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ORIGINAL PAPER

ASSESSMENT OF THE IMPACT OF DIFFERENCES IN FERTILIZATION ON SELECTED YIELD INDICES FOR GRAPES IN SUGHD REGION OF TAJIKISTAN*

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Abstract

Owing to its suitable temperature conditions and the hot and dry climate combined with access to water courses and bodies, Sughd Region is a place that is naturally suited to the production of vines. Rational management of fertilizers is one of the key elements of production that makes it possible to obtain an optimal yield of high quality while considering the impact of fertilization on the environment. The aim of the research was to assess differentiation in the fertilization of vines with phosphorus and potassium with reference to the quality and quantity of the yield obtained, and aspects related to fertilization efficiency under the conditions of Sughd Region of the Republic of Tajikistan. The study was conducted in Sughd Region in Tajikistan, from 2015 to 2017. The experiment comprised two factors. The first factor was fertilization, with five fertilized objects. The second factor consisted of grapevine varieties. During the experiment, the size of yield, the phosphorus and potassium content, as well as the content of sugars and total acidity in the fruits were determined. The Recovery Efficiency, Agronomic Efficiency coefficients and Relative Agronomic Effectiveness were determined for the analysed doses and combinations of fertilizers. Regarding the volumes of the yield, the fertilization variant delivering 200 kg N, 87.2 kg P and 166 kg K ha^{-1} was found to be the most efficient. The research results showed that an increase in the dose of phosphorus by 100% without any parallel increase in the dose of potassium did not cause any significant growth in harvest yield. An increase in the doses of phosphorus and potassium had a significant effect on growth in yield, though also indicated a significantly lower use efficiency for the component applied. The applied fertilizer doses were not found to have caused any differentiation in the sugar content in grapes or in their acidity.

Keywords: phosphorus, potassium, fertilization, Tajikistan, grape quality.

INTRODUCTION

The cultivation of vines in Sughd Region of the Republic of Tajikistan is an important element in crop production, both historically and culturally being an integral part of the regional landscape. In 2016, the area covered by vineyards in the region was 11.850 ha. The hot and dry climate (the total annual rainfall for the lowland region ranges from 200 to 300 mm) combined with access to water courses and reservoirs which provide a source of irrigation in the area: the basins of the Zeravshan, as well of the Syr Darya, Khojabakirgan, Ak-Suu and Isfara rivers, create suitable conditions for the cultivation of grapes. Due to the necessity of intensive irrigation of grape crops at amounts ranging from 500 to 550 mm and because of the methods of irrigation employed with the use of sprinklers as well as surface (furrow) irrigation, there is a risk of loss of nutrients being washed out of the soil and carried away by surface runoff (Chowaniak et al. 2016). Another challenge in the region are the permeable soils (Gypsic Calcisols), which are rocky and poor in organic matter and nutrients (K, P). Under such conditions, determining the optimal doses of nutrients is of fundamental importance. Potassium (K) and phosphorus (P) are elements that are essential for the growth and productivity of vines (Mpelasoka et al. 2008, Ciotta et al. 2018). The functions of potassium and phosphorus are associated with physiological and biochemical processes, including enzyme activation, cell membrane transport processes, regulation of osmotic potential and plant water relations, turgor maintenance and growth (Davies, Zhang 1991, Zhang et al. 1997, Oosterhuis et al. 2014, Carstensen et al. 2018). Availability of phosphorus and potassium is a determining factor in the proper functioning of plants, and the quality and size of crop yields.

Rational management of fertilizers is one of the key elements of sustainable agriculture, and the aim of applying appropriate doses of production fertilizers is to obtain an optimal yield of high quality while considering the impact of fertilization on the environment. Effective soil management and yield quality are basic requirements of quality management systems in agriculture and gardening (Global GAP, Integrated Production), which are becoming necessary for producers to satisfy in order to enable them to join international markets. Providing nutritious, uncontaminated food, produced or obtained according to methods which limit the environmental impact of a given activity, is one of the main goals of the UN 2030 Agenda for Sustainable Development, which was adopted by the President and the Parliament of the Republic of Tajikistan in December 2016. The development and selection of appropriate doses of fertilizers is a key task in the context of sustainable agricultural production.

The aim of the research was to assess differentiation in the fertilization of vines with phosphorus and potassium with reference to the quality and quantity of the yield obtained and aspects related to fertilization efficiency under the conditions of Sughd Region of the Republic of Tajikistan.

MATERIAL AND METHODS

Field trial design and treatments

The study was conducted from 2015 to 2017, on the Umed farm, in the Ghafurov District of Sughd Region of the Republic of Tajikistan (N 40°19′18″ E 69°46′35″). Sughd Region is the northern part of the Republic of Tajikistan. The climate of the region is dry and hot, characterized by an amount of rainfall of around 200 to 300 mm annual with an evaporation value from 1.188 to 1.573 mm and total temperature ranging from 2.000 to 5.000°C (Table 1). The study was conducted on Gypsic Calcisols soil (IUSS 2015), the basic parameters concerning selected physical and chemical properties of the soil being provided in Table 2. The experiment consisted of two factors.

Table 1

Monthly average temperature, humidity and total precipitations for Sughd Region

Month	2015			2016			2017		
	T (°C)	P (mm)	H (%)	T (°C)	P (mm)	H (%)	T (°C)	P (mm)	H (%)
January	2.1	19.3	79	4.3	13.3	72	1.8	29.7	77
February	5.2	43.1	79	6.5	2.2	59	2.5	29.6	73
March	8	27.1	67	13.3	28.8	63	8.1	31.8	66
April	16.7	28.2	54	16.8	6.2	57	14.9	40.9	60
May	22.6	35.3	49	22.5	64.4	56	23.9	18.4	44
June	28.2	7.5	32	27.6	4.8	38	28.2	0.8	32
July	29.8	0	30	29	8.7	37	29.5	0	32
August	26.4	3.6	35	28	0	34	27	0.3	32
September	21.3	0.7	40	24.3	0	38	22.5	7.2	35
October	15.1	17.8	36	12.9	23.4	55	14.7	13.8	58
November	7.6	25.5	74	4.7	29.2	71	9.9	4.5	59
December	3.6	19.9	69	3.4	28.4	79	1.6	10.3	72

T – temperature, P – precipitations, H – humidity

Table 2

Chemical and physical properties of soil

Soil layer	pH	C (g kg^{-1})	N (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})
0-30 cm	7.4	3.4	0.3	140	600
30-50cm	7.5	2.2	0.2	100	1000

The first factor was fertilization. Distinction was made between six fertilized plots: Control "0" – no fertilization, (A – basic dose) – 100 kg N ha^{-1}, 44 kg P ha^{-1}, 83 kg K ha^{-1}, (B) – farmyard manure 30 t ha^{-1} (cow manure) with an average content of: 163 kg N ha^{-1} 36 kg P ha^{-1}, 157 kg K ha^{-1}, (C) – 200 kg N ha^{-1}, 88 kg P ha^{-1}, 83 kg K ha^{-1}, (D) – 200 kg N ha^{-1}, 132 kg P ha^{-1}, 83 kg K ha^{-1}, (E) – 200 kg N ha^{-1}, 88 kg P ha^{-1}, 166 kg K ha^{-1}. Nitrogen was applied in the form of ammonium nitrate, 34% N, phosphorus in the form of triple super phosphate, 48% P_2O_5, and potassium in the form of potassium chloride, 60% K_2O. The amount of nitrogen was split in two doses (50/50), the first dose was applied in early spring (first decade of March), while the second one was applied in the bloom period (third decade of May). Phosphorus and potassium were applied in one dose in late autumn (second decade of November). Manure was applied in November. The second factor consisted of two grape varieties: Husain White (HW) and Tayfi Pink (TP). The plots were replicated three times, with each replication covering a surface area of 0.2 ha. The plots were irrigated every year with amounts ranging from 500 to 550 mm ha^{-1} with irrigation treatments on 6 - 7 planned dates.

Measurements

Each year after the grape harvest, the yield was determined for a surface area of 1 ha. Grapes were taken from each plot for analysis. One collective sample consisted of 15 primary samples from different parts of the plot. Total sugars content and total acidity were determined on fresh samples of fruits. A total sugars assay was performed by the anthrone method as described by Yemm and Wills (1954). Total acidity was measured by titrating sodium hydroxide into a sample of grape juice to neutralize the acid in the juice. For the purpose of determining the P and K content, laboratory samples of berries were dried at a temp. of 65°C, homogenized and subjected to wet mineralization in a closed system by microwave energy. A microwave system Anton Paar Multivawe 3000 was used for mineralization. Samples of berries were mineralized in a mixture of nitric acid solution (V) and dihydrogen dioxide at a volume ratio of 1:3. The weight of an analytical test portion was a maximum of 0.5 g of dry weight. The concentration of the elements under analysis in the solutions obtained was determined by the atomic emission spectroscopy method, using an Optima 7600 instrument made by Perkin Elmer.

For the purpose of determining the Recovery Efficiency coefficient (RE), the following formula was used (Oosterhuis et al. 2014, Niemiec et al. 2015): yield in treatments with added P and K fertilizers

$$RE\,(\%) = \frac{U - U_0}{F} \times 100,$$

where: U – Fertilized crop P/K uptake,
U_0 – Unfertilized crop P/K uptake,
F – P/K applied.

for the purpose of determining the Agronomic Efficiency coefficient (AE), the following formula was used (Øvsthus et al. 2017):

$$AE\,(kg\,kg^{-1}) = \frac{Y - Y_0}{F},$$

where: Y – Yield in treatments with added P/K fertilizers,
Y_0 – Yield without addition of P/K fertilizer (control),
F – P/K applied.

Relative Agronomic Effectiveness (RAE) was determined using the following formula (Saggar et al. 1993. Barreto et al. 2018):

$$RAE(\%) = \frac{Y - Y_0}{Y_i - Y_0} \times 100,$$

where: Y – Yield in treatments with added fertilizers (B, C, D, E)
Y_0 – Yield without addition of fertilizer (control)
Y_i – Yield obtained with basic dose (A)

Statistical analysis

ANOVA was applied to process the results. The significance of mean differences among the objects was tested with the multiple comparison procedure, and the Tukey's range test was applied at a significance level of α=0.05. All analyses were performed using the statistical software package Statistica v. 12.0 (StatSoft Inc. Tulsa, USA).

RESULTS AND DISCUSSION

The research results show that grapes from the unfertilized variant had a significantly lower content of P and K than in those from fertilized objects (Table 3). There were no significant differences in the content of P and K among the fertilized variants. Fertilization led to significant differentiation in the size of yield obtained from both Husain White (HW) and Tayfi Pink (TP) varieties. The Tayfi Pink (TP) produced yield that was on average 6.84% larger than that harvested from Husain White (HW) – Table 3. TP is a late-ripening variety, with a growing period prior to harvest lasting 160 to 170 days, while for HW the growing period duration was from 126 to 138 days, with the differences caused by genetic traits of the varieties. The application of 200 kg N ha^{-1}, 44 kg P ha^{-1} and 83 kg K ha^{-1} (treatment A) had an impact which led to a yield being 3.61-fold larger from the HW variety and 3.74-fold larger from TP in relation to the yield obtained on the control plot (without fertilization). A similar result was obtained using fertilization

Table 3

Selected yield indices for grapes

Indicators	Variety	Fertilization#						Average
		Control „0”	A	B	C	D	E	
P (mg kg^{-1}) in berries	HW	6125.6±335.2*a*	6557.6±389.1*b*	6548.2±399.3*b*	7054.2±767.9*b*	7041.2±582.1*b*	7081.5±596.5*b*	6734.7±872.1*b*
	TP	6119.2±340.1*a*	6591.3±397.3*b*	6591.1±346.5*b*	7052.3±636.7*b*	7062.2±577.6*b*	7094.5±653.4*b*	6751.8±816.5*b*
K (mg kg^{-1}) in berries	HW	682.3±24.2*a*	713.2±30.3*b*	715.2±30.8*b*	754.5±41.9*b*	749.5±43.5*b*	763.5±30.2*bc*	729.7±90.4*a*
	TP	678.2±29.5*a*	714.6±29.7*b*	718.2±33.1*b*	755.2±39.3*b*	752.5±40.2*b*	768.2±42.1*bc*	731.2±87.2*a*
Yield (t ha^{-1})	HW	4.321±0.14*a*	15.63±0.10*c*	15.62±0.09*c*	18.86±0.21*e*	19.12±0.24*e*	20.55±0.08*g*	15.68±0.15*a*
	TP	4.701±0.07*b*	17.21±0.09*d*	17.20±0.08*d*	19.74±0.11*f*	20.13±0.09*f*	21.17±0.11*h*	16.75±0.69*b*
Sugar content (%)	HW	21.52±0.12*d*	20.12±0.21*abc*	21.8±0.15*d*	20.9±0.07*cd*	21.2±0.04*c*	21.6±0.05*d*	21.18±0.03*a*
	TP	21.27±0.14*cd*	19.93±0.09*abc*	19.04±0.10*a*	19.31±0.06*ab*	20.62±0.09*cd*	20.84±0.07*cd*	20.13±0.06*b*
Total acidity (%)	HW	0.281±0.03*bcd*	0.330±0.02*d*	0.301±0.01*cd*	0.314±0.01*cd*	0.344±0.02*d*	0.312±0.02*cd*	0.312±0.01*a*
	TP	0.191±0.08*a*	0.221±0.02*ab*	0.225±0.01*ab*	0.254±0.02*ab*	0.223±0.01*ab*	0.256±0.02*ab*	0.224±0.01*b*
Dry mass (%)	HW	17.92±0.15*a*	22.3±0.05g	23.62±0.03h	23.91±0.21i	20.43±0.06d	22.57±0.07g	21.77±0.55a
	TP	19.21±0.05*b*	20.04±0.04c	21.51±0.06e	21.36±0.05e	21.93±0.05f	21.92±0.08f	20.93±0.03b

[1] control „0” – without fertilization, A – N_{200}, P_{44}, K_{83}, B – farmyard manure, C - N_{200}, P_{88}, K_{83}, D – N_{200}, P_{132}, K_{83}, E – N_{200}, P_{88}, K_{166}, values with different letters are significantly different ($p<0.05$) among the treatments. ± SD, HW – Husain White, TP – Tayfi Pink

with manure (B), where the yield was 3.62- and 3.68-fold larger for HW and TP, respectively, in relation to the yield obtained on the control plot. No statistically significant differences were observed with reference to the yield obtained with treatments A and B from both varieties. An increase in a dose of phosphorus by 44 kg ha^{-1} (treatment C) in relation to variant A led to a significantly larger yield obtained from both cultivated varieties. The HW variety responded by a 20.66% increase in yield and the yield from TP increased by 14.70% in relation to the dose supplied in variant A. While a further increase in the dose by 44 kg P ha^{-1} (treatment D) did indeed cause a significant increase in harvest yield by 22.32% and 16.96% for the varieties HW and TP, respectively, in relation to the yield obtained in variant A, no statistically significant increase was observed in relation to variant C. In a study by Sierra and Alfaro (2008), an increase in fertilization with phosphorus by 88 kg ha^{-1} led to a yield being 23.72% larger in relation to the plots without phosphorous fertilizers. The use of phosphorus by vines is related to the plant's physiological functions, with no excessive accumulation of this element observed in the plant when it is delivered in an optimal amount with fertilizers. An excessive amount of phosphorus in the soil is not a direct problem in the cultivation of vines, although it may impair the uptake of other essential nutrients, such as zinc (Sala, Blidariu 2012, Sala, Dobrei 2015, Brunetto et al. 2015), and thin in turn may limit the size and quality of yield. The largest grape yield from both cultivated varieties was obtained in fertilization variant E (200 kg N ha^{-1}, 88 kg P ha^{-1} and 166 kg K ha^{-1}). This fertilization variant resulted in a yield that was 4.75 and 4.42-fold larger (for HW and TP respectively) than that from the unfertilized control plots, while with reference to the yield obtained in the basic fertilization variant (A), the yield on plots under treatment E was larger by 31.47 and 22.69% for HW and TP, respectively. A factor that had a significant impact on an increase in the harvested yield of grapes in fertilizer variant E was a rise in the dose of potassium from 100 to 200 kg ha^{-1} compared to variant C (with identical doses N and P), which raised the harvested yield by 6.96 and 8.95% for HW and TP, respectively. An increase in the dose of potassium alongside the supply of appropriate amounts of nitrogen and phosphorus enabled such an increase in yields (Mpelasoka et al. 2008, El-Razek et al. 2011). Qualitative analysis of yield showed that berries of the HW variety contained a significantly larger total sugars content, higher by 5.21% on average. Berries of the HW variety reached maturity during a period when days were longer and sunshine was intensive, which resulted in greater saturation of the fruits with sugars (Rienth et. al. 2016, Reshef et. al. 2017, Reshef et. al. 2018). The situation was similar in the case of the acidity of fruits, where the differences between the analyzed varieties reached as much as 28.25% and were statistically significant. Based on the analysis of the effect of fertilization on the total sugar content of grape berries and their overall acidity, it was found that the use of different doses of fertilizers did not have any significant effect on these parameters. In a study by Döring et al. (2015) and Ranca et al. (2016), the use of mineral fertilizers or their abandonment were also found not to have any effect on the total sugar content of grape berries or their overall acidity. In turn, Oliveira et al. (2013) note that a limited level of stress factors introduced into the cultivation of fruits and vegetables (e.g. the restriction of fertilization) can have a favourable effect on the quality of yield, including the sugar content and acidity. Figure 1 shows the values of the RAE coeffi-

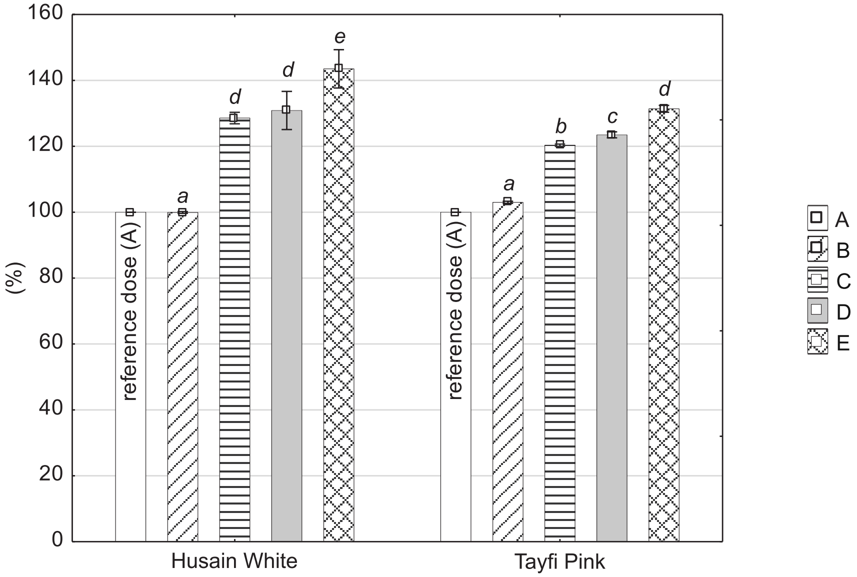

Fig. 1. The values of Relative Agronomic Effectiveness (RAE). Values with different letters are significantly different (p<0.05) among the treatments. Error bars represent the standard deviation. A – N_{200}, P_{44}, K_{83}, B – farmyard manure, C - N_{200}, P_{88}, K_{83}, D – N_{200}, P_{132}, K_{83}, E – N_{200}, P_{88}, K_{166}

cient. It was determined that variant E, characterized by the highest yield, was also the most effective one. In the context of sustainable crop production, an important element in good farming practice is the selection of optimal doses of fertilizers, which makes it possible to obtain the maximum yield while minimizing the loss of nutrients and reducing the impact of production on the environment. Figure 2 shows the RE coefficient for phosphorus, being the highest in variants B and A, with the lowest doses of this element. The increase in the phosphorus dose to 88 kg ha^{-1}(C) caused a statistically significant increase in harvest yield (in relation to variants A and B) simultaneously accompanied by a fall in the RE coefficient by 31.19 (HW) and 36.51% (TP). A further increase in the dose of phosphorus had a significant effect on the growth in yield, although also meant a significantly lower use efficiency of the component applied (Figure 2). The AE coefficient also indicated that a several-fold increase in the fertilizer dose did not cause an increase in the efficiency of the given fertilizer variant (Figure 3). Figure 3

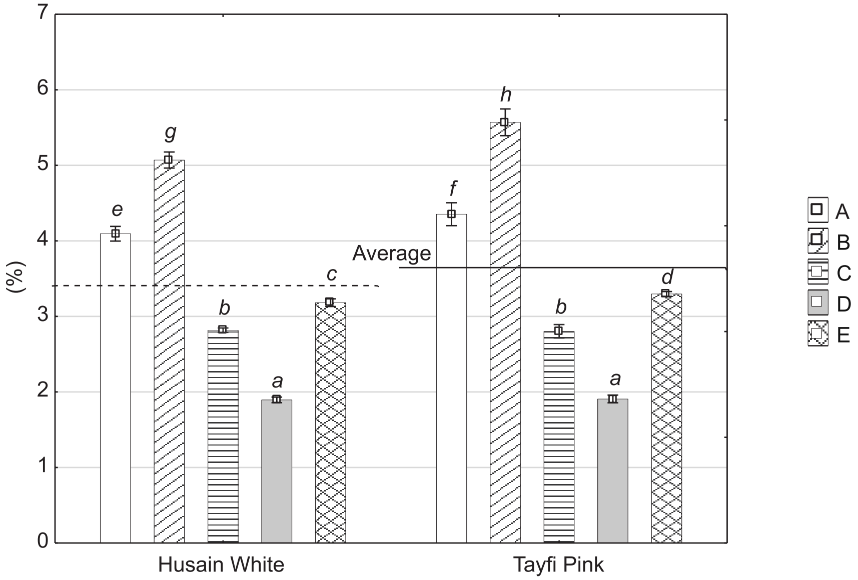

Fig. 2. The values of Recovery Efficiency (RE) for P in the successive variants of fertilization. Values with different letters are significantly different (p<0.05) among the treatments. Error bars represent the standard deviation. A – N_{200}, P_{44}, K_{83}, B – farmyard manure, C – N_{200}, P_{88}, K_{83}, D – N_{200}, P_{132}, K_{83}, E – N_{200}, P_{88}, K_{166}

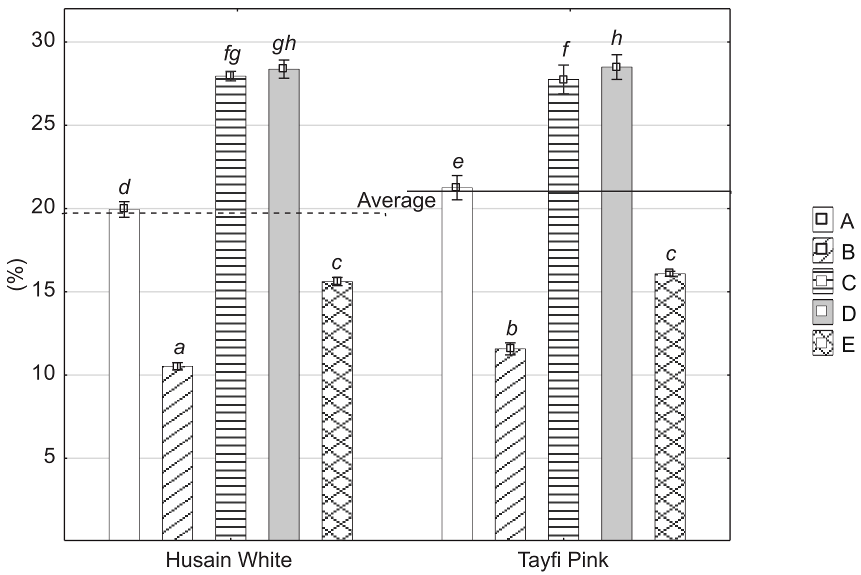

Fig. 3. The values of Recovery Efficiency (RE) for K in the successive variants of fertilization. Values with different letters are significantly different (p<0.05) among the treatments. Error bars represent the standard deviation. A – N_{200}, P_{44}, K_{83}, B – farmyard manure, C – N_{200}, P_{88}, K_{83}, D – N_{200}, P_{132}, K_{83}, E – N_{200}, P_{88}, K_{166}

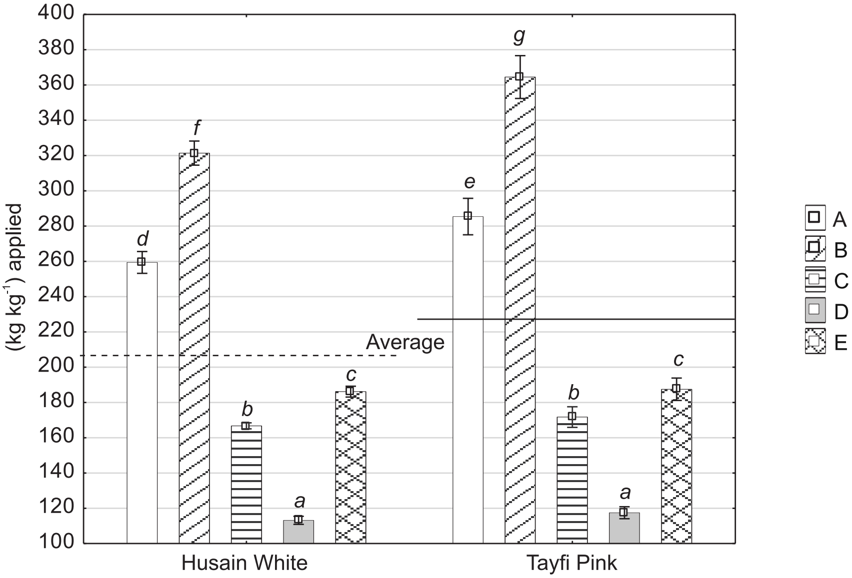

Fig. 4. The values of Agriculture Efficiency (AE) for P in the successive variants of fertilization. Values with different letters are significantly different (p<0.05) among the treatments. Error bars represent the standard deviation. A – N_{200}, P_{44}, K_{83}, B – farmyard manure, C – N_{200}, P_{88}, K_{83}, D – N_{200}, P_{132}, K_{83}, E – N_{200}, P_{88}, K_{166}

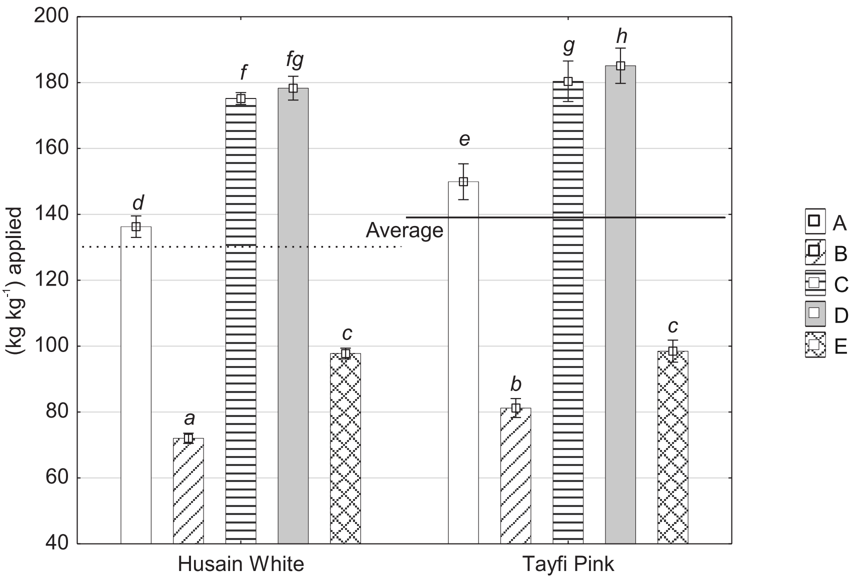

Fig. 5. The values of Agriculture Efficiency (AE) for K in the successive variants of fertilization. Values with different letters are significantly different (p<0.05) among the treatments. Error bars represent the standard deviation. A – N_{200}, P_{44}, K_{83}, B – farmyard manure, C – N_{200}, P_{88}, K_{83}, D – N_{200}, P_{132}, K_{83}, E – N_{200}, P_{88}, K_{166}

shows the RE coefficient calculated for the applied K, with the largest value of the coefficient being obtained under fertilization variants C and D (83 kg K ha^{-1}). An increase in the K dose to 166 kg ha^{-1} (variant E) caused a significant decrease in the value of the RE coefficient for both tested varieties by 12.29% on average in relation to variants C and D. Similar correlations were obtained for the AE (Figure 4), with the greatest efficiency with respect to the dose of potassium obtained at the amount of 83 kg K ha^{-1}. Taking into account phosphorus and potassium use efficiency as expressed by the AE and RE coefficients (Figures 4 and 5), it was observed that values of both coefficients exceeded the average ones only on plots subjected to fertilizer variant A.

CONCLUSIONS

1. Considering the size of the yield obtained, the fertilization variant delivering 200 kg N, 88 kg P and 166 kg K ha^{-1} was found to be the most efficient.

2. An increase in the doses of phosphorus and potassium significantly increased grape yield, although it also entailed a significantly lower use efficiency for the elements applied.

3. The applied fertilizer doses were not found to have caused differences in the sugar content in grapes or their acidity.

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