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Comparative analysis of archival data on yields of main field crops from fertilizer experiments on different soil types in Bulgaria

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Abstract: The main aim of the study was to systematize and summarize archival data on yields from main field crops from multiple fertilizer experiments of Nikola Poushkarov ISSAPP on various soil types in Bulgaria. A large set of results from the field fertilizer experiments carried out on four different soil types: Calcareous Chernozem (Trastenik village), Haplic Chernozem (Gorni Dabnik village), Haplic Luvisol (Nikolaevo village) and Planosol (Sekirovo village) in the geographical network of Bulgaria of the Nikola Poushkarov ISSAPP has been accumulated. Eight fertilization variants were tested with annual application of potassium (0, 8, 16 and 32 kg/da K_2O) on two backgrounds of nitrogen (N) and phosphorus (P) fertilization. Crop rotation during the individual years was as follows: wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), sunflower (*Helianthus annuus* L.) and sugar beet (*Beta vulgaris* L.), grown under non-irrigation conditions. Optimum rates of fertilization with the main nutrients, N, P and K have been established for the different soil types. There are complex interactions between the different rates of fertilization with the main macronutrients and this has a significant impact on the quantity and quality of agricultural crop yields. The difference in yields between the two investigated periods (1963-1970 and 1971-1975), at the same levels of fertilization, shows that the level of yields and accordingly, the use of nutrients are also determined to a significant extent by the climatic conditions. With an increase in the fertilizer rate, the yields also increase, and the rates of 16 kg and 32 kg K_2O remain the most effective, regardless of the occurrence of potassium accumulation in these variants. This was also confirmed by the results of the analysis of variance of the yields of cultivated crops. There was a pronounced increase of the effect of potassium fertilization in soils less supplied with this element, i.e. the Haplic Luvisol (Nikolaevo village) and Planosol (Sekirovo village). The effect of the potassium fertilization increases and expands in well supplied with potassium soils, but possessing unfavorable conditions for nutrition with this element, as in the case with the Calcareous Chernozem (Trastenik village). There was also an effect of potassium fertilization, although inconsistent, in soils well supplied with potassium, such as Haplic Chernozem (Gorni Dabnik village).

Keywords: fertilization; crop rotation; wheat; corn; sunflower; sugar beet

INTRODUCTION

Agricultural research in recent years has been aimed at developing and implementing good agricultural practices to obtain optimal crop yields with quality that meets the requirements of modern international standards (Atanassova et al., 2011). To achieve these goals, it is necessary to control the processes of nutrients translocation in soil, as well as the exchange of nutrients between soil and plants (Stanchev & Valchovski, 2011). Obtaining good information about the level of storage of arable and sub-arable soil horizons with nutrients and their assimilation by cultural plants, makes it possible to maintain a balance of nutrients without deficit and preserve and increase soil fertility in the conditions of sustainable agriculture (Nenov et al., 2020; Estrade et al., 2010; Grifith et al., 2013).

Data bases from long-term stationary fertilizer experiments, conducted in regions with different soil and climatic conditions of our country are available (Petkova et al., 2015, Valchovskiet al., 2015). Information has been accumulated from the analysis of the results of soil-agrochemical research in field fertilizer experiments, which were carried out on a large number of soil types in the experimental fields in the geographical network of the country in Nikola Poushkarov Institute of Soil Science, Agrotechnologies and Plant Protection. In previous publications, the economic efficiency of fertilization in different periods has been partially presented (Valchovski & Petkova, 2003; Petkova & Damqnova-Kirilova, 2003; Tosheva et al., 2009).

Potassium (K) is an essential plant macronutrient and plays a key role in the synthesis of cells, enzymes, protein, starch, cellulose, and vitamins, in nutrient transport and uptake, in conferring resistance to abiotic and biotic stresses, and in enhancing crop quality (ShaojunQiu et al., 2014). Potassium may be retained in soil for several years following fertilizer application, therefore, long-term K fertilization experiments can monitor the effects of K fertilization on cereal production, K use efficiency, and soil K status at different soil depths. The potassium fertilization has been given less attention than that with nitrogen (N) and phosphorus (P) the studies related to cereal productivity. Its positive effect on plant growth is manifested slower compared with that of N and P, especially in K-enriched soils (Jyoti Rawat et al., 2022).

According to Mirohnichenco et al. (2017), adequate fertilization can simultaneously improve soil quality and sustainability against the negative consequences of climate change in order to preserve agricultural productivity. The optimal and balanced use of nutrients in the form of mineral fertilizers is extremely important for the adaptation of agricultural production to abiotic stress (drought, high temperatures, etc.), as well as for improving yield and quality and reducing production costs (Belay et al., 2002; Stanchev & Valchovski, 2011). However, excessive fertilizer application can have adverse effects on the environment, water quality, leaching and runoff. In view of the Farm to Fork strategy of the European Green Deal, the European Union aims the fertilizers use to be reduced with 20% by 2030 (Atanassova, 2022). Therefore, it is important to determine fertilizer application rates, that maximize yields, without creating a risk of environmental pollution (Hoque et al., 2010).

The main goal of the study is to systematize and summarize archival data on yields of main field crops from multi-year fertilizer experiments of Nikola Poushkarov ISSAPP on different soil types.

MATERIAL AND METHODS

To realize the goal set, multi-year field fertilizer trials were conducted in the period 1963-1975 according to a uniform methodology on four soil types: Calcareous Chernozem (Trastenik village), Haplic Chernozem (Gorni Dabnik village), Haplic Luvisol (Nikolaevo village) and Planosol (Sekirovo village) under different soil and climatic conditions. The rotation of the crops during the individual years was as follows: wheat (*Triticum aestivum*, L.), maize (*Zea mays*, L.), sunflower (*Helianthus annuus* L.) sugar beet, (*Beta vulgaris* L.) grown under non-irrigation conditions.

Eight variants of fertilization were tested: background 1 - (NPKo, NPK_8, $NPK_{16,}$ NPK_{32}) and background 2 - (N_2P_2Ko, $N_2P_2K_8$, $N_2P_2K_{16}$, $N_2P_2K_{32}$) with annual input of potassium with increasing rates - 0, 8, 16 and 32 kg/da K_2O. In addition to the potassium content, the content of other nutritional macro-elements was also monitored annually, in order to create an optimal background for the manifestation of the effect of potassium fertilizers. Two rates of nitrogen (N_1 -6 and N_2-12kg/da) and phosphorus (P_1-5 and P_2-10kg/da) fertilization with systematic annual NP fertilization were included (Ikonomova & Nikolova, 1975). The average yields (kg/da) of cultivated crops, with different variants of potassium fertilization, were reported.

Soil and meteorological characteristics of the experimental fields

The experimental field in Trastenik village, Pleven municipality occupies an area of 80 da and falls in the Northern climatic region of the Danube hilly plain. The average annual air temperature is 11.3°C. The average January temperature is 2.2°C. The maximum air temperature is 42.4°C, measured in the month of August. The average annual amount of precipitation is 512 mm, which corresponds to 75% of the annual norm of the country. The data were collected for the period 1963 – 1975. The deviations from the mean are very significant - from 303 mm to 330 mm. Precipitation is unevenly distributed. Summer precipitation prevails over that in winter, which is particularly characteristic of the continental climate of the area.

The experimental station in which the field studies were carried out falls in the zone of Calcareous Chernozems, which are generally less deep than those in Dobrudzha region. The Chernozems are developed on a loess. The mechanical composition of the Calcareuos chernozem in the field is medium-sandy clay. It contains a low amount of silt (18 to 25%) and clay (from 25 to 40%). The regular decrease of clay and silt along the profile from the surface horizon to the soil-forming materials is characteristic. The coarse powder fraction (particles with a size of 0.05-0.01 mm), typical for the loess and the soils formed on it, dominated. By humus content, the soil in the field refers to the slightly humus soils (2.49%). It decreases to 1.17% with soil depth. The total nitrogen content is also low (0.136%). The content of total phosphorus and total potassium is high, and a gradual decrease in their amount with depth is observed. The soil reaction of the arable horizon is slightly alkaline (7.03) and becomes alkaline in depth (8.32). This is largely related to the availability of calcium in the profile (Ninov et al., 1975).

The experimental field in Gorni Dabnik village, Pleven municipality occupies an area of 150 da and falls in the Northern climatic region of the Danube hilly plain. The region is characterized by very cold winters and hot summers. The average annual air temperature is 10.9°C (for the period 1961-1974). The openness of the area allows cold air masses to freely invade in winter. That is why the temperatures in January are negative every year. Air temperatures rise until July and August, which are the warmest and reach 35-39°C every year. Average rainfall was 584 mm for the period 1963-1975 with deviation of 359 to 785 mm. These large deviations from the average precipitation rate indicate that severe droughts are possible. The area is outlined as arid with insufficient spring moistening.

In the experimental field of G. Dabnik village, the soil belongs to the most widespread soil type in the region Haplic Chernozem. The soil-forming rocks are mainly heavy sandy-clay loess materials and clays. Haplic Chernozems are characterized by a heavy sandy-clay mechanical composition and have a medium-powerful humus horizon, and therefore they have a higher water-holding capacity, which implies a more productive use of soil moisture reserves by plants. The content of particles <0.01 mm is uniform throughout the profile. Dominant fractions are loess and similar to loess – coarse powdery fraction (particles of 0.05-0.01 mm). The Haplic Chernozem in the field has a relatively high humus content (3.55%), which decreases with depth of the profile (1.50%). The soil reaction of the plow horizon is slightly alkaline (pH 7.6) and becomes alkaline (pH 8.25) in depth (Ninov et al., 1975). The amount of total N in the surface horizons and in the one-meter soil layer is higher (0.180%) than in the Calcareous Chernozem (Scientific Papers of the National Center for Agricultural sciences, 2005).

Experimental field in Nikolaevo village, Pleven district, was created on an area of 160 da and falls in the elevated part of the middle climatic region of the Danube hilly plain. The proximity of the foothills and the Balkan mountain also influence the characteristics of the climate. The average annual air temperature is 10.4°C.The absolute minimum temperature was measured in January and for this observation period it was -2.8°C. The maximum air temperature is 39.2°C and was measured in July and August. The average annual amount of precipitation is 714 mm and is close to the average precipitation for the country, the fluctuations are from 484 to 961 mm. Summer precipitations prevail over these in winter, e. g. 985 mm compared to 561 mm in winter, which is a characteristic of the continental climate of the area (National Monitoring Network of the National Institute of Meteorology and Hydrology (NIMH) (Figure 1).

In the experimental field of Nikolaevo village, the soil belongs to the Haplic Luvisols, widespread in the region. The soil-forming materials are clayey loess and loess clays. The texture of the Haplic Luvisol in the field is heavy sandy loam. Another characteristic of this soil type is the higher amount of coarse silt (particles with sizes 0.05-0.01 mm) along the entire profile. The humus content (the amount varies from 2.21 to 2.82%), characterizes the soil as soil of low to medium humus content. The reserves of the soil with total nitrogen are only 0.11%. Similarly to the humus content, the amount of nitrogen decreases greatly in depth. Due to the small content of the humus-eluvial horizon, the low contents of humus and total N, these soils have a much worse nutritional regime compared to Chernozems soils. The reaction of the soil up to 100 cm is acidic (pH 6.20), and with depth due to the presence of carbonates it becomes alkaline (pH 7.70) (Ninov et al., 1975).

The experimental field in Sekirovo village, Plovdiv district occupies an area of 40 da and falls in the western part of the climatic region of Eastern Bulgaria. The average annual air temperature is 12.2°C.The coldest weather is in January and the warmest is in July. The absolute maximum temperature is 41.3°C, and the average rate of precipitation is 595 mm, which varies greatly in individual years (30-60.17 mm).There are often periods when no precipitation falls for a whole month, or often the precipitation amounts is small, 10-15 mm. The precipitations are insufficient to maintain good soil moisture, so the experimental field area is too dry.

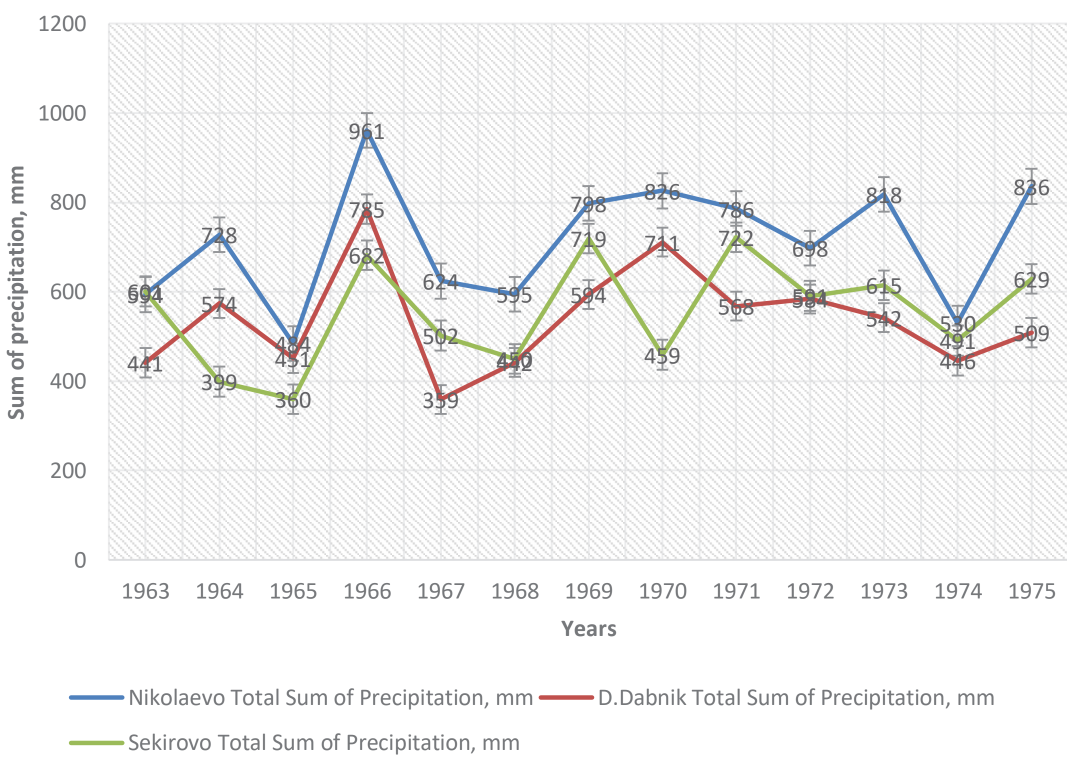

Figure 1. Sum of precipitation in mm during the period 1963-1975.
National Institute of Meteorology and Hydrology (NIMH)

The experimental field, in which the field studies were carried out, falls in the zone of Planosols. Soil-forming rocks are mainly acidic, non-calcic and their weathered products. In terms of mechanical composition, the surface horizon of this soil is slightly sandy loam and the deeper B horizon is medium sandy loam. The sandy fraction (particles 1-0.05 mm) and the coarse silt fraction (0.05-0.01mm) dominate there. Despite the coarser texture, a well-defined differentiation is observed in the distribution of silt along the soil profile. The soil is characterized by a low content of humus (1.11%), which gradually decreases in depth (0.57%). The reserves of soil with total N are very low (0.067%). The soil reaction is averagely acidic in the surface horizon (pH 4.50) and slightly acidic in depth (pH 5.65) (Ninov et al., 1975).

The statistical analysis of the obtained results was done with Statgraphics statistical product (ANOVA).To establish the differences between the studied variants, the Multiple-Sample Comparison method was used to compare mean values with 95% statistical confidence interval selected.

RESULTS AND DISCUSSION

The database we used is a valuable source of knowledge to clarify the role of the different types of mineral fertilizers, the soil type and agro-climatic conditions for obtaining stable yields of high quality.

The degree of influence of the tested factor, i.e. fertilization, was evaluated by analysis of variance of yields data. A statistical evaluation of the yields of the crops grown in the crop rotation at different levels of K fertilization was carried out (a total of eight fertilizing variants with annual K input, including 0,8,16 and 32kg/da K_2O with two levels of nitrogen (N) and phosphorus (P) fertilization) for two periods: 1963 - 1970 and 1971-1975.

The comparison made of wheat yields in the first period (1963-1970) as influenced by the soil type forms a total of 3 homogeneous groups. The lowest wheat yields were recorded on the Haplic Chernozem soil type (Gorni Dabnik), which falls into homogeneous group A (Table 2). The yields of plants, grown on Calcareous Chernozem (Trastenik) were the highest (homogeneous group C). The data on wheat yields of these two soil types have a statistically proven difference between them and in relation to the other two soil types. The Haplic Luvisol (Nikolaevo) and the Planosol (Sekirovo) fall into group B, which shows that the differences between them were close and not statistically significant (Table 2).The fallen precipitation in the period 1963-1970, during the ripening of wheat grain on the four soil types, was twice less in quantity (7 to 144 mm), which was connected with the quantity of the yields obtained. They were lower (Figure 1.). Ac-

Table. 1. Yields (kg/da) from the crops grown on Calcareous Chernozem soil (Trastenik village)

	Wheat		Maize		Sunflower		Sugar beet	
Variants	1963 -1970	1971 -1975	1963 -1970	1971 -1975	1963 -1970	1971 -1975	1963 -1970	1971 -1975
NP Ko	367	328	431	640	221	339	2328	4354
NP K8	370	365	450	673	237	425	3159	4364
NP K16	367	380	487	676	235	437	3104	4458
NP K32	362	375	454	660	244	422	3147	4875
N2P2 Ko	374	335	428	648	233	373	3045	4542
N2P2 K8	409	370	479	660	237	411	3216	4896
N2P2 K16	415	360	444	682	242	424	3219	5281
N2P2 K32	395	365	490	631	239	378	3571	5219

cording to Marijanovic et al. (2010), the supply of wheat with moisture when the grain reaches wax, maturity at the end of June is of great importance for yield formation.

The distribution of wheat yields for the following period (1971-1975) was in 4 homogeneous groups and each soil type falls into a separate homogeneous class (Tables 2 and 3). In contrast to the previous period, in this case the highest wheat yields were on Haplic Luvisol (Nikolaevo), which falls into homogeneous class D, and the lowest were on Calcareous Chernozem (Trastenik), which falls into class A. This can be explained by the increased effect of potassium fertilization in the less supplied with K soil and the more favorable climatic conditions in the respective regions of the country during this period (Ninov et al., 1975). It was known that the average annual amount of precipitation is 512 mm, which corresponds to 75% of the country's annual levels. This was a proof of the importance of precipitations for agricultural crops nutrition. Despite the higher natural fertility of Calcareous Chernozem, the yields were lower compared to the other soil types, which was explained by the increased effect of potassium fertilization in soils well supplied with potassium, however the conditions for nutrition with this element are less favorable.

Compared to wheat, **maize** grown under different soil-climatic conditions is more often threatened by drought and damage during dry growing seasons leads to large yield losses (Petkova et al., 2011). The amount and distribution of precipitation during the growing season is of particular importance for the formation of the yield of maize for grain. The change in the moisture availability of the crop during different periods of the vegetation affects the yield in a different way. Mihov et al. (1989) found that total precipitation in June and the period July 1-August 10 had the greatest influence.

In the case of maize grown on Calcareous Chernozem (Trastenik), the yields vary from 428 to 490 kg/da in the first period and from 631 to 682 kg/da in the second period, and they were higher in the fertilized variants with a greater level of potassium fertilization applied (Tables 1, 4 and 5). There was no data for maize grown on Haplic Chernozem soil type (Gorni Dabnik) in the archive. The highest yields of maize were re-

Table 2. Summary statistics for the yields of wheat (1963-1970). Multiple range test

Soil types	*Count*	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*
Calcareous Chernozem	8	382.4**C**	20.85	5.45%	362.0	415.0	53.0
Haplic Luvisol	8	353.5 **B**	12.56	3.55%	326.0	365.0	39.0
Haplic Chernozem	8	296.4**A**	10.78	3.64%	276.0	309.0	33.0
Planosol	8	357.9 **B**	8.75	2.45%	343.0	369.0	26.0
Total	32	347.5	34.68	9.99%	276.0	415.0	139.0

Table 3. Summary statistics for the yields of wheat (1971-1975). Multiple range test

Soil types	*Count*	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*
Calcareous Chernozem	8	359.75 **A**	18.61	5.17%	328.0	380.0	52.0
Haplic Luvisol	8	568.12 **D**	31.53	5.55%	513.0	607.0	94.0
Haplic Chernozem	8	433.37 **C**	27.40	6.32%	394.0	473.0	79.0
Planosol	8	396.25 **B**	7.57	1.91%	388.0	407.0	19.0
Total	32	439.375	82.99	18.89%	328.0	607.0	279.0

corded on Haplic Luvisols (Nikolaevo), and they varied from 516 to 543 kg/da in the first period and from 946 to 1034 kg/da in the second period. The highest were in the variants $N_2P_2K_{16}$ and $N_2P_2K_{32}$ with a greater level of potassium fertilization applied (Tables 4, 5 and 6). Haplic Luvisol fall into homogeneous group D. On the Planosol (Sekirovo) relatively low yields of maize were obtained, and they varied from 272 to 291 kg/da and from 316 to 356 kg/da for the two studied periods (Table 4, 5 and 10). In the July-August period, the fallen precipitation in this region during the maize vegetation was relatively low, from 4 to 66 mm, which is also confirmed by the low yields obtained.

The difference in yields between the two investigated periods at the same fertilization levels and the use of nutrients respectively, indicates that they were also determined to a significant extent by the climatic conditions. During the years 1964, 1965, 1968, 1969, 1970, there was drought in Sekirovo (Planosol) during the ripening of the maize grain and adverse effect of fertilization is observed, especially at the high doses.

The comparison of maize yields during the studied periods (1963-1970; 1971-1975) as influenced by the soil type formed a total of 3 individual homogeneous groups and they were the same for both periods. Therefore, each soil type falls into a different homogenous class and yield date were statistically significant. The Haplic Chernozem was excluded due to the lack of data (Tables 4, 5 and 9).

Sunflower is the main oil crop in Bulgaria. The need for nutrients to form yields depends both on the specific soil type and the climate conditions of the area, as well as on a number of other factors. The importance of the fertilization is primary. The sunflower responds well to nitrogen fertilization; however, excess nitrogen reduces oil content and lowers plant resistance to diseases. Appropriate balanced phosphorus and potassium fertilization increases yields and oil content. The sunflower needs for K are high (7-11 kg for 100 kg of seeds, i.e. 1.5-2 times more than N and 4-5 times more than P). Potassium increases the absolute weight and oiliness of the seeds. Experiments, carried out in our country show an

Table 4. Summary statistics for yields of maize (1963-1970). Multiple range test

Soil types	*Count*	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*
Calcareous Chernozem	8	457.87 **C**	24.52	5.36%	428.0	490.0	62.0
Haplic Luvisol	8	527.75 **D**	8.68	1.64%	516.0	543.0	27.0
Haplic Chernozem	8	-	-	-	-	-	-
Planosol	8	283.37 **B**	7.54	2.66%	272.0	291.0	19.0
Total	32	317.25	207.30	65.34%	0	543.0	543.0

Table 5. Summary statistics for the yields of maize (1971-1975). Multiple range test

Soil types	*Count*	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*
Calcareous Chernozem	8	658.75 **C**	18.05	2.74%	631.0	682.0	51.0
Haplic Luvisol	8	994.62 **D**	32.06	3.22%	946.0	1034.0	88.0
Haplic Chernozem	8	-	-	-	-	-	-
Planosol	8	346.12 **B**	14.11	4.07%	316.0	356.0	40.0
Total	32	499.87	374.99	75.02%	0	1034.0	1034.0

increase in oils yield under the influence of K fertilization (Nikolova, 2010).

On the Haplic Luvisol (Nikolaevo), higher sunflower yields were obtained in the first period (1963-1970) and ranged from 306 to 335 kg/da (Table 6 and 7). They fall into the homogeneous class D, and in the second period (1971-1975) the highest yields were recorded on Calcareous Chernozems (Trastenik) in the variant NPK_{16}-437 kg/da, which again falls in class D (Table 1 and 8).

In the case of sunflower, the yields obtained on Haplic Chernozem soil type in Gorni Dabnik were the lowest and were in the range of 175 to 195 kg/da for the first reporting period. They fall into homogeneous class A (Tables 7 and 9). This dependence was also preserved in the next period (1971-1975), when the obtained yields were lower, i.e.153 to 186 kg/da (Tables 8 and 9). There was a positive response to potassium fertilization, although inconsistent in soils well supplied with K, such as Haplic Chernozem, however the conditions for nutrition with this element are unfavorable.

On the Planosol (Sekirovo), sunflower yields for the two studied periods varied from 202 to 216 kg/da and respectively from 240 to 270 kg/da (homogeneous class B), however on this soil type, again slightly higher yields were reported in the variants with higher rate of fertilization with potassium fertilizer (Table 7, 8 and 10).

The obtained yields of sunflower grown on the four soil types were low, which we assign to the drought that occurred in the respective regions of the country during this period, and therefore the effect of the applied fertilization was weakly pronounced. The low amount of precipitation (Figure 1) that fell during the sunflower budding and flowering period were the likely reason for the lower yields. This was also confirmed by the results of the analysis of variance performed on sunflower yields (Tables 7 and 8).

The sugar beet was the next crop grown in crop rotations. Sugar beet (*Beta vulgaris var. saccharifera*) is the crop from which white crystalline sugar is produced in the countries of the

Table 6. Yields (kg/da) from the crops grown on the Haplic Luvisol (Nikolaevo)

	Wheat		Maize		Sunflower	
Variants	1963 -1970	1971 -1975	1963 -1970	1971 -1975	1963 -1970	1971 -1975
NP Ko	351	528	516	996	306	240
NP K8	352	588	532	962	313	275
NP K16	364	573	531	969	335	290
NP K32	359	582	543	946	328	286
N2P2 Ko	326	513	518	1016	309	230
N2P2 K8	361	581	525	1024	329	276
N2P2 K16	350	573	525	1034	328	292
N2P2 K32	365	607	532	1010	325	296

Table 7. Summary statistics for the yields of sunflower (1963-1970). Multiple range test

Soil types	*Count*	*Average*		*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*
Calcareous Chernozem	8	236.0	**C**	7.03	2.98%	221.0	244.0	23.0
Haplic Luvisol	8	321.62	**D**	10.71	3.33%	306.0	335.0	29.0
Haplic Chernozem	8	185.0	**A**	7.270	3.93%	175.0	195.0	20.0
Planosol	8	206.62	**B**	5.579	2.70%	198.0	216.0	18.0
Total	32	237.31		53.29	22.46%	175.0	335.0	160.0

temperate climatic zone. Due to the dry continental climate in our country, moisture is a decisive factor in the cultivation of beet. The summer droughts in July-August, accompanied by relatively high average daily temperatures and low atmospheric humidity, are also unfavorable for sugar beet development (Enchev et al., 2018). The results of some studies (Kikindonov, 2011a) show that in extreme climatic conditions of prolonged drought, sugar beet productivity is placed at serious risk.

There was no data in the archive for growing sugar beet on the Haplic Luvisol (Nikolaevo). In the period of 1963-1970, the highest sugar beet yields were recorded in the region of Gorni Dabnik on the Haplic Chernozem and ranged from 3188 to 3670 kg/da, falling into homogeneous class C. The yields were higher in the $N_2P_2K_{16}$ and $N_2P_2K_{32}$variants with applied the higher rate of potassium fertilization (Tables 9 and 11). Therefore, the applied K in combination with NP stabilizes the yield and had a positive effect. The higher content of humus of Haplic Chernozem compared to that of the Calcareous Chernozem is one of the important components determining the higher fertility and better water regime of this soil, since humus is closely related to the thermal regime, water permeability, moisture capacity and soil nutrition (Valchovski et al., 2015).

In the second studied period (1971-1975), the highest yields of sugar beet were reported on the Calcareous Chernozem (Trastenik) from 4354 to 5281 kg/da (Tables 11 and 12). On the Planosol (Sekirovo) during this period, sugar beet yields were also good and ranged from 3906 to 4323kg/da, which can be explained by an increase in the effect of potassium fertilization in the less supplied with K soil type and the favorable conditions for mineral nutrition. (Table 10 and 12).

The analysis of the results shows that when growing sugar beet on different soil types in the country, balanced nutrition with nitrogen, phosphorus and potassium has a key-role, in order to obtain stable yields of high quality.

Table 8. Summary statistics for the yields of sunflower (1971-1975). Multiple range test

Soil types	*Count*	*Average*		*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*
Calcareous Chernozem	8	401.12	**D**	34.01	8.48%	339.0	437.0	98.0
Haplic Luvisol	8	321.62	**C**	10.71	3.33%	306.0	335.0	29.0
Haplic Chernozem	8	168.12	**A**	12.80	7.61%	153.0	186.0	33.0
Planosol	8	254.62	**B**	12.50	4.90%	235.0	270.0	35.0
Total	32	286.37		89.14	31.12%	153.0	437.0	284.0

Table 9. Yields (kg/da) from the crops grown on the Haplic Chernozem soil (Gorni Dabnik)

	Wheat		Maize		Sunflower		Sugar beet	
Variants	1963 -1970	1971 -1975	1963 -1970	1971 -1975	1963 -1970	1971 -1975	1963 -1970	1971 -1975
NP Ko	299	427	-	-	175	186	3188	2194
NP K8	305	423	-	-	186	180	3328	2247
NP K16	285	456	-	-	189	182	3310	2164
NP K32	297	473	-	-	177	166	3405	2270
N2P2 Ko	301	394	-	-	192	155	3266	2132
N2P2 K8	309	411	-	-	179	153	3445	2078
N2P2K16	276	462	-	-	187	161	3670	2194
N2P2K32	299	421	-	-	195	162	3640	2196

Table 10. Yields (kg/da) from the crops grown on the Planosol soil (Sekirovo)

	Wheat		Maize		Sunflower		Sugar beet	
Variants	1963 -1970	1971 -1975	1963 -1970	1971 -1975	1963 -1970	1971 -1975	1963 -1970	1971 -1975
NP Ko	369	407	290	354	216	250	2540	3906
NP K8	361	389	291	335	198	264	2543	4114
NP K16	359	402	272	348	202	270	2793	4364
NP K32	359	397	284	316	206	252	2759	4323
N2P2 Ko	350	405	273	356	208	235	2792	4188
N2P2 K8	368	391	283	348	205	262	3145	4708
N2P2 K16	354	388	283	356	206	264	2898	4198
N2P2 K32	343	391	291	356	212	240	3068	4250

Table 11. Summary statistics for the yields of sugar beet (1963-1970). Multiple range test

Soil types	*Count*	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*
Calcareous Chernozem	8	3098.63 **B**	349.31	11.27%	2328.0	3571.0	1243.0
Haplic Chernozems	8	3406.5 **C**	172.54	5.06%	3188.0	3670.0	482.0
Planosols	8	2817.25 **A**	218.27	7.74%	2540.0	3145.0	605.0
Total	24	3107.46	38.0	11.19%	2328.0	3670.0	1342.0

Table 12. Summary statistics for the yields of sugar beet (1971-1975).Multiple range test

Soil types	*Count*	*Average*	*Standard deviation*	*Coeff. of variation*	*Minimum*	*Maximum*	*Range*
Calcareous Chernozem	8	4748.63 **C**	372.86	7.85%	4354.0	5281.0	927.0
Haplic Chernozems	8	218438 **A**	61.00	2.79%	2078.0	2270.0	192.0
Planosols	8	4256.38 **B**	230.26	5.41%	3906.0	4708.0	802.0
Total	24	3729.79	1160.95	31.13%	2078.0	5281.0	3203.0

With an increase in the fertilizer rate, the yields also increase, and the rate of 16 kg and 32 kg K_2O remains the most effective, regardless of the occurrence of potassium accumulation in these variants. The effect of the cumulative action of potassium has long been known. It has been established by many researchers that the long-term and systematic use of potassium fertilizers on a nitrogen-phosphorus levels, does not reduce its effect, but multiplies it. The increase in the effect when a higher level of potassium is created can be explained by some new assumptions about the nutrition of plants with potassium and specifically by increasing the concentration of potassium in the soil solution.

In this aspect, the question on the relationship between the amount of potassium fertilizers used and the increase in yields arises. It was considered that the effect of potassium fertilization can be expected only if it has led to an increase in the concentration of potassium in the soil solution.

CONCLUSIONS

The main conclusions from the analysis of the results of soil-agrochemical research in the field fertilizer experiments, derived on four soil types in the experimental fields of Nikola Poushkarov ISSAPP are the following:

The optimal rates of fertilization with the main nutritional elements N, P and K have been established for different soil types. There are complex interactions between different rates of fertilization with the main macronutrients and this has a significant influence on the quantity and quality of agricultural crop yields. The specific soil and climate conditions are important factors for optimal fertilization and achieving high efficiency.

Higher yields from cultivated crops were reported during the second period of study (1971-1975), as a result of increased soil fertility. This is especially true for the less fertile soils - the Planosol and the Haplic Luvisol. It was established that low yields were obtained from the experimental crops, especially during the first test period (1963-1970) under non-irrigation conditions. With an increase in the fertilizer rate, the yields also increase, and the rate of 16 kg and 32 kg K_2O remains the most effective, regardless of the accumulation of potassium in these variants during the years of the study.

The difference in the yields between the two studied periods (1963-1970 and 1971-1975), at the same levels of fertilization, shows that the level of yields and, respectively, the use of nutrients, were to a significant extent determined by the climatic conditions. In the year during which there was drought, an adverse effect of fertilization was observed, especially at the high rates of NPK fertilization. This was also confirmed by the results of the analysis of variance of yields of the cultivated crops, wheat, maize, sunflower and sugar beet, which proves the importance of precipitation for ensuring the nutrition of agricultural crops in non-irrigation conditions.

There was a pronounced increase of the effect of potassium fertilization in soils less supplied with this element, i.e. the Haplic Luvisol (Nikolaevo) and Planosol (Sekirovo). The effect of potassium fertilization increases and expands in well supplied with potassium soils, but possessing unfavorable conditions for nutrition with this element, as was the case with the Calcareous Chernozem (Trastenik). There was an effect of potassium fertilization, although inconsistent, in soils well supplied with potassium, such as Haplic Chernozem (Gorni Dabnik).

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