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Influence of fertilization on uptake of macroelements with sunflower biomass

Влияние на торенето върху износа на макроелементи с биомасата на слънчоглед

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ABSTRACT

The study was conducted under pot experimental conditions with Alluvial-meadow soil. The aim of the trial was to evaluate the effect of different nitrogen, phosphorus, potassium, and silicon fertilizer rates in the soil and their impact on the uptake of basic macronutrients with sunflower (*Helianthus annuus* L.) biomass. The experiment included 16 variants of increased fertilizer rates in 3 replications. Data on the yield of fresh and absolutely dry biomass from the above-ground part of plants and on the content of N, P, K, Si, Ca and Mg in the dry biomass was obtained. According to the data obtained, the content and uptake of the examined macroelements with the sunflower biomass were significantly influenced by the rates and fertilizer combinations. The highest uptake of nitrogen was in the variants with the following rates: N_{200}, N_{300}, and N_{400}. The changes in the macroelements' uptake followed the changes in the quantities of the relevant elements in dry biomass in the variants of the experiment. By increasing the fertilizer rates the content of N, P, and Si, and their uptakes with sunflower biomass was increased. This trend with potassium was expressed to a lower extent.

Keywords: fertilizer rates, nitrogen, phosphorus, potassium, silicon, uptake

РЕЗЮМЕ

Проведено е изследване в условията на съдов опит върху Алувиално-ливадна почва. Целта на експеримента е да се оцени ефективността и взаимодействието на различни норми на азотни, фосфорни, калиеви и силициеви торове в почвата и влиянието им върху износа на основни макроелементи с биомасата от слънчоглед (*Helianthus annuus* L.). Опитът включва 16 варианта на торене с 3 повторения. Получени са данни за добива от свежа и абсолютно суха биомаса от надземната част и съдържанието на N, P, K, Si, Ca и Mg в получената суха биомаса от растенията. Съгласно получените експериментални данни съдържанието и износът на изследваните макроелементи с биомасата са повлияни значително от торовите норми и комбинации. Най-висок е износът на азота във вариантите с норма N_{200}, N_{300} и N_{400}. Установено е, че измененията на износите на изследваните макроелементи следват измененията на количествата от съответните елементи в сухата биомаса по варианти в опита. С повишаване на нормите на торене се повишава не само съдържанието, но и износът на N, P, и Si. При калия тази тенденция е изразена в по-малка степен.

Ключови думи: норми на торене, азот, фосфор, калий, силиций, износ

INTRODUCTION

Sunflower is a major oilseed crop in Bulgaria. New hybrids and promising sunflower lines, distinguished by a number of their characteristics and physiological requirements are constantly grownning. The hybrids with high oil content have high requirements in the nutrient supply while those with low oil content are the least demanding (Nikolova, 2010). Many of the studies with sunflowers in Bulgaria were conducted in DAI - General Toshevo and were mainly dedicated to the selection of this crop (Tonev, 2005; Georgiev et al., 2012; Encheva et al., 2015; Valkova et al., 2017) and on the productive potential and resistance to powdery mildew and blue bunting of experimental sunflower hybrids (Valkova et al., 2017). Other research was related of establishing the appropriate parameters of seeding rate, mineral, and bacterial fertilization, and use of biostimulants (Nankova and Tonev, 2004; Yankov and Drumeva, 2012).

The need for nutrients for yield formation depends both on the specific soils and climatic conditions and on several other factors. The importance of fertilization is the most significant (Ahmad et al., 2017). Sunflower reacts well to nitrogen fertilization and nitrogen excess lowers the seed oil content and plant resistance to diseases. Balanced phosphorus and potassium fertilization increase yield and oil content in seeds. Sunflower's potassium needs are high - 7-11 kg per 100 kg of seed, i.e. 5-2 times higher than nitrogen and 4-5 times higher than phosphorus. Potassium increases the absolute weight and fat content of the seeds. Experiments conducted in Bulgaria show an increase in fat yield under the influence of potassium fertilization (Nikolova, 2010). Determining the optimal nutrient regime for crops requires establishing the export and consumption of nutrients to form an unit of production, and their balance in the soil for different soil conditions (Mitova and Dinev, 2013; Nenova and Mitova, 2018). Establishing nutrient balance is an effective method for assessing nutrient use by crops (Slavov et al., 2010). In this way, the negative consequences of improper fertilization could be avoided. Furthermore, balanced nutrition plays a key role in obtaining stable yields of high quality. Research related to optimizing sunflower nutrition is scarce and information on silicon fertilization is absent. Sunflower forms two fold more roots, which contain 1.5 fold more nitrogen and 5 fold more potassium, compared to other spring crops (Nikolova, 2010; Saldzhiev, 2020). This crop is also distinguished by its exceptional micronutrient requirements. The growth of the stem is of great importance. The stem should be resistant to lodging and provide a continuous transfer of metabolites to the growing seeds, and here is mainly the role of Si. In our country, the use of silicon fertilizers is poorly developed. Silicon (Si) is not classified as an essential element for plants, but numerous studies have described its beneficial effects under various soil and climatic conditions, including low levels of plant-available forms of silicon. The application of Si shows the potential to increase the availability of nutrients in the rhizosphere and their uptake by plants (Pavlovic et al., 2021). As a beneficial and essential element, the accumulation of silicon in the rhizosphere of plants can reduce the adverse effects of both biotic and abiotic stress in many plant species through several resistance mechanisms and thus increase plant biomass accumulation and yield (Li et al., 2018). Plant species vary greatly in their ability to accumulate Si, with values ranging from 0.1% to 10% Si (Epstein and Bloom, 2008). Consequently, some plant species are minimally affected by the introduction of Si compared to others (Coskun et al., 2019).

The main objective of the study was to determine the content and uptake of macronutrients (N, P, K, Si, Ca, and Mg) with biomass of sunflower (*Helianthus annuus* L.), under the influence of increasing fertilizer rates of nitrogen, phosphorus, potassium and silicon.

MATERIALS AND METHODS

In the spring of 2021, a pot fertilizer experiment with a an early to mid-early hybrid of sunflower (*Helianthus annuus* L.) - Sumiko HTS of Singenta was performed. The initial soil is Alluvial-meadow soil supplied by the experimental field in Tsalapitsa, Plovdiv region. According to the classification of soils in Bulgaria (Koinov, 1987), it is defined as Eutric Fluvisol - FLeu (IUSS Working Group WRB, 2015). It is characterized by a neutral soil reaction in the plowing horizon (pH_{H_2O} 7.4), with a low content of total (0.052%) and mineral nitrogen (11.52 mg N/kg soil). The soil has a low supply of mobile phosphorus (8.09 mg P_2O_5 /100 g soil) and available potassium (14.35 mg K_2O /100 g soil). The total quantity of SiO_2 is 73.56% (in % of ignition residue). Silicon in the form of SiO_2 has a significant share in the total chemical composition of the different soil types in Bulgaria (Raikov and Ganev, 1972; Garbouchev, 1974). The content of soluble Si is about 91 mg/100g soil and the quantity of exchangeable Si is 285 mg/100g soil, determined by extraction with 0,01M $CaCl_2$ and 0,5M CH_3COOH solutions, respectively (Berthelsen and Korndörfer, 2005). So the studied soil is well stocked with Si.

Before sowing the seeds, fertilizers with different amounts of active substances in mg/pot were added to the experimental containers of 3 kg capacity, as presented in Table 1.

Table 1. Scheme of a pot experiment and quantities of active substance in mg/pot

1. $N_0P_0K_0Si_0$ - Control
2. $N_0P_{160}K_{140}Si_{800}$
3. $N_{400}P_{160}K_{140}Si_{800}$
4. $N_{200}P_0K_{140}Si_{800}$
5. $N_{200}P_{320}K_{140}Si_{800}$
6. $N_{200}P_{160}K_0Si_{800}$
7. $N_{200}P_{160}K_{280}Si_{800}$
8. $N_{200}P_{160}K_{140}Si_0$
9. $N_{200}P_{160}K_{140}Si_{2000}$
10. $N_{200}P_{160}K_{140}Si_{800}$
11. $N_{300}P_{240}K_{70}Si_{400}$
12. $N_{300}P_{80}K_{210}Si_{400}$
13. $N_{300}P_{80}K_{70}Si_{1200}$
14. $N_{100}P_{240}K_{210}Si_{400}$
15. $N_{100}P_{240}K_{70}Si_{1200}$
16. $N_{100}P_{80}K_{210}Si_{1200}$

Five sunflower seeds were sown, leaving 3 plants in each pot at a later stage. On the 67th day of vegetation in the budding phase, the plants were harvested, weighed, and prepared for chemical analysis. The content (%) of absolutely dry weight (a.d.w.) of macronutrients N, P, K, Si, Ca, and Mg in sunflower plant biomass was determined by acid digestion and ICP readings (5800 ICP - OES system - Agilent). The export of the tested elements with the plant production was determined.

The experiment included 16 fertilization treatments in 3 replications. It is a multifactorial scheme with four factors varied at 5 levels (Sadovski, 2020). Table 1 shows the experimental design and the imported amounts of the active substance of the macroelements used in mg/pot. There were used solid granular ammonium nitrate as a source of N, triple super phosphate – as P and solid potassium sulphate – as K macronutrient.

The following soil analyses were performed before and after the experiments: pH – potentiometrically in H_2O and KCl (Arinushkina, 1962); total and mineral nitrogen content - Bremner and Kinney method (Bremner, 1965b; Bremner, 1965a); mobile forms of phosphorus and potassium (P_2O_5 и K_2O) - by the acetate-lactate method (Ivanov, 1986), organic carbon (humus) content - according to Turin's method (Kononova, 1963).

One-way ANOVA analysis (at 95% confidence level) was performed for the data for fresh and dry biomass of sunflower plants depending on the variants of fertilization. Regression analysis presented as polynomials of the second-degree was done between fertilization rates and nutrient uptake with sunflower biomass. For the statistical analysis of the obtained results the program of Statgraphics package was used.

RESULTS AND DISCUSSION

From the data presented in Table 2, the role of applied fertilizers on the amount of fresh and dry weight of sunflower plants is highlighted. The data obtained showed that the dry weight of the total biomass obtained from a plant per pot varied in proportion to the corresponding fresh weight recorded.

Table 2. Influence of fertilization rate and fertilizer combinations on the yield of fresh and dry biomass from the above-ground part of sunflower plants

Weight of sunflower plants (g/pot) on the 67th day		
Variants	Fresh biomass	Dry biomass
1. $N_0P_0K_0Si_0$	46.76 a	9.25 a
2. $N_0P_{160}K_{140}Si_{800}$	83.03 bcde	13.32 bcde
3. $N_{400}P_{160}K_{140}Si_{800}$	91.96 cde	15.20 cdef
4. $N_{200}P_0K_{140}Si_{800}$	93.51 cde	16.71 ef
5. $N_{200}P_{320}K_{140}Si_{800}$	77.21 bcd	10.03 ab
6. $N_{200}P_{160}K_0Si_{800}$	86.14 bcde	13.16 bcde
7. $N_{200}P_{160}K_{280}Si_{800}$	75.66 bc	12.76 abcd
8. $N_{200}P_{160}K_{140}Si_0$	100.49 e	16.11 def
9. $N_{200}P_{160}K_{140}Si_{2000}$	81.10 bcde	15.29 cdef
10. $N_{200}P_{160}K_{140}Si_{800}$	69.45 b	12.26 abc
11. $N_{300}P_{240}K_{70}Si_{400}$	86.14 bcde	13.44 bcde
12. $N_{300}P_{80}K_{210}Si_{400}$	98.16 de	16.34 def
13. $N_{300}P_{80}K_{70}Si_{1200}$	88.85 bcde	13.94 cde
14. $N_{100}P_{240}K_{210}Si_{400}$	72.94 bc	13,77 cde
15. $N_{100}P_{240}K_{70}Si_{1200}$	88.08 bcde	16.05 def
16. $N_{100}P_{80}K_{210}Si_{1200}$	80.32 bcde	14.69 cdef
Average	82.49	14.12
St. deviation	16.42	2.98

From the data obtained the lowest weight is in the control variant and the highest in the variants V8 ($N_{200}P_{160}K_{140}Si_0$), V12 ($N_{300}P_{80}K_{210}Si_{400}$), and V13 ($N_{300}P_{80}K_{70}Si_{1200}$), was reported. The weights in variants V5 ($N_{200}P_{320}K_{140}Si_{800}$), V7 ($N_{200}P_{160}K_{280}Si_{800}$), V10 ($N_{200}P_{160}K_{140}Si_{800}$) and V14 ($N_{100}P_{240}K_{210}Si_{400}$) were lower. The combinations of different rates and types of mineral fertilizers used failed to emit the most favorable combination that influenced the plant's fresh and dry weight at the budding stage of sunflower in the pot experiment. The N_{300} and N_{200} in combination with lower rates of the other macronutrients were most conducive to sunflower development. It is noteworthy that the highest result was not achieved in the variant with the highest nitrogen rate (N_{400}).

As a result of the One-way ANOVA analysis of the data for the plant biomass on the 67th day, the leading role of nitrogen fertilization in the rate of 200 mg/per pot was established (Table 2). Nitrogen is an essential nutrient that determines the growth of oilseeds and increases the amount of protein and yield. The accumulation of biomass in sunflower is associated with the absorption of nutrients during the whole growing season (Detmann et al., 2012; Hassan and Kaleem, 2014).

Under the influence of mineral nutrition, significant changes in the amount of nutrients absorbed by the biomass of sunflower plants occur (Table 3). The content of total N in the dry biomass of plants varied from 0.89 in the control to 3.22% in variant V8 ($N_{200}P_{160}K_{140}Si_0$). Approximately in the same order varied the content of total N in variants V6 ($N_{200}P_{160}K_0Si_{800}$), V10 ($N_{200}P_{160}K_{140}Si_{800}$), and V13 ($N_{300}P_{80}K_{70}Si_{1200}$). The average content of total N in the five variants with norm N_{200} and in the three variants with rate N_{300} was approximately the same, 2.65 and 2.64% respectively. The application of mineral nitrogen in the soil in most cases is accompanied by an increase in the content of N in plants (Atanassova, 2005; Hara and Sonoda, 1979; Kołota and Chohura, 2015; Nenova and Mitova, 2018; Vasileva and Ilieva, 2017). In the present study there was a trend of increasing nitrogen concentration in plants tissues until N_{200} fertilization norm.

The content of phosphorus in sunflower plants was significantly lower than the nitrogen content and varied in a lower extend depending on the combinations of rates and types of mineral fertilizers applied - from 0.23 in the control to 0.63% in the fertilized variants. The phosphorus content was the highest in V5 ($N_{200}P_{320}K_{140}Si_{800}$). There was a tendency to increase the phosphorus content in the plants with increasing fertilizer rate.

The potassium content was slightly higher than the phosphorus content and ranges from 1.39 in the control to 2.53% in the variant with the highest potassium level (K_{280}). Other authors have reported similar results. Summarized results from a large number of experiments showed that "economically" nitrogen, high phosphorus,

Table 3. Content of total N, P, K, Si, Ca, and Mg in sunflower biomass (in % of absolutely dry weight)

Variants	N	P	K	Si	Ca	Mg
1. $N_0P_0K_0Si_0$	0.89	0.23	1.39	0.0111	0.13	0.33
2. $N_0P_{160}K_{140}Si_{800}$	1.48	0.42	1.83	0.0268	1.42	0.54
3. $N_{400}P_{160}K_{140}Si_{800}$	2.44	0.53	2.12	0.0305	2.02	0.47
4. $N_{200}P_0K_{140}Si_{800}$	2.49	0.35	2.39	0.0345	2.03	0.66
5. $N_{200}P_{320}K_{140}Si_{800}$	2.15	0.63	2.11	0.0351	2.02	0.59
6. $N_{200}P_{160}K_0Si_{800}$	3.11	0.58	1.98	0.0374	2.17	0.75
7. $N_{200}P_{160}K_{280}Si_{800}$	2.26	0.53	2.53	0.0319	1.91	0.60
8. $N_{200}P_{160}K_{140}Si_0$	3.22	0.57	2.38	0.0402	2.30	0.76
9. $N_{200}P_{160}K_{140}Si_{2000}$	2.51	0.49	1.86	0.0976	1.92	0.50
10. $N_{200}P_{160}K_{140}Si_{800}$	2.82	0.52	2.00	0.0372	2.10	0.71
11. $N_{300}P_{240}K_{70}Si_{400}$	2.46	0.60	1.90	0.0468	2.17	0.72
12. $N_{300}P_{80}K_{210}Si_{400}$	2.46	0.39	1.82	0.0464	1.66	0.40
13. $N_{300}P_{80}K_{70}Si_{1200}$	2.99	0.51	1.98	0.0936	1.89	0.44
14. $N_{100}P_{240}K_{210}Si_{400}$	2.19	0.49	2.26	0.0292	1.67	0.55
15. $N_{100}P_{240}K_{70}Si_{1200}$	2.04	0.55	2.02	0.0825	1.77	0.55
16. $N_{100}P_{80}K_{210}Si_{1200}$	2.24	0.42	2.26	0.0110	1.77	0.47

and abundant potassium fertilization were suitable for sunflower cultivation. On magnesium-poor soils, both yields and oil content can be increased by magnesium fertilization (Nikolova, 2010).

The calcium content was very low - 0.13% in the control variant, but it was significantly higher in the fertilized variants. It varied from 1.66 to 2.30% and the higher fertilization rates led to a higher accumulation of Ca in sunflower plants. The change in the content of Mg varied similarly, but the amount in the control variant was slightly higher - 0.33%. In the fertilized variants it varied between 0.44 and 0.76%. It can be concluded that fertilization had a significantly lower effect on the accumulation of Mg in sunflower plants. The Si content increased from 110.8 mg/kg in the control variant to 975.85 mg/kg in the variant with the highest Si rate. The combinations of norms and fertilizers used in the experiment did not establish a direct relationship between increasing the accumulation of Si in plants with increasing the imported Si level. In the studies by De Melo Peixoto et al. (2022) a higher total leaf area of Si-treated plants led to increased overall CO_2 uptake by the plant. Plants treated with Si had an increase of 24-39% in biomass yield.

Based on the obtained dry biomass and the content of N, P, K, Si, Ca, and Mg in it (Table 3), the uptake from the soil of the studied elements was determined. The changes in the uptakes of the studied macro-elements followed the changes in the quantities of the respective elements in the dry biomass according to the variants of the experiment (Table 4). As the fertilization rates increased, not only the content but also the uptake of N, P, K, and Si was increased.

Table 4. Uptake of total N, P, K, Si, Ca, and Mg with biomass of sunflower (kg/ha)

Variants	N	P	K	Si	Ca	Mg
1. $N_0P_0K_0Si_0$	63.3	16.4	98.9	0.8	9.2	23.5
2. $N_0P_{160}K_{140}Si_{800}$	244.0	69.2	301.7	4.4	234.1	89.0
3. $N_{400}P_{160}K_{140}Si_{800}$	333.8	72.5	290.0	4.2	276.3	64.3
4. $N_{200}P_0K_{140}Si_{800}$	374.4	52.6	359.3	5.2	305.2	99.2
5. $N_{200}P_{320}K_{140}Si_{800}$	194.1	56.9	190.4	3.2	182.3	53.3
6. $N_{200}P_{160}K_0Si_{800}$	368.3	68.7	234.5	4.4	257.0	88.8
7. $N_{200}P_{160}K_{280}Si_{800}$	259.6	60.9	290.7	3.7	219.4	68.9
8. $N_{200}P_{160}K_{140}Si_0$	466.9	82.6	345.1	5.8	333.5	110.2
9. $N_{200}P_{160}K_{140}Si_{2000}$	345.4	67.4	255.9	13.4	264.2	68.8
10. $N_{200}P_{160}K_{140}Si_{800}$	311.1	57.4	220.6	4.1	231.7	78.3
11. $N_{300}P_{240}K_{70}Si_{400}$	297.6	72.6	229.8	5.7	262.5	87.1
12. $N_{300}P_{80}K_{210}Si_{400}$	361.6	57.3	267.6	6.8	244.0	58.8
13. $N_{300}P_{80}K_{70}Si_{1200}$	375.1	64.0	248.4	11.7	237.1	55.2
14. $N_{100}P_{240}K_{210}Si_{400}$	271.4	60.7	280.1	3.6	207.0	68.2
15. $N_{100}P_{240}K_{70}Si_{1200}$	294.6	79.4	291.7	11.9	255.6	79.4
16. $N_{100}P_{80}K_{210}Si_{1200}$	296.2	55.5	298.8	1.5	234.0	62.1

Statistical regression analysis of the relationship between fertilization rates of the nutrients and uptake with biomass is able to reveal the corresponding response curves and doses of maximum export.

On figures 1 and 2 are shown the regression curves of the exports of N and P, depending on the imported quantities of the respective elements, presented as polynomials of the second degree. The R-Squared statistic indicates that the model as fitted explained 74,626% of the variability in N_{uptake}, 47,3784% of the variability in P_{uptake}. Relationships between potassium and silicon with exports of these elements were not significant.

Table 5 was prepared up by converting and averaging the resulting exports with plants according to the imported fertilization rates for N, P, K, and Si in the different variants. The difference between the imported quantities of the nutrients with fertilizers and the uptake with the obtained biomass was significant and showed that in the variants with high fertilization rates, large amounts of nutrients were available, which will be able to ensure the nutrition of sunflower even after the "R4" phase until the end of the growing period.

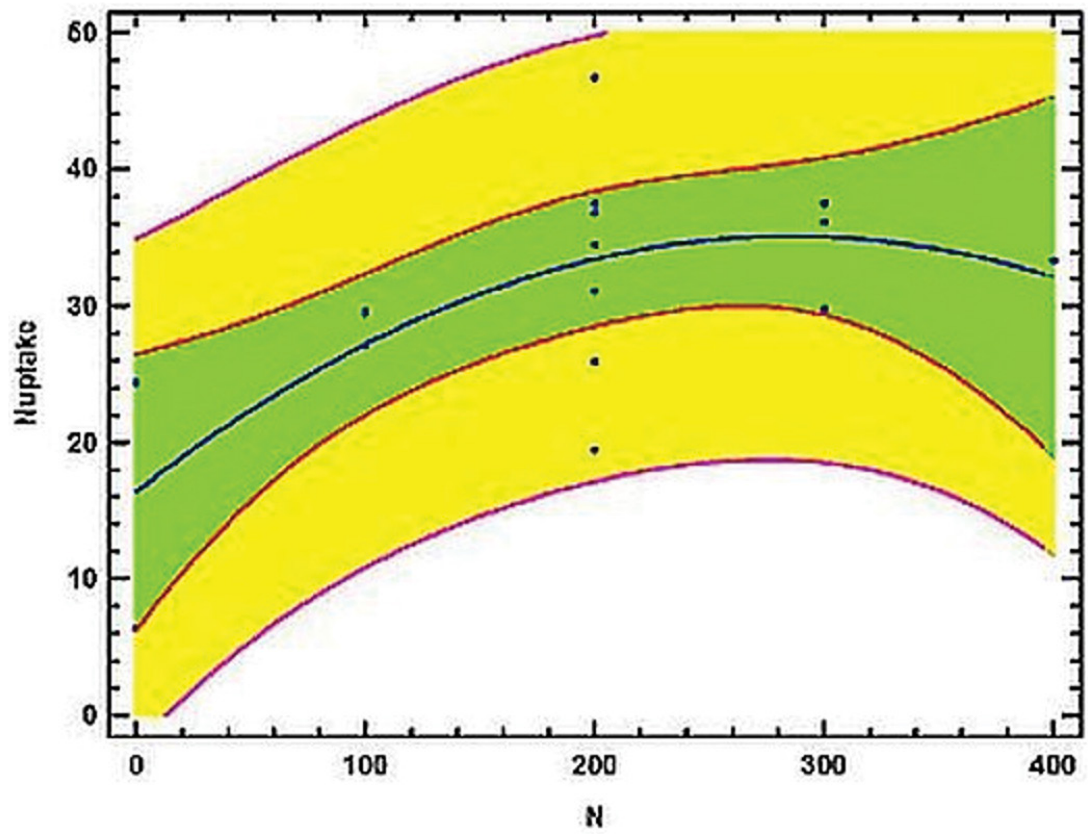

Figure 2. Nitrogen export N_{max} = 285.64 mg/pot

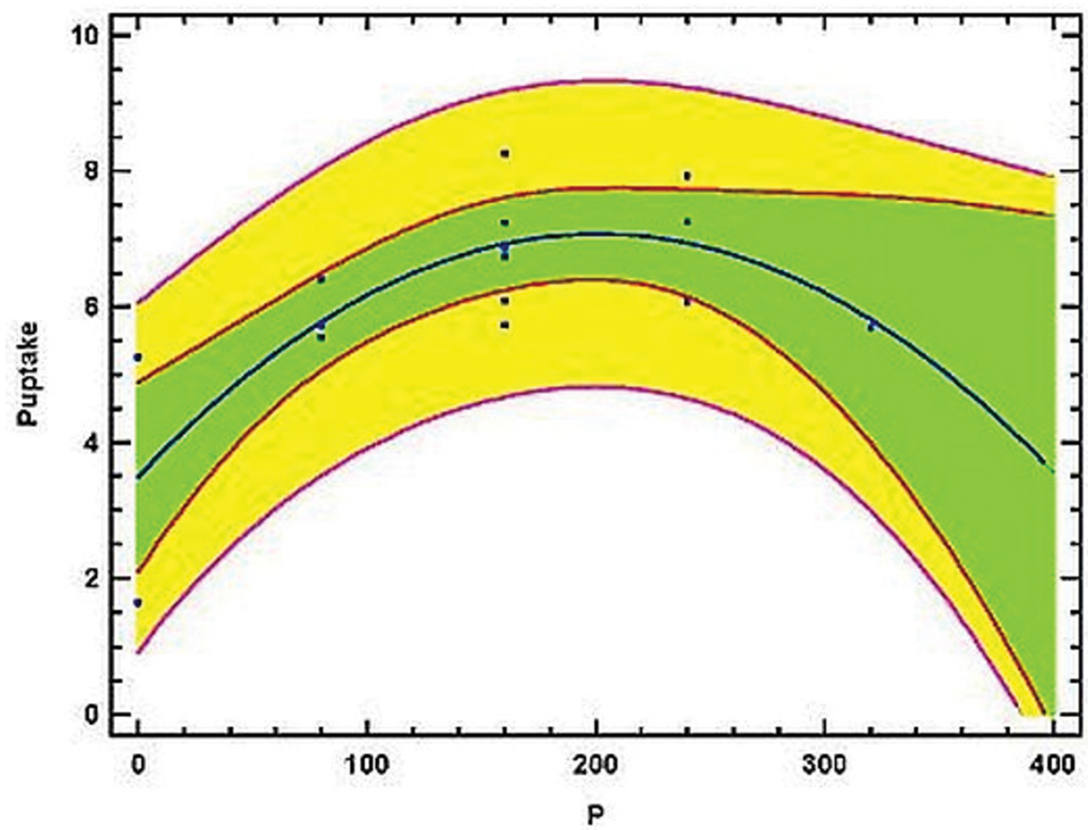

Figure 2. Phosphorus export - P_{max} = 200.96 mg/pot

Table 5. Average export of N for variants 4 to 10 with N norm 200mg/pot, P, K, and Si with biomass of sunflower (kg/ha)

norms of N	average export of N	norms of P	average export of P	norms of K	average export of K	norms of Si	average export of Si
0	153.6	0	52.6	0	234.5	0	5.8
100	244.0	80	58.9	70	229.8	400	5.4
200	287.4	160	68.7	140	280.4	800	4.2
300	331.4	240	70.9	210	298.8	1200	8.4
400	344.8	320	56.9	280	290.7	2000	13.4

CONCLUSIONS

The largest biomass was reported in variants V4 ($N_{200}P_0K_{140}Si_{800}$), V8 ($N_{200}P_{160}K_{140}Si_0$) and V12 ($N_{300}P_{80}K_{210}Si_{400}$), so these combinations of fertilizers were optimal for plant nutrition.

Significant changes occurred in the amount of nutrients absorbed by the biomass of sunflower plants after the applied fertilization. Highest was the content of total N in the dry biomass of plants varying from 0.89 in the control to 3.22% in variant V8 ($N_{200}P_{160}K_{140}Si_0$). The other macronutrients were influenced by the applied fertilization rates but their concentrations varied in a narrower range. A direct relationship between increasing the accumulation of Si in plants with increasing the imported Si level was not established.

Based on the obtained dry biomass and the content of N, P, K, Si, Ca, and Mg in it, the export from the soil of the studied elements was calculated. The changes in the export of the studied macronutrients followed the changes in the contents of the respective elements in the dry biomass, according to the variants. Increasing the fertilization rates increased not only the content but also the export of N, P, and Si. Regarding potassium, this tendency was less pronounced. The export of nitrogen was the highest in the variants with norms N_{200} and N_{300}, as well as in comparison with the export of all other studied elements.

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REFERENCES

Ahmad, I., Jadoon, S., Said, A., Adnan, M., Mohammad, F., Munsif, F. (2017) Response of sunflower varieties to NPK fertilization. Pure and Applied Biology, 6 (1), 272-277. DOI: http://dx.doi.org/10.19045/bspab.2017.60024

Arinushkina, E. (1962) Guide for chemical analysis of soils. Moscow: Moscow State University Press. (in Russian)

Atanassova, E. (2005) Changes in biochemical quality indicators in vegetable crops under the influence of different norms and sources of nitrogen fertilization. Dissertation, ISSAPP "N. Poushkarov", Sofia, 160 pp. (in Bulgarian)

Berthelsen, S., Korndörfer G.H. (2005) Methods for silicon analysis in soil, plant and fertilizers. In: Proceedings of the Third International Conference on Silicon in Agriculture, Brazil, 85-91.

Bremner, J. (1965b) Inorganic forms of Nitrogen. In: Black C.A. et al., eds. Methods of Soil Analysis, Part 2, Agronomy Monograph No. 9, ASA and SSSA, Madison, 1179-1237.

Bremner, J. (1965a) Organic Nitrogen in Soils, In: Bartholomew, W. V., Clark F. E., eds. Soil Nitrogen, 10, 93-149. DOI: https://doi.org/10.2134/agronmonogr10.c3

Coskun, D., Deshmukh, R., Sonah, H., Menzies, J., Reynolds, O., Ma, J., Kronzucker, H., Belanger, R. (2019) The controversies of silicon's role in plant biology. New Phytologist, 221 (1), 67-85. DOI: https://doi.org/10.1111/nph.15343

De Melo Peixoto, M., Flores, R., Do Couto, C., Pacheco, H., De Mello Prado, R., Pereira Souza-Junior, J., Castro-Netto, J., Graciano-Ribeiro, D. (2022) Silicon application increases biomass yield in sunflower by improving the photosynthesizing Leaf Area. Silicon, 14, 275–280. DOI: https://doi.org/10.1007/s12633-020-00818-2

Detmann, K., Araujo, W., Martins, S., Sanglard, L., Reis, J., Detmann, E., Rodrigues, F., Nunes-Nesi, A., Ferine, A., Damatto, F. (2012) Silicon nutrition increases grain yield, which, in turn, exerts a feed-forward stimulation of photosynthetic rates via enhanced mesophyll conductance and alters primary metabolism in rice. New Phytologist, 196 (3), 752-762.
DOI: https://doi.org/10.1111/j.1469-8137.2012.04299.x

Encheva, J., Georgiev, G., Nenova, N., Valkova, D. (2015) Developing of sunflower lines and hybrids resistant to herbicides. Plant Sciences, 52 (4), 3-11. (in Bulgarian)

Epstein, E., Bloom, A. (2008) Mineral nutrition of plants: Principles and perspectives. 2nd Edition, Sunderland: Sinauer Associations.

Georgiev, G., Peevska, P., Shindrova, P., Penchev, E. (2012) Productive potential and resistance to downy mildew and Orobanche of experimental sunflower hybrids developed by using line 217 as a mother component. Field Crops Studies, 8 (2), 283-290. (in Bulgarian)

Garbouchev I. (1974) Maintaining and improving soil fertility. Sofia: Zemizdat. (in Bulgarian).

Hara, T., Sonoda, Y. (1979) The role of macronutrients for cabbage head formation (preliminary report). Soil Science and Plant Nutrition, 25 (1), 103-111.
DOI: https://doi.org/10.1080/00380768.1979.10433150

Hassan, F., Kaleem, S. (2014) Influence of seasonal disparity on NPK uptake in sunflower. The Journal of Animal & Plant Sciences, 24 (1), 190-196.

IUSS Working Group WRB. (2015) World reference base for soil resources 2014, update 2015, International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports, 106. Rome: FAO.

Ivanov, P. (1984) New Acetate-lactate Method for Determination of Available Forms of P and K in Soil. Soil Science and Agrochemistry, 19 (4), 88-98. (in Bulgarian)

Koinov, V. (1987) Correlation between the soils of Bulgaria and the soils distinguished by the major soil classification systems in the world. Soil Science, Agrochemistry and Plant Protection, 22 (5), 5-13. (in Bulgarian)

Kołota, E., Chohura, P. (2015) Control of head size and nutritional value of cabbage by plant population and nitrogen fertilization. Acta Scientiarum Polonorum - Hortorum Cultus, 14 (2), 75-85.

Kononova, M.M. (1963) Soil organic matter. Its nature, properties and methods of study. Moscow: Academy of Science of the USSR.

Li, Z., Song, Z., Yan, Z., Hao, Q., Song, A., Liu, L., Yang, X., Xia, S., Liang, Y. (2018) Silicon enhancement of estimated plant biomass carbon accumulation under abiotic and biotic stresses. A meta-analysis. Agronomy for Sustainable Development, 38, 26.
DOI: https://doi.org/10.1007/s13593-018-0496-4

Mitova, I., Dinev, N. (2013) Plant uptake and export of nutritional elements by cabbage yield. Soil Science Agrochemistry and Ecology, 46 (4), 91-95. (in Bulgarian)

Nankova, M., Tonev, T. (2004) Concentration of main macroelements and their distribution in plants during development stages according to previous crop and direct nitrogen fertilization of sunflower; I. Concentration and re-distribution of nitrogen. Field Crops Studies, 1 (3), 439-447. (in Bulgarian)

Nenova, L., Mitova, V. (2018) Content and uptake of macroelements with the production of cabbage. Bulgarian Journal of Soil Science, Agrochemistry and Ecology, 52 (3), 34-42. (in Bulgarian)

Nikolova, M. (2010) Potassium – decisive nutrient for yield and quality. Horgen, Switzerland: International Potash Institute.

Pavlovic, J., Kostic, L., Bosnic, P., Kirkby, E., Nikolic, M. (2021) Interactions of silicon with essential and beneficial elements in plants. Frontiers in Plant Science, 12, 697592.
DOI: https://doi.org/10.3389/fpls.2021.697592

Raikov L., Ganev, S. (1972) Total chemical composition. In: Chemical composition of soils in Bulgaria. Sofia: Bulgarian Academy of Science. (in Bulgarian)

Sadovski A. (2020) An introduction to mathematical agronomy: Theoretical and experimental bases. LAP Lambert Academic Publishing.

Saldzhiev, I. (2004) Influence of the main agrotechnical factors on the yield of sunflower. Plant Science, 41 (6), 536-540. (In Bulgarian)

Slavov, D., Koutev, V., Kozelov, L., Yanchev, I. (2010) Achieving nutrient balance at farm level: a tool for managing sustainable agriculture. A practical guide. Sofia: Ambrosia. (in Bulgarian)

Tonev, T. (2005) Seed oil content depending on previous-year and direct applied nitrogen rates in sunflower. Research Communication of U.S.B. branch Dobrich, 7, 7-12. (in Bulgarian)

Valkova, D., Penchev, E., Encheva, V. (2017) Hybridization between cultivated sunflower and wild species *Helianthus praecox* Engelm. & Gray. Bulgarian Journal of Crop Science, 54 (4), 9-13. (in Bulgarian)

Valkova, D., Jecheva, K., Kiryakov, I. (2022) Response of sunflower genotypes to mid-stalk rot caused by *Sclerotinia sclerotiorum*. Bulgarian Journal of Agricultural Science, 28 (1), 110–116.

Vasileva, V., Ilieva, A. (2017) Some physiological parameters in mixtures of cocksfoot and tall fescue with subterranean clover. Bulgarian Journal of Agricultural Science, 23 (1), 71–75.

Yankov, P., Drumeva, M. (2012) Investigation on the effect of some leaf fertilization products on the development, productivity and quality of sunflower. I. Morphology and productivity. Agricultural Sciences, 4 (11), 81-88. (in Bulgarian)