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Analyzing the effects of potassium fertilization on the yield and total N, K_2O and P_2O_5 export of tomato plants

Анализ на ефекта от калиево торене върху добива и износа на общ N, K_2O и P_2O_5 от доматени растения

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ABSTRACT

The tomato (*Solanum lycopersicum*) is a crop that is characterized by considerable nutrient export because of its intensive growth, development, fruiting, and high biomass production. The purpose of this study is to determine how single-dose and split potassium fertilization impact the overall amount of nitrogen, potassium, and phosphorus exported from soils during crop harvest. A field experiment was carried out on Fluvosol (FAO, ISRIC World Soils) with K_2O content of 20.3 mg/100g, P_2O_5 content of 5.8 mg/100g, and mineral N of 19.6 mg/kg. It was found that the biological yield and N, P_2O_5 and K_2O nutrient export are significantly influenced by planting time and potassium fertilization treatments. Higher tomato fruit and biomass yields (61878.9 and 27184.9 kg/ha), along with higher nutrient export rates were observed in mid-early tomato plants. The highest yield and total N, K_2O and P_2O_5 export from the soil was measured at split potassium ($K_{80+80+80}$) fertilization treatment. A positive linear correlation between yield quantity and nutrient export was observed. The biological yield and nutrient export were shown to be significantly impacted by potassium fertilization ($P<0.05$).

Keywords: nutrient uptake, potash, soil balance, sustainable agriculture, *Solanum lycopersicum*

АБСТРАКТ

Доматът (*Solanum lycopersicum*) е култура, която се характеризира със значителен износ на хранителни вещества, заради интензивния си растеж, развитие, плододаване и високо производство на биомаса. Целта на настоящата работа е да се определи влиянието на калиево торене – еднократно и дробно върху износа на общ азот, калий и фосфор от почвите с прибиране на реколтата. Изведен е полски експеримент върху алувиално-ливадна почва – Fluvosol (FAO, ISRIC World Soils), със съдържание на K_2O - 20.3 mg/100g, на P_2O_5 – 5.8 mg/100g и на минерален N - 19.6 mg/kg.

Установено е, че биологичният добив и износът на хранителни вещества са значително повлияни от времето на засаждане и начина на внасяне на калиевата норма. По-висок добив на доматени плодове и биомаса (61878.9 и 27184.9 kg/ha), заедно с по-високи нива на износ на хранителни елементи се наблюдават при средно-ранните домати. Износът на хранителни вещества следва положителна линейна връзка с увеличаването на добива. Най-висок добив и съответно най-висок общ N, K_2O и P_2O_5 са изнесени при трикратно калиево торене ($K_{80+80+80}$). Установена е значителна корелационна зависимост между начина на внасяне на калиевата норма и износа на хранителни вещества с биологичния добив ($P<0.05$).

Ключови думи: калий, почвен баланс, усвояване на хранителни вещества, устойчиво земеделие, *Solanum lycopersicum*

INTRODUCTION

Tomato (*Solanum lycopersicum*) is a major crop of significant nutritional and economic value, ranking as one of the most widely grown and consumed vegetables both domestically and worldwide. Tomato production is positively affected by mineral nutrition and its intensive fertilization requirements are primarily determined by economic demands for high yield and quality, reduced time-to-market factor, and improved soil management with crop rotation (Petrov et al., 1977).

Recent data reveals imbalanced fertilization practices in Bulgaria – vegetable croplands are overfertilized with nitrogen, while phosphorus and potassium are alarmingly neglected (Ministry of Agriculture, Food and Forestry of the Republic of Bulgaria, 2018).

According to researchers, the main reason for underestimating potassium fertilization is the common misconception that most soils are potassium-rich (Jouany et al., 1996; Patra et al., 2017). In Bulgaria, soils are under-fertilized with potassium, resulting in negative potassium balance. For the 1989-2002 period potassium-rich soils have decreased from 71% to 27% and soils with low available K have doubled (Nikolova, 2005), turning potassium into a limiting factor for crop productivity over the longer term.

Tomato plants have specific potassium requirements to maintain intensive growth and development. (Scholberg et al., 2000; Hebbar et al., 2004; Chapagain and Wiesman, 2004). Split potassium fertilization ensures constant high levels of soil potassium, directly available to plants, to satisfy their requirements throughout the vegetation period (Vasileva, 2015). Tomato plants export 114.0-460.0 kgN/ha, 16.0-114.0 kgP/ha and 107.0-715.0 kgK/ha (Hegde, 1997, Roy et al., 2006).

Optimal plant nutrient management is key to achieving enhanced and sustainable agricultural production with a minimal negative effects on the environment. Adequate mineral fertilization could balance the soil potassium supply and plant uptake (Nikolova, 2014; Nikova et al., 2018). Determining the optimal nutrient application rates, timing, form and delivery method are of utmost importance for maintaining and increasing soil fertility and achieving sustainable crop production (4Rs).

The primary motivation for this research study is to optimize the nutrient application rates by examining the nutrient loss processes and by analyzing the influence of single and split potassium fertilization (240 kg/ha) on the export of total N, K_2O and P_2O_5 with the yield and vegetative biomass of tomato plants, and monitoring the soil status at the end of the vegetation.

MATERIALS AND METHODS

A two-year field experiment was conducted on Fluvisol (FAO, ISRIC World Soils). The tomato cultivar used was „Sadeen F1", which has determinate growth habit. Plants were sowed on two dates, on 25-30 April as early, and on 5-15 May, as mid-season production. The soil at the experimental field had low pH (pH_{H_2O}-7.0; pH_{KCl}-6.1) and poor humus content – 1,15% at 0-30 cm soil sample. Mineral nitrogen content was low – 19.6 mg/kg, P_2O_5 was 5.8 mgP/100g, and K_2O was 20.3 mgK/100g.

The objective of this experiment was to evaluate the effect of single and split (2 and 3 doses) of the established potassium rate 240 kg/ha as K_2SO_4, at constant nitrogen (240 kg/ha as NH_4NO_3) and phosphorus (120 kg/ha as triple superphosphate) rates.

The experiment was conducted in field plots (9.6 m^2, 24 plants), arranged in a randomized complete block design with four replications. Four potassium fertilization treatments were tested:

1 – Control (unfertilized); 2 – $N_{240}P_{120}K_{240}$ (single basal dose), applied with phosphorus during field preparation; 3 – $N_{240}P_{120}K_{120+120}$ (split in two) - 50% applied during field preparation and 50% – surface applied during initial crop tillage; 4 – $N_{240}P_{120}K_{80+80+80}$ (split in three) – 33% at field preparation, 33% at initial crop tillage and 33% at fruit size of 2-3 cm.

The phosphorus fertilizer treatment was applied during the field preparation, and the nitrogen fertilizer was applied at three stages – 33% at field preparation, 33% at initial tillage, and 33% at fruit size 2-3 cm.

At the full-ripe stage, tomato fruits from each plot were harvested and the yield was calculated in kg/ha. Fruit and biomass dry matter content was weighted after drying the samples at 65 °C with initial fixation at 105 °C.

Total N, P_2O_5 and K_2O in vegetative biomass (leaves and stems) and in fruits was measured for the representative harvests. K_2O and P_2O_5 content was measured using a spectrophotometer, and total nitrogen was determined via the Kjeldahl method.

Post-harvest soil samples were taken at 0-30 cm depth, pH в H_2O and KCl content was measured potentiometrically, mineral N was measured using Bremner and Keeney method, and P_2O_5 and K_2O – via Egner-Riehm method (in lactate extract).

Statistical analyses (ANOVA) were conducted using StatGraphics Centurion software package.

RESULTS AND DISCUSSION

Nutrient export is directly correlated to the biological yield and is key to calculating the fertilization rates for optimal plant growth, development and fruiting (Hegde, 1997).

Different plant parts uptake and therefore export different amounts of nutrients. According to Ebrahim et al. (2012), the highest amount of nutrients is accumulated by the fruits, and less in leaves and stems. In our research, we observed a similar pattern (Figure 1).

Tomato fruits exported 52-177.5 kgN/ha, 8.9-24.3 kgP/ha and 93.0-253.5 kgK/ha, leaves exported 39.4-121.3 kgN/ha, 4.4-11.5 kgP/ha and 46.5-128.0 kgK/ha, and stems – 16.6-41.5 kgN/ha, 3.6-6.2 kgP/ha and 44.6-85.4 kgK/ha (Figure 1). Comparable results were also obtained by other researchers (Ozores-Hampton et al., 2015; Brewer et al., 2018).

According to Mitova (2014), nutrient export in tomato fruits varies depending on the time of planting, environmental conditions, and cultivar specifics. The current study clearly highlights the effect of the time of planting on fruits yield (47956.2 kg/ha for early and 61878.9 kg/ha mid-early) and vegetative biomass (19175.5 kg/ha early and 27184.9 kg/ ha for mid-early respectively), therefore also impacts the nutrient export of total N, P_2O_5 and K_2O (Table 1).

Optimal soil-climate conditions for tomato plant development, with average daily temperatures of 18-25 °C, are present during mid-season (Zhai et al., 2009). Higher air and soil temperatures enhance nutrient mobilization and ease nutrient accumulation by plants (Harper et al., 1979).

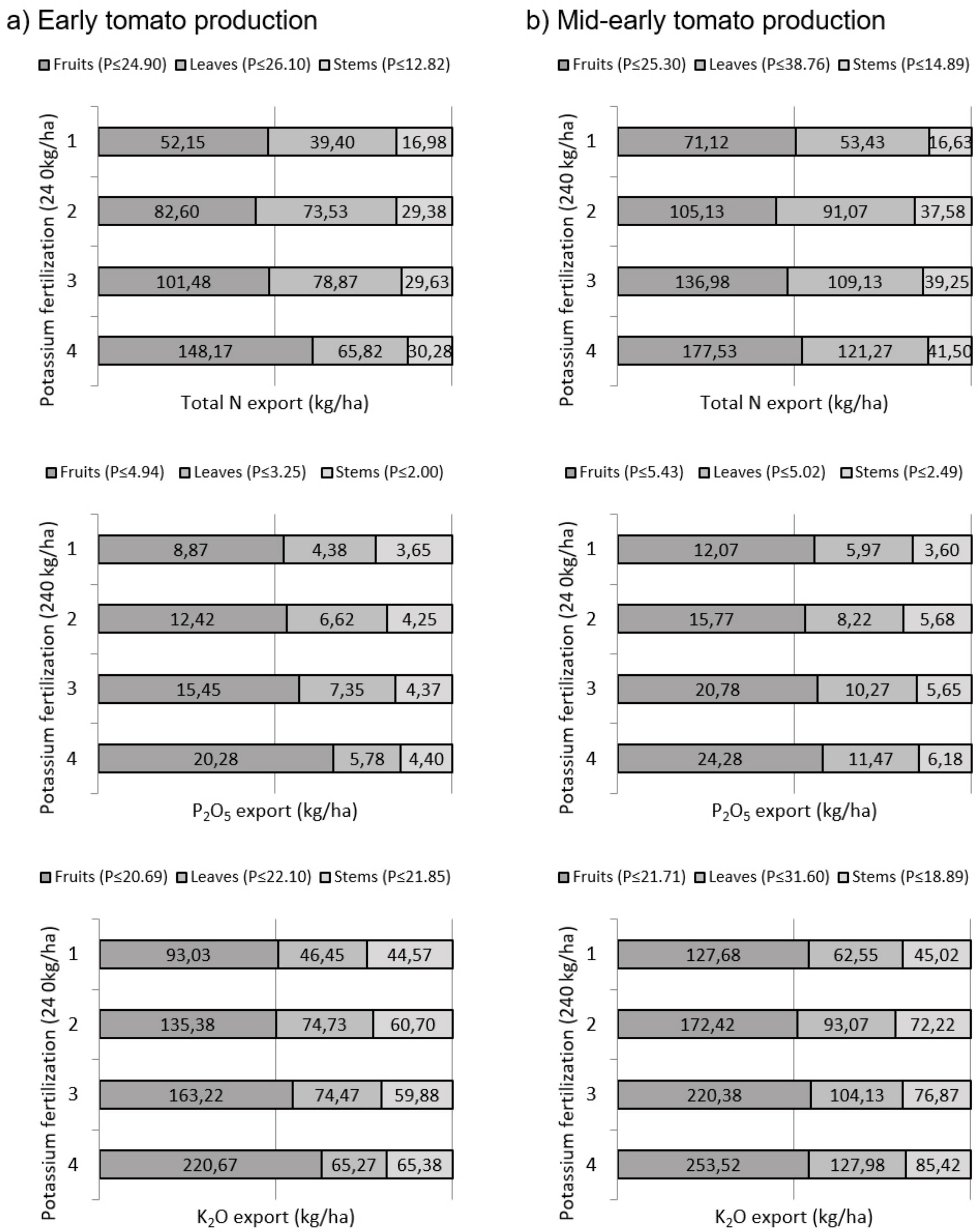
Differences in measured yields (fruit and vegetative biomass) in early and mid-early tomatoes and the exported total N, P_2O_5 and K_2O content were statistically significant, $P<0.05$ (Table 1).

Potassium fertilization positively affects vegetative biomass and increases plant productivity (Boteva and Kostova, 2009). Splitting the potassium fertilization rate in separate applications provides a steady nutrient supply and balanced nutrition. A nutrient management practice that provides adequate K_2O content in soils during the reproductive development stage extends the fruiting period and results in higher total yield.

The highest yield was recorded in plants subjected to split in three doses potassium fertilization 69525.1 kg/ha, which also exported highest total N, P_2O_5 and K_2O content (95% confidence level). Potassium fertilization was a significant ($P<0.05$) factor, effecting total yield and nutrient export (Table 1).

Selection of determinate varieties is directed towards reducing the vegetation period and synchronizing flowering and fruiting, which enables mechanical harvesting. On the other hand, these varieties are characterized by rapid growth and enhanced biomass development (Vicente et al., 2015).

Highest biomass was measured in plants, subjected to split potassium fertilization, but the differences in exported total N, P_2O_5 and K_2O content were not significant (Table 1).



* 1. Control (unfertilized); 2. $N_{240}P_{120}K_{240}$; 3. $N_{240}P_{120}K_{120+120}$; 4. $N_{240}P_{120}K_{80+80+80}$

Figure 1. Nutrient export with tomato fruits, leaves and stems affected by potassium fertilization

Table 1. Nutrient export affected by time of planting and potassium fertilization

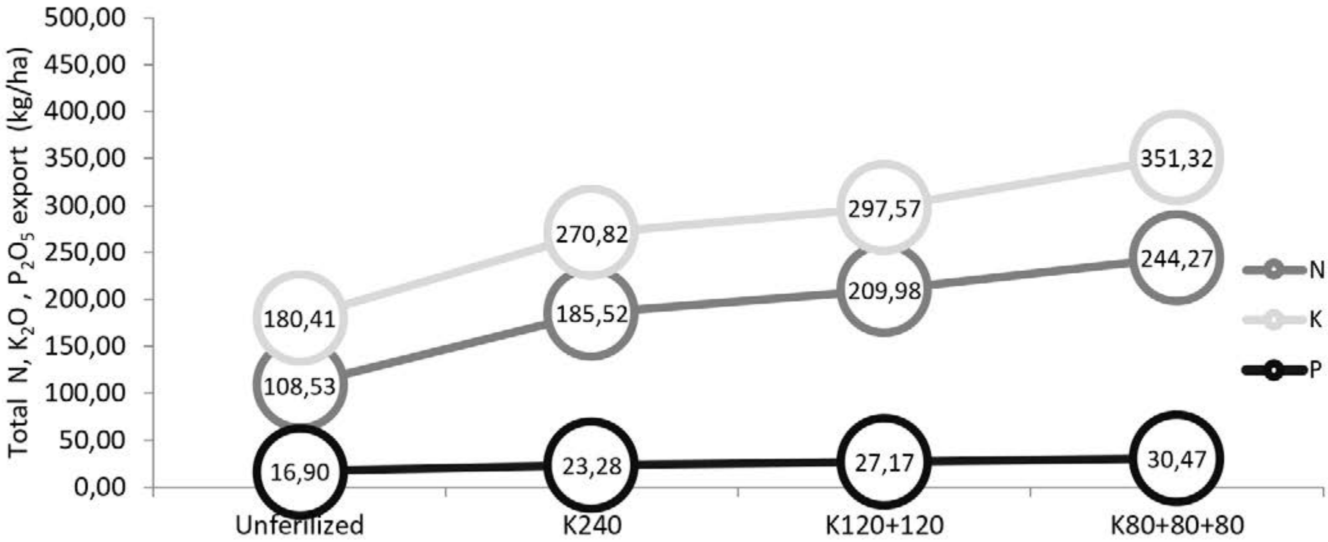
		Fruits								Vegetative biomass							
		Yield		total N		P_2O_5		K_2O		Yield		total N		P_2O_5		K_2O	
		kg/ha															
Time of planting	E	47956.2	a	96.1	a	0.9	a	153.1	a	19175.5	a	91.0	a	10.2	a	122.9	a
	ME	61878.9	b	122.7	b	0.9	a	193.5	b	27184.9	b	127.5	b	14.3	b	166.8	b
LSD≥95%		1528.24		12.16		2.51		10.27		1903.65		17.13		2.55		17.50	
Fertilization	1	37146.9	a	61.6	a	10.5	a	110.4	a	16557.3	a	63.2	a	8.8	a	99.3	a
	2	51583.6	b	93.9	b	14.1	b	153.9	b	24052.1	b	116.6	b	12.4	ab	150.4	b
	3	61414.6	c	119.2	c	18.1	c	191.8	c	25363.5	bc	127.6	b	13.8	b	157.7	b
	4	69525.1	d	162.9	d	22.3	d	237.1	d	26747.9	c	129.4	b	13.9	b	172.0	b
LSD≥95%	2161.26		17.20		3.55		14.53		2692.16		24.23		3.60		24.75		
Effect	A	0.000	*	0.000	*	0.003	*	0.000	*	0.000	*	0.000	*	0.003	*	0.000	*
	B	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.021	*	0.000	*
	AxB	0.013	*	0.774	NS	0.927	NS	0.310	NS	0.003	*	0.171	NS	0.407	NS	0.056	NS

* Means within each column followed by the same letter are not significantly different at *P*<0.05

** Time of planting: E – Early, ME – Mid-early; Fertilization: 1. Control (unfertilized); 2. $N_{240}P_{120}K_{240}$; 3. $N_{240}P_{120}K_{120+120}$; 4. $N_{240}P_{120}K_{80+80+80}$; Effect: A – Time of planting (early and mid-early); B – Fertilization. NS, * – No significant or significant at *P*<0.05

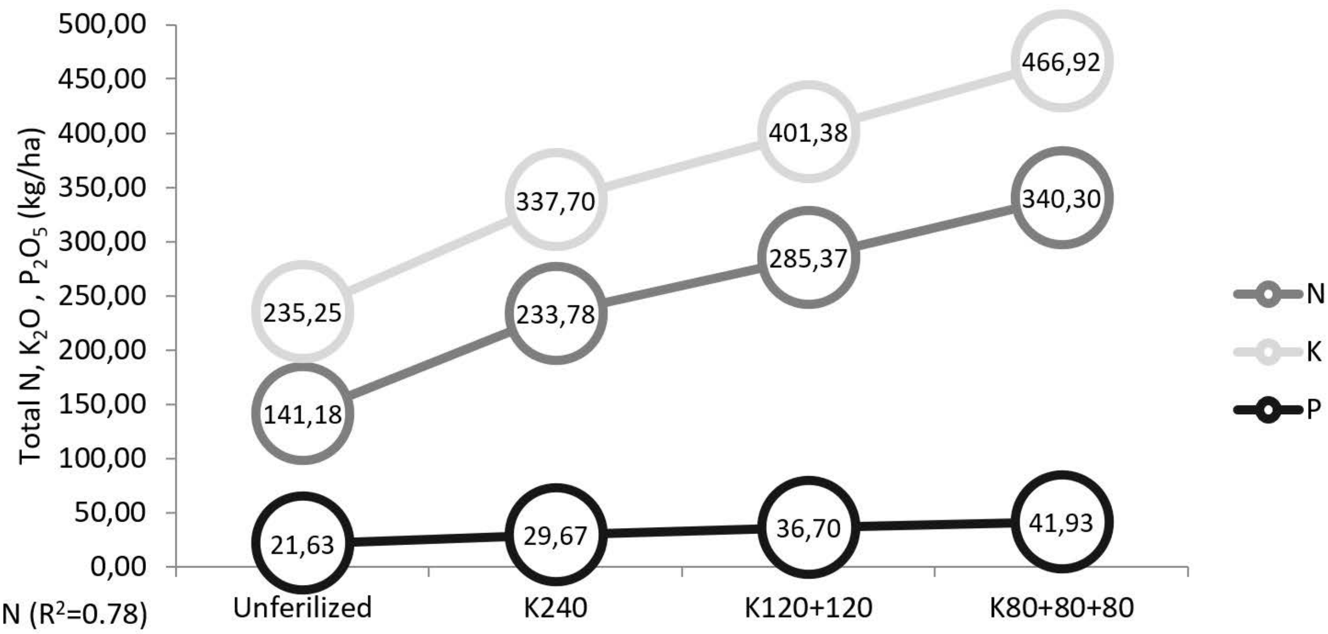
Plant nutritional status affects fruit yield (Fandi et al., 2010). A positive correlation between the nutrient export with the total biological yield and the fertilization treatments is evident. Total N, P_2O_5 and K_2O, exported with mid-early tomato plants was significantly higher for all replications. On the other hand, highest yield was measured in plants subjected to split potassium fertilization, regardless of the time of planting (Figure 2).

a) Early tomato production



N (R^2=0.73)
P_2O_5 (R^2=0.75)
K_2O (R^2=0.85)

b) Mid-season tomato production



N (R^2=0.78)
P_2O_5 (R^2=0.71)
K_2O (R^2=0.87)

Figure 2. Correlation between total N, K_2O and P_2O_5 export and potassium fertilization

To maximize the effectiveness of nutrients from fertilizers, analysis of the quantity of nutrients applied and their absorption is necessary (Gaj and Rebarz, 2014). To sustain soil fertility, it is crucial to maintain optimal soil nutrient levels and balance the nutrient export with sufficient fertilizer application, therefore residual quantities of N, P_2O_5 and K_2O, as well as pH, were measured post-harvest (Table 2).

Soil pH levels dropped from 7.0 to 6.5-6.8 due to the high total yield (especially mid-early production) and because plant preferred P and N-NO_3 sources are in the form of KCl and NH_4NO_3. Tomato plants prefer nitrate to ammonium ions and residual – Cl^- and NH_4^+ ions contribute to soil acidification (Mengel and Kirkby, 1987; Filcheva et al., 2012).

Csathó et al. (2006) reported a trend towards negative phosphorus balance in Central and Eastern Europe soils. On the contrary, our results reveal a positive P_2O_5 soil-plant balance, 120 kg/ha applied, at maximum export of 41.9 kg/ha yearly. As a result, P_2O_5 soil content increased to 7.85 mg/100 g for mid-early, and to 11.98 mg/100 g for early tomato production, available P soil status changed from low to medium (Table 2).

Regardless of the optimal timing of application and adequate rates (240 kg/ha yearly), potassium balance was negative for all treatments and replications – export ranges from 184.1 to 466.9 kg/ha depending on the time of planting (Figure 2). Split potassium fertilization plants exported more nutrients, compared to single potassium treatment, therefore K_2O soil content was reduced from 20.3 to 15.98 mg/100g (mid-early) and to 17.43 mg/100g for early season production (Table 2). Available K soil status decreased from high to medium, confirming Nikolova's (2005) findings.

Maintaining nitrogen soil balance is essential for intensive irrigation agriculture systems, such as the one in Bulgaria, due to the nitrogen's susceptibility to leaching. A decrease from 19.60 mg/kg to 15.03-16.10 mg/kg in mineral nitrogen content in soil post-harvest was recorded. However, the fertilization rate of 240 kg/ha was sufficient to cover nutrient export losses (108.5-244.3 kg/ha), except for mid-early production plants, undergone split potassium fertilization 285.4 for the split in two and 340.3 kg/ha for the split in three treatments (Figure 2).

Table 2. Change in soil characteristics

	N mg/kg	P_2O_5 mg/100g	K_2O mg/100g	pH (H_2O)
Pre-experiment soil sample	19.60	5.80	20.30	7.0
After Early production harvest	16.10	11.98	17.43	6.8
After Mid-season production harvest	15.03	7.85	15.98	6.5

CONCLUSION

The present research confirmed, that the time of planting factor and the potassium fertilization had a significant effect on the total biological yield and export of total N, P_2O_5 and K_2O. Nutrient exports were linearly correlated to the obtained yield. Tomato plants subjected to $N_{240}P_{120}K_{80+80+80}$ fertilization measured the highest yield and respectively highest nutrient export. Due to the better soil-climate conditions, mid-early production plants measured higher fruit and biomass yield (61878.9 and 27184.9 kg/ha), along with higher nutrient uptake.

The intensive export of nutrients with tomato plants demands for close monitoring in order to avoid decreasing of soil fertility and negative soil nutrient balance. Tomatoes are a crop with high nutrient requirements and despite the optimal K_2O and N nutrition rates applied (240 kg/ha), negative balance in soil was recorded. Based on the obtained results, a tomato crop rotation scheme, involving less-nutrient-demanding crops (root crops, legumes) is recommended to ensure soil nutrient replenishment for more productive and sustainable agriculture systems.

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