Bulgarian Journal of Agricultural Science, 30 (No 6) 2024, 966–973

Export of macroelements with sunflower biomass in dependence of fertilizer types and norms

Iliyana Gerasimova*, Ana Katsarova and Zdravka Petkova

Agricultural Academy, ISSAPP "N. Poushkarov", 1331Sofia, Bulgaria
**Corresponding author:* ilianich_ilieva@abv.bg

Abstract

Gerasimova, I., Katsarova, A. & Petkova, Z. (2024). Export of macroelements with sunflower biomass in dependence of fertilizer types and norms. *Bulg. J. Agric. Sci., 30*(6), 966–973

The aim of the study was to evaluate the effect of different rates and combinations of nitrogen, phosphorus, potassium, and silicon fertilizers in Alluvial-meadow soil and their impact on the export of basic macronutrients with sunflower biomass in a pot experiment. The test culture was an early to medium-early hybrid Sunflower (*Helianthus annuus* L.) – Sumiko HTS. The experiment includes 16 variants of fertilization with 3 replications. Data are obtained on the yield of fresh and absolutely dry biomass from the above-ground part and the content of N, P, K, Si, Ca, and Mg in the resulting dry biomass from plants. According to the experimental data obtained, the content and uptake of the examined macroelements with the sunflower biomass are significantly influenced by the imported rates and combinations of fertilizers. The highest is the uptake of nitrogen in the variants with the following norms: N_{200}, N_{300}, and N_{400}. N uptake is the highest also in comparison with all other examined elements. It is established that the changes in the macroelements uptake significantly follow changes in the quantities of the relevant elements in dry biomass in the variants of the experiment. With an increase in fertilization rates, not only the content of N, P, and Si is increased, but also the uptakes with sunflower biomass. This trend with potassium is expressed to a lesser extent.

Keywords: fertilization rates; nitrogen; phosphorus; potassium; silicon; uptake

Introduction

Sunflower is a valuable oilseed crop and it is grown all over the world. In Bulgaria new hybrids and promising sunflower lines, distinguished by a number of their characteristics and physiological requirements, are constantly entering the practice. Growing sunflower seeds severely depletes the soil. The creation of conditions for a balanced diet of sunflower is achieved by appropriate fertilization, based on an analysis of the content of the main mineral substances in the soil. It is necessary to achieve optimization of the norms of different types of fertilizers in accordance with both the physiological requirements in the successive stages of sunflower development and the reserves of nutrients in the soil. In terms of nutrient supply, hybrids with the highest requirements are followed by varieties with high oil content, while those with low oil content are the least demanding (Nikolova, 2010). Many of the studies with sunflowers were conducted in DAI – General Toshevo and were mainly dedicated to the selection of this crop (Valkova et al., 2017; Encheva et al., 2015; Tonev, 2005; Georgiev et al., 2012) and on the productive potential and resistance to powdery mildew and blue bunting of experimental sunflower hybrids (Valkova et al., 2022). Other research was related to establishing the appropriate parameters of seeding rate, mineral, and bacterial fertilization, and use of biostimulants (Yankov and Drumeva, 2012; Nankova and Tonev, 2004).

The nutrient requirements for yield formation depend both on the specific soil and climatic conditions of the area and on several other factors. The importance of fertilization is paramount (Ahmadet al., 2017). Sunflower responds well to nitrogen fertilization, excess nitrogen lowers oil content and lowers plant resistance to disease. Appropriately balanced phosphorus and potassium fertilization increase yield and oil content. The potassium requirements of sunflower are high – 7–11 kg per 100 kg of seed, i.e. 5–2 times more than nitrogen and 4–5 times more than phosphorus. Potassium increases the absolute weight and fat content of the seeds. Experiments conducted in our country 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 a unit of production, and their balance in the soil for different soil conditions (Nenova and Mitova, 2018; Mitova and Dinev, 2012). Establishing nutrient balance is an effective method for assessing nutrient use by crops (Koutev 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 almost non-existent. Sunflower forms twice as many roots, which contain 1.5 times more nitrogen and 5 times more potassium, compared to other spring crops (Nikolova, 2010; Saldzhiev, 2004). This crop is also distinguished by its exceptional micronutrient requirements. Very important is also the growth of the stem, which must 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 (pathogens and pests) and abiotic (e.g., drought, salinity, heavy metals, UV irradiation, nutrient imbalances) 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 export of macronutrients (N, P, K, Si, Ca, and Mg) with biomass of sunflower (*Helianthus annuus* L.), under the influence of increasing levels of fertilization with nitrogen, phosphorus, potassium, and silicon under the conditions of a growing experiment on Alluvial-meadow soil.

Materials and Methods

In the spring of 21.04.2021, a vegetation fertilizer trial with a test crop of an early to mid-early hybrid of sunflower (*Helianthus annuus* L.) – Sumiko HTS of Syngenta was set up and established. 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 (FAO, 2015). It is characterized by a neutral soil reaction in the plowing horizon (pH_{H2O} 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/100 g soil and the quantity of exchangeable Si is 285 mg/100 g 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/plant were added to the experimental containers of 3 kg capacity, as presented in Table 1. Five sunflower seeds were sown, leaving 3 plants in each pot at a later stage (on the 57th day 2 plants from each pot were cut). Plants were grown in the conditions of natural light – about 15/9 h day/night photoperiod, 15–35°C temperature, and 60% water-holding capacity).

On the 67th day of vegetation in the budding phase, the plants were harvested, weighed, and prepared for chemical analysis. The content (% a. b.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, and Si (diatomic soil which represents 89–95% silica in amorphous form).

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

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

The following soil analyses were performed before and after the vegetation experiments: pH – potentiometric in H_2O and KCl (Arinushkina, 1962); total and mineral nitrogen content – Bremner and Kinney method (Bremner,1965a, b); 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. 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 Figure 1, the role of applied fertilizers on the amount of fresh and dry weight of sunflower plants is highlighted. It can be seen quite clearly that the dry weight of the total biomass obtained from 1 plant per pot varies in proportion to the corresponding fresh weight in the different variants.

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 ($N_{300}P_{80}K_{70}Si_{1200}$, the differences between them were insignificant. 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

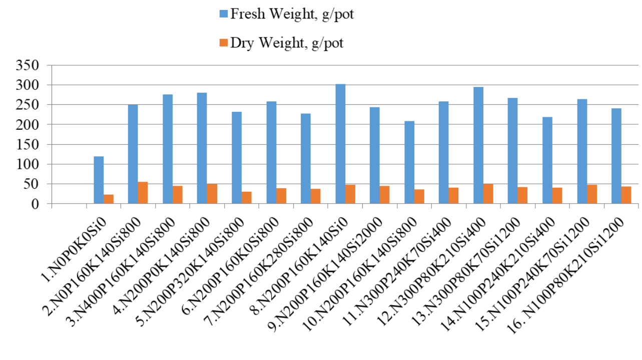

Fig. 1. Fresh and dry weights of sunflower plants at harvest of the experiment on the 67th day after sowing

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 & Kaleem, 2014).

From the data presented in Tables 2 and 3, 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.

Under the influence of mineral nutrition, significant changes in the amount of nutrients absorbed by the biomass of sunflower plants occur (Table 4). 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 (Hara and Sonoda, 1979); Atanassova, 2005; Kolota and Chohura, 2015; Nenova and Mitova, 2018; Vasileva and Ilieva, 2017). No such trend was found in the current experiment.

Table 2. Influence of fertilization rate and fertilizer combinations on the yield of fresh biomass from the aboveground part of sunflower plants (One-way ANOVA analysis)

Fresh weight of Sunflower plants, g/per pot				
Variant	57^{th} day		67^{th} day	
1. $N_0P_0K_0Si_0$	36.67	c	47.00	a
2. $N_0P_{160}K_{140}Si_{800}$	26.67	a	83.33	bcdef
3. $N_{400}P_{160}K_{140}Si_{800}$	51.67	de	92.00	cdef
4. $N_{200}P_0K_{140}Si_{800}$	66.67	i	93.67	def
5. $N_{200}P_{320}K_{140}Si_{800}$	63.33	h	77.33	bcde
6. $N_{200}P_{160}K_0Si_{800}$	51.67	de	86.00	bcdef
7. $N_{200}P_{160}K_{280}Si_{800}$	58.33	g	75.67	bcd
8. $N_{200}P_{160}K_{140}Si_0$	25.00	a	100.33	f
9. $N_{200}P_{160}K_{140}Si_{2000}$	55.00	f	81.00	bcdef
10. $N_{200}P_{160}K_{140}Si_{800}$	66.67	i	69.33	b
11. $N_{300}P_{240}K_{70}Si_{400}$	50.00	d	86.00	bcdef
12. $N_{300}P_{80}K_{210}Si_{400}$	60.00	g	98.00	ef
13. $N_{300}P_{80}K_{70}Si_{1200}$	33.33	b	89.00	bcdef
14. $N_{100}P_{240}K_{210}Si_{400}$	53.33	ef	72.67	bc
15. $N_{100}P_{240}K_{70}Si_{1200}$	36.67	c	87.67	bcdef
16. $N_{100}P_{80}K_{210}Si_{1200}$	36.67	c	80.33	bcdef
Average	48.23		82.45	
Std. deviation	13.590		16.32	
Std. error	1.96		2.36	
LSD≥95%	2.200		20.97	

Table 3. Influence of fertilization rate and fertilizer combinations on the yield of dry biomass from the aboveground part of sunflower plants

Weight of sunflower plants (g/pot) on the 67^{th} day	
Variants	Dry biomass
1. $N_0P_0K_0Si_0$	9.25 a
2. $N_0P_{160}K_{140}Si_{800}$	13.32 bcde
3. $N_{400}P_{160}K_{140}Si_{800}$	15.20 cdef
4. $N_{200}P_0K_{140}Si_{800}$	16.71 ef
5. $N_{200}P_{320}K_{140}Si_{800}$	10.03 ab
6. $N_{200}P_{160}K_0Si_{800}$	13.16 bcde
7. $N_{200}P_{160}K_{280}Si_{800}$	12.76 abcd
8. $N_{200}P_{160}K_{140}Si_0$	16.11 def
9. $N_{200}P_{160}K_{140}Si_{2000}$	15.29 cdef
10. $N_{200}P_{160}K_{140}Si_{800}$	12.26 abc
11. $N_{300}P_{240}K_{70}Si_{400}$	13.44 bcde
12. $N_{300}P_{80}K_{210}Si_{400}$	16.34 def
13. $N_{300}P_{80}K_{70}Si_{1200}$	13.94 cde
14. $N_{100}P_{240}K_{210}Si_{400}$	13,77 cde
15. $N_{100}P_{240}K_{70}Si_{1200}$	16.05 def
16. $N_{100}P_{80}K_{210}Si_{1200}$	14.69 cdef
Average	14.12
St. deviation	2.98

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 ($N_{200}P_{320}K_{140}Si_{800}$) variant, which contains the high estrate of triple superphosphate. 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, 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 (Figure 1) and the content of N, P, K, Si, Ca, and Mg in it (Table 4), the export from the soil of the studied elements was determined.

Table 4. Content of total N, P, K, Si, Ca, and Mg in sunflower biomass (in% of absolutely dry weight) by variants (pot experiment on Alluvial-meadow soil, 2021)

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	2.1	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

Table 5. Export of total N, P, K, Si, Ca, and Mg with biomass of sunflower ($kg.da^{-1}$) by variants (pot experiment on Alluvial-meadow soil, 2021)

Variants	N	P	K	Si	Ca	Mg
1.$N_0P_0K_0Si_0$	6.33	1.64	9.89	0.08	0.92	2.35
2.$N_0P_{160}K_{140}Si_{800}$	24.40	6.92	30.17	0.44	23.41	8.90
3.$N_{400}P_{160}K_{140}Si_{800}$	33.38	7.25	29.00	0.42	27.63	6.43
4.$N_{200}P_0K_{140}Si_{800}$	37.44	5.26	35.93	0.52	30.52	9.92
5.$N_{200}P_{320}K_{140}Si_{800}$	19.41	5.69	19.04	0.32	18.23	5.33
6.$N_{200}P_{160}K_0Si_{800}$	36.83	6.87	23.45	0.44	25.70	8.88
7.$N_{200}P_{160}K_{280}Si_{800}$	25.96	6.09	29.07	0.37	21.94	6.89
8.$N_{200}P_{160}K_{140}Si_0$	46.69	8.26	34.51	0.58	33.35	11.02
9.$N_{200}P_{160}K_{140}Si_{2000}$	34.54	6.74	25.59	1.34	26.42	6.88
10.$N_{200}P_{160}K_{140}Si_{800}$	31.11	5.74	22.06	0.41	23.17	7.83
11.$N_{300}P_{240}K_{70}Si_{400}$	29.76	7.26	22.98	0.57	26.25	8.71
12.$N_{300}P_{80}K_{210}Si_{400}$	36.16	5.73	26.76	0.68	24.40	5.88
13.$N_{300}P_{80}K_{70}Si_{1200}$	37.51	6.40	24.84	1.17	23.71	5.52
14.$N_{100}P_{240}K_{210}Si_{400}$	27.14	6.07	28.01	0.36	20.70	6.82
15.$N_{100}P_{240}K_{70}Si_{1200}$	29.46	7.94	29.17	1.19	25.56	7.94
16. $N_{100}P_{80}K_{210}Si_{1200}$	29.62	5.55	29.88	0.15	23.40	6.21

From the obtained results it is evident that the changes in the exports of the studied macroelements significantly follow the changes in the quantities of the respective elements in the dry biomass according to the variants of the experiment (Table 5). As the fertilization rates increased, not only the content but also the exports of N, P, K, and Si was increased.

Figures 2 to 5 show the regression curves of the exports of N, P, K, and Si depending on the imported quantities of the respective elements, presented as polynomials of the second degree.

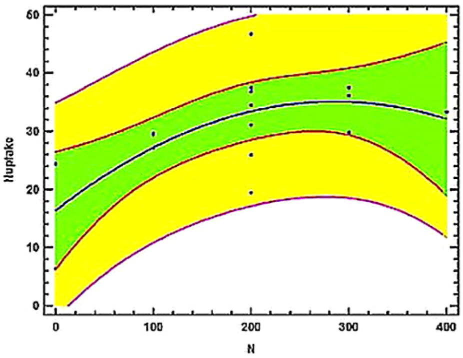

Fig. 2. Nitrogen export

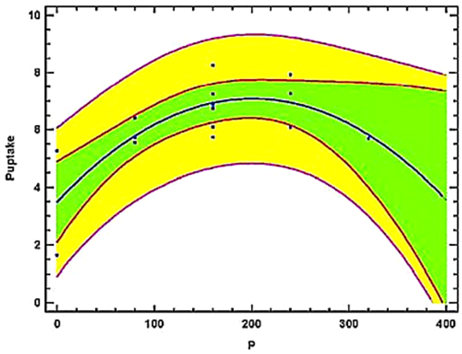

Fig. 3. Phosphorus export

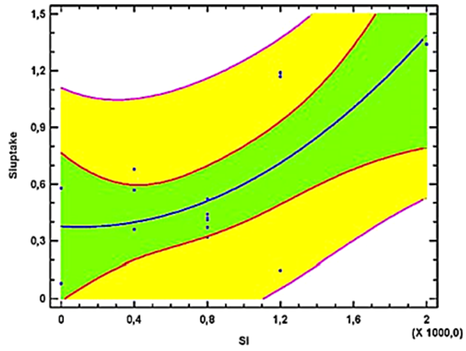

Fig. 4. Potassium export

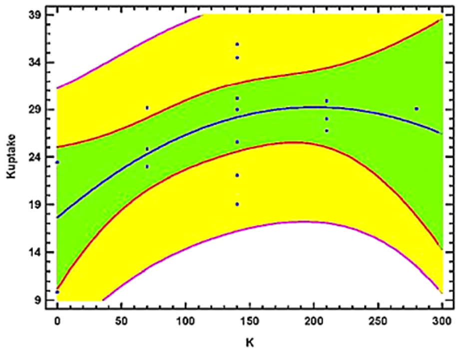

Fig. 5. Silicon export

Table 6 is compiled by conversion following the imported fertilization rates and the average values of exports with the relevant macronutrients, the patterns established for N, P, K, and Si are very clear. From this table, we can summarize that the difference between the imported quantities of active substances with fertilizers and the export with the obtained biomass is significant. This means that in the variants with high fertilization rates, large amounts of nutrients are available, which will be able to ensure the nutrition of sunflower even after the „R4" phase until the end of the growing period.

Table 6. Average export of N, P, K, and Si with biomass of sunflower (kg.da^{-1}) by variants and rates of fertilization (kg.da^{-1})

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	15.36	0	5.26	0	23.45	0	0.58
30	24.40	24	5.89	21	22.98	120	0.54
60	28.74	48	6.87	42	28.04	240	0.42
90	33.14	72	7.09	63	29.88	360	0.84
120	34.48	96	5.69	84	29.07	600	1.34

Conclusions

As a result of the one-way variance analysis, the data obtained for the amount of plant biomass on the 57th and 67th day established the leading role of the nitrogen rate of 200 mg per pot and silicon at 800 mg per pot (the proven difference between the options is high confidence level $P \leq 0.001$).

The largest biomass was reported in variant V4 ($N_{200}P_0K_{140}Si_{800}$) on the 57th day from the beginning of the experiment. As the vegetation progresses on day 67, plant development in variants V4 ($N_{200}P_0K_{140}Si_{800}$) and V12 ($N_{300}P_{80}K_{210}Si_{400}$) is optimal.

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 largely follow the changes in the contents of the respective elements in the dry biomass according to the variants of the experiment. Increasing the rates of fertilization increases not only the content but also the export of N, P, and Si. In potassium, this tendency is less pronounced. The export of nitrogen is the highest in the variants with norms N_{200}, N_{300}, and N_{400}, as well as in comparison with the export of all other studied elements.

The content of Ca is very low – 0.13% in the control variant, but is significantly higher in the fertilizer variants from 1.66 to 2.30% and it cannot be said categorically that higher fertilization rates lead to higher accumulation of Ca in sunflower plants. The change in the content of Mg varies similarly. Its amount in the control variant is slightly higher than that of Ca – 0.33% Mg, in the fertilized variants it is between 0.44 and 0.76%. Applied fertilization has a significantly lower effect on the accumulation of Mg in sunflower plants.

Acknowledgments

We express gratitude to Prof. Alexander Sadovski for his assistance in the statistical analysis of experimental data. The publication is a result of the work on Project KP-06 – N 36/15 of 17.12.2019, financed by the Bulgarian Fund "Scientific Research".

References

Ahmad, I., Jadoon, S.A., Said, A., Adnan, M., Mohammad, F. & Munsif, F. (2017). Response of sunflower varieties to NPK fertilization. *Pure and Applied Biology (PAB), 6*(1), 272-277.

Arinushkina, E.(1962). Guide for chemical analysis of soils. *Moscow: Moscow State University Press.* Moscow, 490 (Ru).

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 (Bg).

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. M. (1965a). Organic Nitrogen in Soils. *Agron. J., 10*, 93-149.

Bremner, J.M. (1965b). Inorganic forms of Nitrogen. *In:* C.A. Black et al., /Eds./. *Methods of Soil Analyses. Part 2: Chemical and Microbiological Properties. № 9, Agronomy.* American Society of Agronomy Inc. Madison, Wisconsin, USA, 1179-1237.

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.

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, LII*(4), 3-11 (Bg).

Epstein, E. & Bloom, A. J. (2008). Mineral Nutrition of Plants: Principles and Perspectives, *2nd Edn. Sunderland: Sinauer Associations,* 67–85. DOI: 10.1111/nph.15343.

FAO (2015). World reference base for soil resources 2014. FAO, Rome, 203. http://www.fao.org/3/i3794en/I3794en.pdf.

Garbouchev, I. (1974). Maintaining and improving soil fertility. Sofia: *Zemizdat* (Bg).

Georgiev, G., Peevska, P., Shindrova, P. & Penchev, E. (2012). Productive possibilities and resistance of manna and blue wrist of experimental sunflower hybrids obtained with the participation of line 217 as a maternal component. *Field Crops Studies, 8*(2), 283-290 (Bg).

Hara, T. & Sonoda, Y. (1979). The role of macro nutrients for cabbage head formation. I. Contribution to cabbage head formation of nitrogen phosphorus or potassium supplied at different growth stages. *Soil Science and Plant Nutrition, 25*(1), 113-120.

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

Ivanov, P. (1986). New Acetate-lactate Method for Determination of Available Forms of P and K in Soil. *Soil Science and Agro-*

chemistry, 19(4), 88-98 (Bg).

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 (Bg).

Kołota, E. & Chohura, P. (2015). Control of head size and nutritional value of cabbage by plant population and nitrogen fertilization. *Acta Sci. Pol. 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, 314.*(Ru).

Mitova, I. & Dinev, N. (2012). Plant uptake and export of nutritional elements by cabbage yield. *Soil Science, Agrochemistry and Ecology*, *XLVI*(4), 91-95 (Bg).

Koutev, V., Slavov, D., Kozelov, L. &Yanchev, I. (2010). Achieving Nutrient Balance At Farm Level: A Tool For Managing Sustainable Agriculture, 95. *Ambrosia Ltd.* ISBN 978-954-90671-9-4 (Bg).

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), 1-19. https://doi.org/10.1007/s13593-018-0496-4.

Nankova, M & Tonev, T. (2004). Concentration of the main macroelements and their distribution in plants by phases of development depending on the previous and direct nitrogen fertilization of sunflower; I. Nitrogen concentration and redistribution. *Field Crops Studies, 1*(3), 439-447 (Bg).

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

Nikolova, M. (2010). Potassium – a nutrient for yield and quality. International Potash Institute, Horgen-Switzerland, 50-52 (Bg).

Pavlovic, J., Kostic, L., Bosnic, P., Kirkby, E. A. & Nikolic, M. (2021). Interactions of silicon with essential and beneficial elements in plants. *Frontiers in Plant Science, 12,* 1224.

Peixoto, M. M., Flores, R. A., Couto, C. A., Domingos, H., Pacheco, N., Prado, R. M., Souza-Junior, J. P., Castro-Netto, J. A. & Ribeiro, D.G. (2022). Silicon Application Increases Biomass Yield in Sunflower by Improving the Photosynthesizing Leaf Area. *Silicon, 14,* 275–280.

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

Sadovski, A. (2020). An Introduction to Mathematical Agronomy: Theoretical and Experimental bases. *LAP Lambert Academic Publishing*. ISBN 978-620-2-51889-5, 284 (Bg).

Saldzhiev, I. (2004). Influence of fertilization and seeding density on the yield of sunflower variety Peredovik. *Field Crops Studies, Vol. 1-3*, 434-438 (Bg).

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 (Bg). http://geocities.com/usb_dobrich/001.pdf.

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(Bg).

Valkova, D., Jecheva, K. & Kiryakov, I. (2022). Response of sunflower genotypes to mid-stalk rot caused by *Sclerotinia sclerotiorum*. *Bulg. J. Agric. Sci., 28*(1), 110–116 (Bg).

Vasileva, V. & Ilieva, A.(2017). Some physiological parameters in mixtures of cocksfoot and tall fescue with subterranean clover. *Bulg. J. Agric. Sci*., *23*(1), 71–75 (Bg).

Yankov, P. &Drumeva, M. (2012). Study of the influence of some fertilizer products for foliar application on the development, productivity and quality of sunflower. I. Morphology and productivity. *Agricultural Sciences*, *IV*(11), 81-88 (Bg).

Received: **October, 05, 2023**; *Approved*: **April, 11, 2024;** *Published:* **December, 2024**