Table 6. It is evident that the model has moderate fitting quality (according to the value of correlation coefficient), and reasonable prediction accuracy (according to the value of MAPE, which falls within the range 20-50%) with a greater inclination to good accuracy (requires MAPE within 10-20%).

Table 6. Regression statistics and the model's equation for the prediction of clary sage yields depending on mineral fertilisers rates, spacing, and depth of ploughing

Statistical parameter	Value
Correlation coefficient	0.5885
Coefficient of determination	0.3463
Adjusted coefficient of determination	0.3020
Predicted coefficient of determination	0.2383
Mean absolute percentage error	24.12%
Equation	$15.325-6.3403\times10^{-3}\times N+1.5644\times10^{-1}\times P-3.3250\times10^{-3}\times S+5.6563\times10^{-2}\times D$

Note: *N – the dose of Nitrogen fertilisers applied, kg×ha^{-1}; P – the dose of Phosphorus fertilisers applied, kg×ha^{-1}; S – spacing, cm; D – depth of ploughing, cm*

Source: *compiled by the authors*

According to the modelling results and obtained values of regression coefficients for each element of cultivation technology, it is possible to state that every kg of Nitrogen fertilisers applied per ha reduces clary sage yields by 6.3403 kg, every kg of Phosphorus fertilisers applied per ha increases clary sage yields by 156.44 kg, every additional cm of between row spacing reduces the yields by 3.325 kg, and every cm of additional depth of ploughing above 22 cm improves the crop yield by 56.563 kg. Therefore, it is quite surprising that Nitrogen fertilisers manifested their action not in supposed enhancement of clary sage yields but provided weak inhibitory activity. It is also proved that greater spacing, meaning lower plant density, results in the yield losses. Deep ploughing is favourable for obtaining higher yields of clary sage in the south of Ukraine; therefore, it is reasonable to spend additional labour, time, and material resources to provide deeper loosening of the soil under clary sage. Visual approximation and fitting quality assessment are provided in Figure 1.

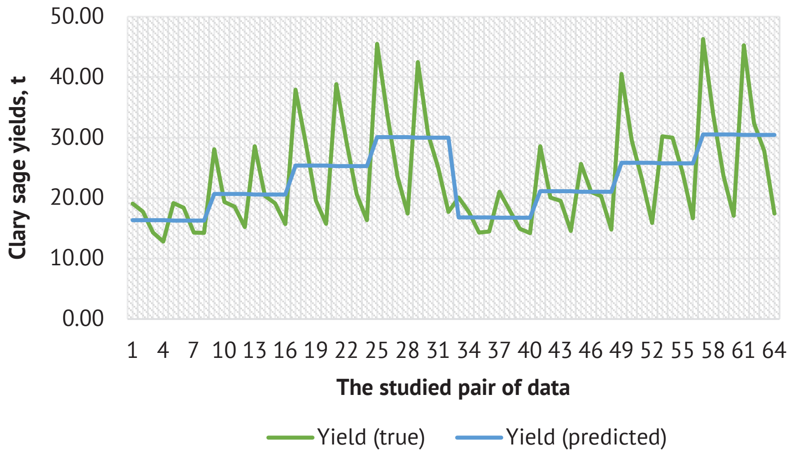

Figure 1. *Visual approximation of clary sage productivity model*
Source: *compiled by the authors*

Current study has no analogues in Ukraine, and it is the first to provide deep mathematical analysis of clary sage productivity formation under the drip-irrigated conditions of the South of Ukraine, as well as to provide the mathematical equation for yield prediction of this crop, though the studies on cultivation technology and biological features of the crop were performed by Ukrainian researchers (Yurchak & Pobirchenko, 1997). For example, Knyazyuk *et al.* (2018) conducted the investigation of clary sage productivity depending on the terms of sowing and plant spacing and obtained the results, which are in agreement with the current study, that the highest yields of the crop could be harvested under a spacing of 45 cm. But there was no deep mathematical analysis of the formation of crop productivity in the research papers quoted above. It was also impossible to find any similar work in foreign sources, as most studies devoted to clary sage productivity investigation are limited to field work and focused on the interpretation of the crop productivity with no complicated statistical apparatus engaged (while correlation coefficient and error calculations are common for almost every work), and provide no deep statistical analysis, e.g., as the studies by Singh *et al.* (2008), Verma *et al.* (2010), Fathi *et al.* (2012), Yaseen *et al.* (2014), and other foreign researchers. Therefore, the current study presents novel insights for global scientific knowledge on the formation of clary sage yields under the influence of some agrotechnological factors, such as mineral fertilisation, plough depth and plant spacing. The results are of a special value for the South of Ukraine and could be extrapolated to the areas with similar soil-climatic conditions with accordance to modern climate classification – namely, BSk zone, the cold Steppe climate (Beck *et al.*, 2018).

To sum up the results of the current study, it is required to note that it has some limitations, mainly with respect to the number of agrotechnological factors studied, as many elements of cultivation technology remained out of sight in this research. Furthermore, the results about the low efficiency of the tillage depth in the increase in yield could be put under doubt if the crop is grown in rainfed conditions, as it is believed that irrigation can lead to the nullification of positive effects from deep ploughing (Lavrenko *et al.*, 2021). At the same time, the developed model for clary sage productivity prediction has no analogues in Ukraine and in the world, and it is the first one to implement mathematical methods for better understanding of the crop yield formation under various cultivation technology practices.

CONCLUSIONS

Clary sage's productivity in the drip-irrigated conditions of the South of Ukraine mainly depends on fertilisation, as the depth of ploughing and plants spacing play neglectable role and provide yield increase, which is not statistically significant according to the ANOVA results. The best yield capacity (46.29±6.28 t/ha^{-1}) is attributed to the variant with the ploughing 28-30 cm, the spacing of the plants 45 cm, and the rates of application of mineral fertilisers $N_{60}P_{90}$. Statistical analysis testifies about the highest importance of phosphorus fertilisers (Pearson's correlation coefficient is 0.59) in achieving the best yield quantity, while plant spacing and ploughing depth play a secondary role in clary sage productivity.

As a result of our study, a mathematical equation for the prediction of the yield of clary sage inflorescences has been developed based on the rates of mineral fertilisers, the spacing and the depth of ploughing. The model has moderate fitting quality (correlation coefficient is 0.5885) and reasonably good prediction accuracy (mean absolute percentage error is 24.12%), providing novel information on the specifics of the formation of crop productivity under irrigated conditions in the south of Ukraine. Surprisingly, regression analysis revealed that nitrogen fertilisers can slightly decrease yield (per 6.34 kg ha^{-1} for each kg ha^{-1} applied), although it is commonly expected that they improve crop productivity. The results of the study have no analogues in Ukraine or elsewhere and provide valuable scientific information on the cultivation of clary sage in the climatic zone of the soil of BSk.

Further investigations are to be conducted to deepen the obtained theoretical knowledge on clary sage productivity formation, including the factors, which were not embraced in current study. In addition, other mathematical and statistical approaches should be applied to improve the quality of the yielding model.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Моделювання врожайності *Salvia sclarea* L. залежно від ширини міжрядь, мінеральних добрив та глибини оранки в зрошуваних умовах холодного Степу

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Анотація. Україна має сприятливі природні умови для вирощування лікарських та ароматичних рослин, але бракує наукових знань та практичних рекомендацій щодо їх вирощування. Шавлія мускатна є цінною та перспективною культурою для Півдня України і заслуговує на особливу увагу. Метою даної роботи є дослідження теоретичних механізмів формування продуктивності шавлії мускатної на зрошуваних землях Півдня України. Експериментальною базою дослідження є дані про врожайність суцвіть культури, зібрані під час польових досліджень технології вирощування шавлії мускатної на краплинному зрошенні в Херсонській області протягом 2013-2018 рр. Теоретичне дослідження формування врожайності залежно від елементів технології вирощування проводилося за допомогою рангового кореляційного та гетероскедастичного аналізів, а математична модель для прогнозування врожайності розроблялася з використанням множинної регресії. В результаті нульова гіпотеза про вплив досліджуваних факторів на врожайність була спростована за критеріями Бреуша-Пагана та Глейзера, хоча результати дисперсійного аналізу не виявили значущого впливу глибини плуга та ширини міжрядь на врожайність. Аналіз рангової кореляції показав, що найбільший вплив на врожайність мають фосфорні добрива. Крім того, визначено інформацію про вплив кожного агротехнологічного фактора на врожайність шавлії мускатної, а саме 1 кг азотних добрив, внесених на 1 га, зменшує врожайність на 6,34 кг; 1 кг фосфорних добрив, внесених на 1 га, збільшує врожайність на 156,44 кг; 1 додатковий сантиметр ширини міжрядь зменшує врожайність на 3,33 кг; оранка на 1 см глибше підвищує врожайність на 56,56 кг. Модель має помірну якість підгонки (коефіцієнт кореляції 0,5885) і досить хорошу точність прогнозування врожайності (середня абсолютна відсоткова похибка 24,12 %). Дослідження не має аналогів в Україні та світі і дає нові теоретичні та практичні уявлення про формування продуктивності шавлії мускатної в зоні холодного Степу

Ключові слова: дисперсійний аналіз; краплинне зрошення; лікарські рослини; множинний регресійний аналіз; рангова кореляція; Південь України; прогнозування врожайності