Effect of potassium fertilization on capacity and grape yield of the vines and on some characters of the must of the grape cultivar Agiorgitiko (*Vitis vinifera* L.) under vineyard conditions

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Abstract:

This study was conducted to investigate the effect of potassium fertilization on capacity and grape yield of the vines and on some characters of the must of cv "Agiorgitiko/110R" under vineyard conditions. Seven fertilization treatments were applied annually during three growing years (2009, 2010, 2011) on clay loam soil, in a K-deficient vineyard, of Nemea vine growing zone, in a completely randomized design. The results show that the concentration of exchangeable and soluble potassium in soil increases compared to the control treatment and so does the concentration of potassium in all treatments during flowering and ripening. The potassium fertilization seems to cause an increase in the average number of inflorescences within limits, which resulted in an increase of the yield, confirming the fact that potassium in sufficient quantities is essential in the process of the differentiation of the buds and the formation of the flower primordium. The highest average load per vine was combined with the highest average number of inflorescences and the higher weight of grape with lower number of inflorescences. The characters of the must of the grapes from treatments showed improvement approaching the normal levels of red musts, which can be attributed to potassium fertilization. Additionally, it seems that the effect of potassium fertilization on the characters studied depends on the initial concentration of potassium in the soil and vines, the soil content of clay, the weather conditions, the rootstock used and the type of potassium fertilizer used. Finally, potassium fertilization affects up to a limit the capacity as well as the must characters of the grape cultivar "Agiorgitiko" under vineyard conditions.

Key words: grapevine nutrition, fertilization, potassium, capacity, K response, juice potassium, grape yield, must quality

INTRODUCTION

The fertilization of the grapevine is an important viticultural procedure that affects the production in terms of both quality and quantity (Jackson and Lombard 1993, Nair 1998). The fertilization programs aim to cope with the deficiency of certain elements that may appear on vines, in order to ensure a balance between growth and fruit set, the normal course of maturation of the grapes for the production of high quality wine and the timely and full differentiation of shoots.

It is known that K is among those mineral elements (N, P, Mg) that continue to accumulate throughout berry growth (Rogiers et al. 2006, Petek et al. 2008) and it is also known that the grapevine is one of the most potassium-friendly plants and has a better ability to utilize soil K than most of the other plants (Bravdo & Hepner 1987). Potassium (K) constitutes up to 3% of the dry weight of a grapevine. In red varieties, potassium is important for berry colour development. Like phosphorus, high levels of potassium do not directly affect the vine or fruit but may limit calcium and magnesium uptake and increase grape juice pH levels. Berry K concentrations can be manipulated, intentionally or otherwise, by numerous viticultural and enological factors (Mpelasoka et al. 2003, Bell and Henschke 2005) that influence yeast growth, must pH (Bisson 1999).

Potassium nutrition status not only affects grapevine growth and development but also plays an important role in plant resistance to diseases (Marschner 1995,Huber et al. 1999, Sharma et Duveiller 2004, Sharma et al. 2005, Dordas 2008) The impact of K fertiliser on the level of available soil K and uptake is influenced by various factors, such as the amount of fertiliser applied, the timing and frequency of application, soil characteristics (Conradie 1989), the amount and frequency of irrigation (Mpelasoka et al. 2003), plant root activity (Mengel & Kirkby 1982) and rootstock-scion combination (Wolpert et al. 2005). As with any nutrient, potassium programs should be based on soil test results.

There are several studies in literature where the role of K was investigated as well as its concentration in many grape varieties. According to Kasimatis & Christensen (1976), crop yield and vine growth increases when K fertilisation is applied to soil that is low in available K. On the other hand, Poni et al. (2003) found that although K fertilisation increased soil exchangeable K significantly, vegetative growth was not affected. An oversupply of K resulting from excessive fertilizer use or a low crop yield in relation to canopy size can lead to high berry K concentrations and quite often, high juice pH (Conradie and Saayman 1989b).Low K supply results in poor vine growth, low yield, premature leaf fall, delayed ripening and low fruit K concentrations and must pH (Conradie and Saayman 1989b, Kubo et al. 1998, Schreiner et al. 2013). Adding potassium to the soil resulted in higher K concentration in berries at harvest of Cabernet Sauvignon grapevines (Poni et al. 2003). The bunch number and fruit yield increased with the increase of K doses up to 200g per vine (Dhillon et al. 1999). Application of potassium in K deficient vineyards significantly increased the fruitfulness of latent buds of *Thompson Seedless* and its mutant (Ganeshamurthy et al. 2011). However, to fully evaluate grapevine supply of N, K, P and Ca it is necessary to know the optimal values for individual elements as well as the cation ratio K/ (Ca+Mg) in leaves. According to Amiri et al. (2007), flower induction (cluster number) and fruit setting, which are important yield components, are influenced by mineral nutrition and the application of macro nutrients (N, K and Mg) combination created more balance between vegetative and reproductive and this observation is in partial agreement with Keller et al., 1998. While it is well known that N and K, in particular, are required for crop yield (Conradie & De Wet 1985, Hunter et al. 2000), vine growth (Conradie & De Wet, 1985), especially when applied on soil low in available K (Kasimatis & Christensen, 1976) and they influence fruit and wine quality (Mpelasoka et al. 2003, Bell and Henschke 2005), the optimum levels of these nutrients present in grapevines are largely unknown particularly for "Agiorgitiko" grown in Nemea.

This experiment was conducted to gain a better understanding of the needs of potassium for optimum growth, yield, fruit and must quality in *Vitis vinifera* cv. "Agiorgitiko", under climatic conditions of Nemea.

MATERIALS AND METHODS

Plant material, Experimental design and vine management

The study was carried out in a full- production vineyard of an important commercial wine grape cultivar "Agiorgitiko" (*Vitis vinifera L.*), on *Richter 110* rootstock, at location of Nemea vine growing zone (PDO, AOC), at an altitude of about 750m above sea level. The experimental vineyard is homogeneous as far as the slope and exposure are concerned as well as to the soil type. The vineyard was on clay loam soil, with pH 7.36 and 0.74% organic matter content. The extractable K was 98 mg kg^{-1}, before the fertilizations treatments took place. Marked foliar symptoms of K deficiency were observed before the initiation of the trial, when soil samples were collected at 30 cm increments to 60 cm and composited for depth. Major physical and chemical properties of the soil were determined before the trial was set up, using the standard methods of the E.E.C. at an analytical laboratory of Ministry of Rural Development and Food (Table 1).

Vines were planted at spacing 1.2m x 2.3m. They were grafted on *Richter 110* rootstocks and were trained to a double Cordon Royat system. All vines were annually winter pruned so that every vine had 6-8 spurs of two buds on cordons. Besides the nutrient treatments, all cultural practices in this experimental vineyard were similar to those of commercial vineyards in the region.

Seven fertilization treatments were applied annually during three growing years 2009, 2010 and 2011, in a completely randomized design with four replicates and 10 vines per replication, per experimental treatment. All treatments were randomized throughout the vineyard and separated by guard (control) vines. In these treatments, in all vines including the control, the amount of lubricant doses of nitrogen and phosphorus was kept stable (80 kg N/ha, applied at budbreak and 40 kg P_2O/ha, applied at winter). The type (source) and/or dose (rate) of potassium application varied in each treatment. Three sources of potassium fertilizer (KCL, K_2SO_4 and K_2SO_4 enriched with magnesium) were used and two rates of K of each of them were compared: 80 and 160 kg /ha. The applications were performed at the same time for all vines. Fertilizers were broadcast uniformly between the rows (Table 2).

Vegetative growth, yield components and berry quality attributes at harvest were measured. The data and results of analysis and measurements presented in this study start from September 2009 to March - April 2011. Fruits from all treatments were harvested on 23rd September 2009 and 2nd October 2010.

Results of all three seasons were combined and only the average values are presented in this report.

Soil and tissue analysis

Hence representatives samples of soil, once a year (2009, 2010), as well as, representatives samples of leaves were collected, during the growing period: at flowering (full bloom) and at ripening (before harvest) times every year from each treatment, for further analysis of potassium changes in soil and leaves.

It is known that leaf tissue analysis provides a guide for vineyard nutrient management (Robinson 1992). Leaves samples were collected early in the morning, per vine and per treatment-replicate. They were taken from fully developed leaves, opposite to the clusters, at bloom and opposite to the bunches at ripening (Hepner and Bravdo 1985; Bravdo 2008). They were sent to an analytical laboratory, using the standard methods of the E.U, for processing and analysis. The nutrient levels in these plant tissues most accurately reflect the uptake of nutrients by the crop. (Dhillon et al. 1999, Patel and Chadha 2002)

To determine soil nutrient status, soil samples were collected per treatment- replicate, at a depth of 0 to 30 cm, mixed into a composite for each treatment (total number of samples: 7) and were sent to an analytical laboratory of Ministry of Rural Development and Food, using the standard methods of E.E.C., for processing and analysis.

Measurements

During the experiment, the number of inflorescences and their average number and also the weight (and the average) of grapes (bunches) were recorded. Cane pruning weights of dormant vines and their average were collected after each growing season. We also determined the performance of the vines, the capacity index and the grape yield for each treatment and for each year. Finally, we performed an analysis of the must for each treatment and for each year (berries were randomly sampled) for the determination of sugars, active acidity (pH), total acidity (as tartaric acid equivalent), tartaric, malic, citric acid, potassium content to investigate the effects of potassium levels and sources.

Statistical analysis

Data were statistically evaluated by one way analysis of variance (ANOVA) in order to compare the effects of different sources and types of potassium applications. Statistical differences with *P* values under or equal 0.05 were considered significant and their means were compared by Student's t test, using JMP 8.1 (SAS Institute Inc., Cary, NC, USA) program.

Table 1: Soil analysis of the vineyard before fertilization treatments

electrical conductivity saturation	pH	water saturation (SP)	extractable Ca	extractable Mg	exchangeable K	exchangeable Na	Mg/K	Ca/Mg	Ca/K	organic substance	total $CaCO_3$	active $CaCO_3$	assimilable P	soluble K	exchangeable sodium pe

(EC)															rcentage (ESP)
mS/cm		%	mg/kg	mg/kg	mg/kg	mg/kg				%	%	%	mg/kg	mmol/l	%
1,24	7,36	47	6814	100	98	60	3,3	41,5	136	0,74	19	3,1	3	0,18	0,5

Table 2: Fertilization treatments of the experiment

TREATMENT	FERTILIZER	N	P_2O_5	K_20	MgO
		[g fertilizer per vine]			
A	N:P (CONTROL)	88	25	0	0
B	N:P:K – KCL	88	25	46	0
Γ	N:P:K – KCL	88	25	92	0
Δ	N:P:K – K_2SO_4	88	25	38	0
E	N.P:K – K_2SO_4	88	25	76	0
Z	N:P:K: Mg	88	25	76	
H	N:P:K: Mg	88	25	152	

RESULTS – DISCUSSION

The results of the experiment are presented in tables 3,4,5,6 and in figures 1,2,3,4,5,6,7.

A comparative study of the results on the effect of potassium fertilization treatments (0, 46, 92, 38, 76, 76, 152 g / vine) on performance, grape yield and on some characters of the must of "Agiorgitiko" (*Vitis vinifera L.*) reveals the following:

All the treatments of fertilization in the experimental vineyard caused, initially, increase in the concentration of exchangeable (treatments: E, Z, H) and water-soluble (treatment: Z, H) potassium in the soil compared to the control. The treatment Z gave the same concentration as the treatment H, with half the amount of K_2O (Figure1). Significant increases in soil K content were obtained for the K fertilisation treatments. In addition, the data of the experiment showed that an excess of potassium fertilization does not imply a corresponding increase of the concentration of readily available potassium in grapevines, probably due to the clay soil. (Tan 1982, Tisdale et al. 1985)

The level of potassium in leaves fluctuated during the spring of 2009 in all treatments with potassium fertilization varying from 0.58 to 0.75 %. These values were lower than normal below which occur K deficiency (Fregoni 1998). The concentration of potassium appears to increase in all treatments, during the flowering of the next year. The highest level of potassium in leaves (year 2010) is found in the treatments Z, H and E (Figure 2). None of the K fertilisation treatments, however, succeeded to raise leaf K concentrations above acceptable maximum norms (Conradie 1986c). It could be noted that this increase was accompanied by a decrease in the concentrations of the cations Na, Mg Ca. Contrary to what was expected (Barker and Pilbeam 2007), there was not statistically significant decrease in treatments Z and H. The ratio K/Mg was satisfactory in all treatments, with high rate to treatment Z. A reduction of concentrations of potassium in leaves is also observed in all replications of treatments from bloom to ripening that confirmed the literature data (Christensen 1969). The factor "year experiment" was found to exert a significant effect on the concentration of potassium in the various treatments during the flowering (2009, 2010) (Table 3).

The potassium fertilization seems to cause an increase in the average number of inflorescences. The highest average numbers of inflorescences were given by the treatment Z (2010), with a statistically significant difference from all the others in all years (Figure 3). In comparison with the previous year, in 2011 there was a decrease in the average numbers of inflorescences with no differences found among the treatments (Figure 3). The above confirm that the potassium in sufficient quantities is necessary in the stage of differentiation of the buds and the formation of flower primordium (Dhillon et al. 1999, Ganeshamurthy et al. 2011). Additionally, it could be suggested that the effect of potassium fertilization increases up to a maximum the average number of inflorescences. Significant difference was observed in factors "treatment" and "year experiment", with no interaction between these factors. (Table 4)

Regarding the average load (average weight of grapes) per vine and treatment, the highest values were given by the treatment Z in 2010, which also had the highest number of inflorescences per vine for the same year (Table 5). (Amiri 2007).

The average weight per grape per vine had significant difference by year and treatment. In the two years of the experiment, the greater weight per grape vine and treatment was found at grapes of the treatment E (Figure 5). The analysis showed that the greatest influence on character “average weight grape” was the factor “year of experiment” (Table 6). It seems that the greatest average load per vine is combined with the highest average number of inflorescences and the greater weight grape with the lower number of inflorescences.

The grape yield of the vines (tn/ha) appears to have increased in all treatments with potassium fertilization, during the second year of the experiment (2010). The highest rates of grape yield were given by the treatment Z and H. (Figure 6).

The average weight of canes per vine and treatment had no significant difference by year and treatment. (Figure 7).

The effect of K on the characters of grape must quality in all treatments was similar, despite the content of must in potassium (data not shown). Thus the content of the must potassium in all treatments was higher in 2010 and it was followed by an increase of sugars, up to a limit, an increase of pH and a decrease in total acidity, as well as a decrease of tartaric and malic acids. The results were in agreement with previous studies (Morris et al. 1982, Rühl 2000, Mpelasoka et al. 2003).

In conclusion this study indicates that K pronounced effects on various yield and quality components of "Agiorgitiko" with previous reports. The effect of K concentration on must quality also needs to be further studied.

Tables and Figures

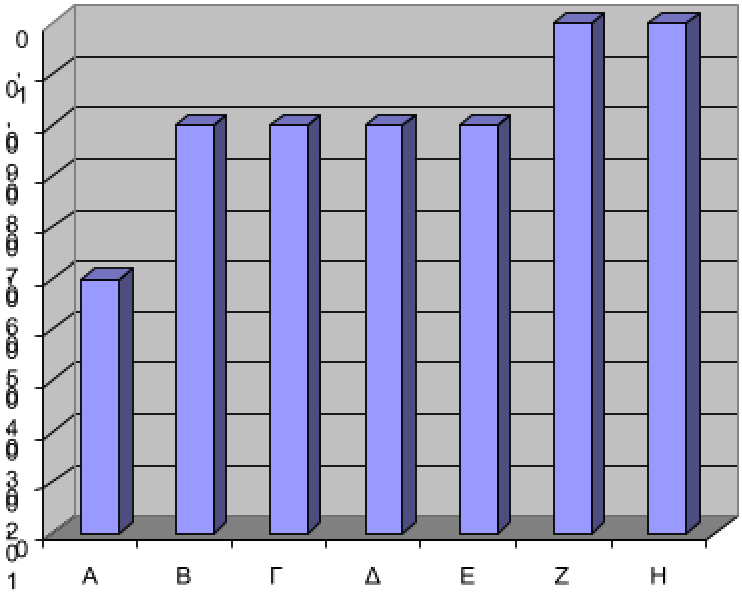

Figure 1: Water soluble K of soil per treatment (2010)

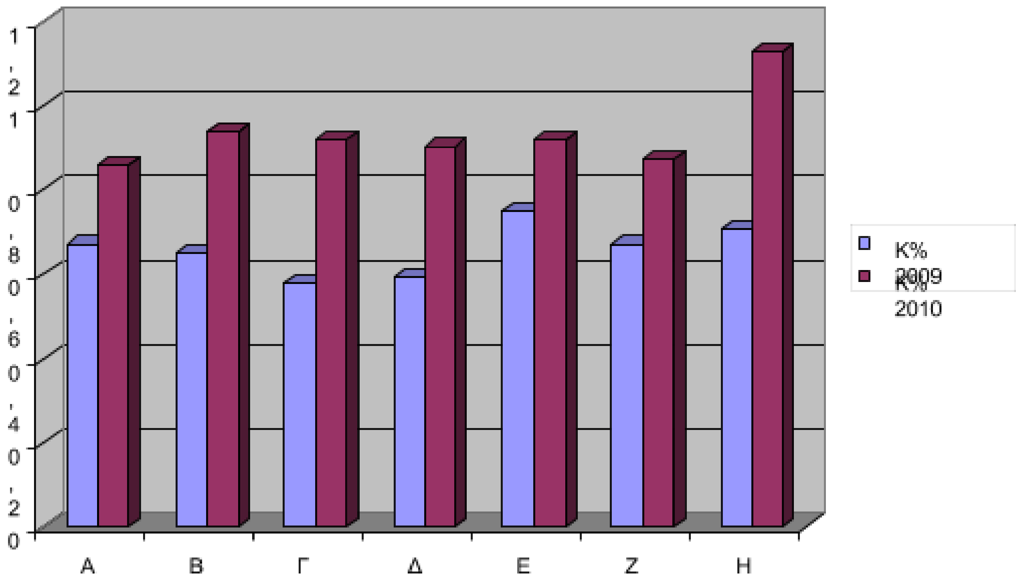

Figure 2: K concentration in leaves during bloom

Table 3: Analysis of K concentration in leaves (bloom 2009, 2010)

	A	B	Γ	Δ	E	Z	H	AVG

2009	0.66 bcde	0.65 cde	0.57 e	0.60 de	0.74 bcde	0.67 bcde	0.70 bcde	0.65 b
2010	0.85 bcd	0.93 ab	0.92 abc	0.90 abc	0.92 abc	0.87 abc	1.13 a	0.93 a
AVG	0.76 a	0.80 a	0.75 a	0.74 a	0.83 a	0.77 a	0.92 a	

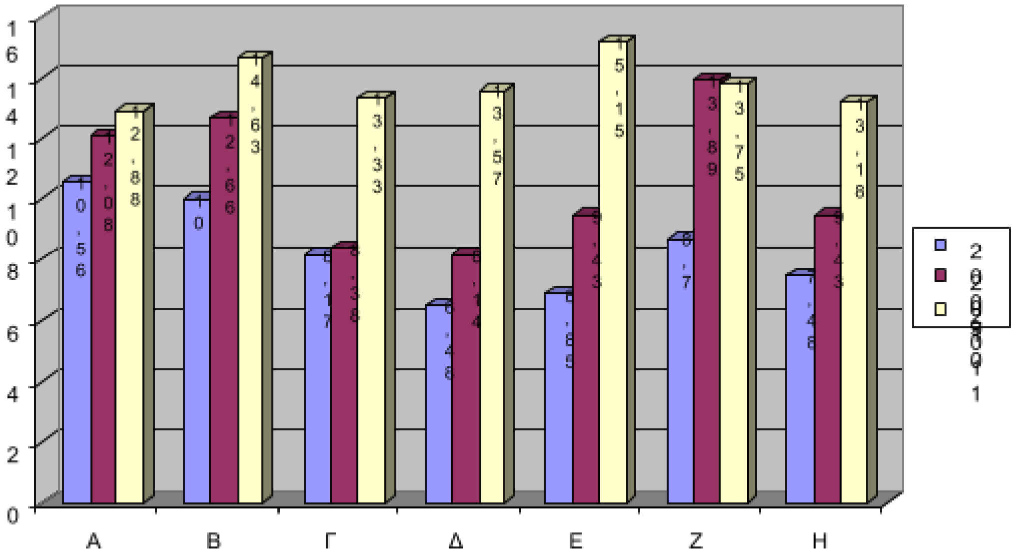

Figure 3: Average number of the inflorescences per treatment and per year (2009, 2010, 2011)

Table 4: Analysis of the average number of inflorescences (2009, 2010, 2011)

	A	B	Γ	Δ	E	Z	H	AVG
2009	10,56 cdef	10 defg	8,17fghi	6,48 i	6,85 hi	8,7 fghi	7,48 ghi	8,31 c
2010	12,08 bcde	12,66 abcd	8,38fghi	8,14 fghi	9,43 efgh	13,89 ab	9,43 efgh	10,57 b
2011	12,88 abcd	14,63 ab	13,33abc	13,56 ab	15,15 a	13,75 ab	13,17 abc	13,78 a
AVG	11,84 ab	12,42 a	9,95 c	9,39 c	10,47 bc	12,11 ab	10,02 c	

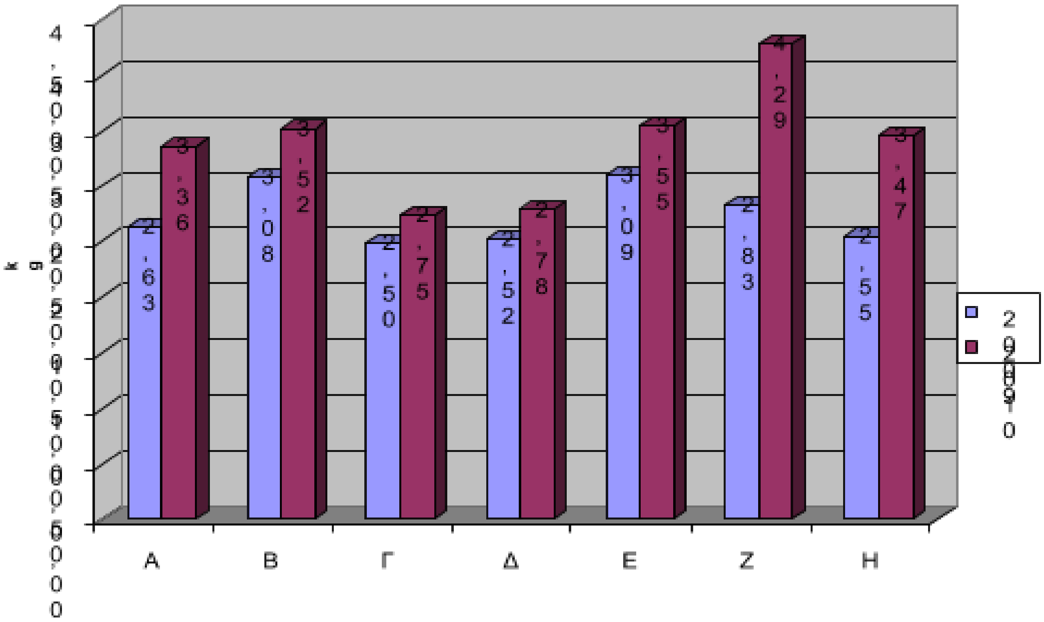

Figure 4: Average weight of the grapes per vine and treatment (2009, 2010)

Table 5: Analysis of the average number of grapes (2009, 2010)

	A	B	Γ	Δ	E	Z	H	AVG
2009	2,63 cd	3,08 bcd	2,50 cd	2,52 cd	3,09 bcd	2,83 bcd	2,46 d	2,73 b
2010	3,36 bc	3,52 ab	2,75 bcd	2,78 bcd	3,55 ab	4,29 a	3,56 ab	3,40 a
AVG	3,00 ab	3,30 a	2,62 b	2,65 b	3,32 a	3,56 a	3,01 ab	

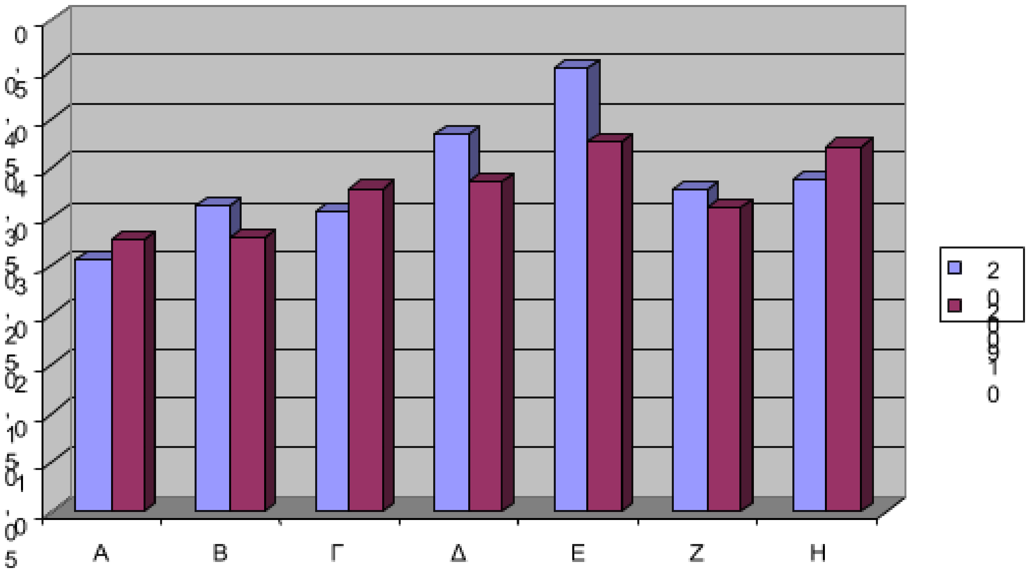

Figure 5: The average weight per grape per vine and per treatment (2009, 2010)

Table 6: Analysis of the average weight per grape per vine and per treatment (2009, 2010)

	A	B	Γ	Δ	E	Z	H	AVG
2009	0,25 f	0,31def	0,306 def	0,38 b	0,45 a	0,32 cde	0,338 bcd	0.33
2010	0,27 ef	0,27 ef	0,32 bcde	0,33 bcd	0,37 bc	0,31 def	0,37 bc	0.32
AVG	0,26	0,29	0.31	0.36	0.41	0.31	0.35	

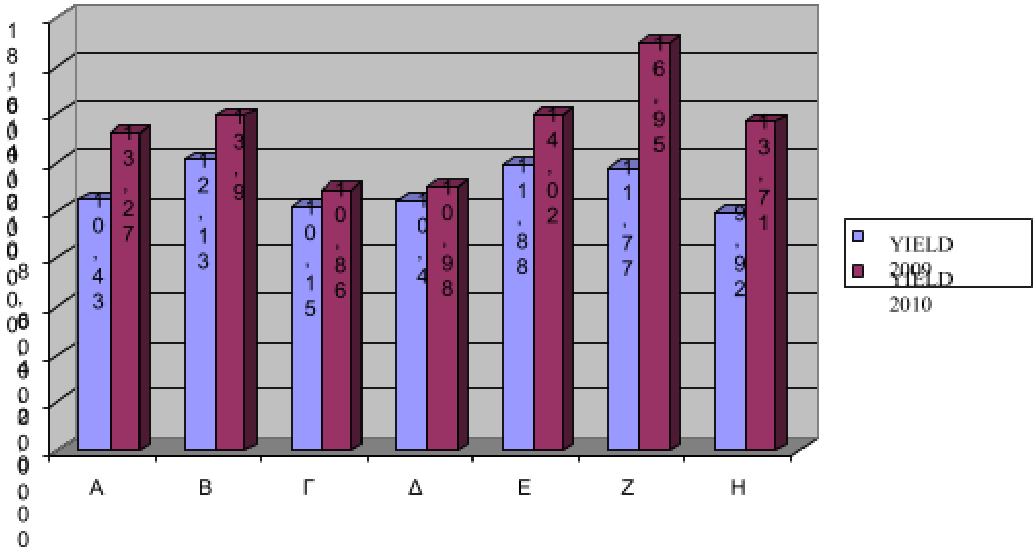

Figure 6: The grape yield of the vines (tn/ha) per treatment (2009, 2010)

Figure 7: The average weight of canes per vine and per treatment (2009, 2010)

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