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Irrigation and fertigation effects on phosphorus and potassium nutrition of wine grapes

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Summary

The optimal rate of irrigation of the three wine grapes Sauvignon blanc, Merlot, and Cabernet Sauvignon, grown in a semi-arid environment in Israel, was investigated during 1992 - 1998. The drip irrigation rate was gradually raised after bud break up to a level of either 0.3, 0.4 or 0.5 Pan A coefficient, and then these coefficients were maintained throughout the rest of the growing season. In an additional experiment the effects of secondary purified recycled effluent and fresh water irrigation was compared in Merlot and Cabernet Sauvignon, irrigated by surface and sub-surface drippers. The nutritional status of the vineyard was followed by leaf petiole and leaf blade analyses carried out at flowering and at harvest. Leaf petiole and blade analyses indicated that the nitrogen status of the vines was adequate. The tissue potassium level in the young vineyard was luxurious (ca. 2-3 % in petiole at harvest), reflecting an abundant supply of K by the soil, while the tissue concentration of P was at a deficient level (ca. 0.1 % and less in blades at harvest). Potassium levels declined as the vines matured, probably as a result of K depletion from the limited soil volume explored by the root system under drip irrigation. Low rates of annual phosphate fertigation (5.6-13.7 kg ha^{-1} P) raised tissue-P proportionally to the rate of fertigation. Irrigation according to a Pan A coefficient of 0.3, as compared to coefficients of 0.4 and 0.5, significantly reduced tissue-K levels. Irrigation with recycled water (high in NPK) raised tissue-P significantly. The relative depletion of K and P in leaf petioles and blades, from flowering to harvest, was found to be a good indicator of the nutritional status of these two elements. At flowering petiole-P was polynomially and linearly correlated with petiole- and blade-P at harvest, respectively, under a wide range of P nutritional intensities. Leaf blades at flowering and harvest had higher priority for P under low intensity of P nutrition. Suboptimal P nutrition could be diagnosed best by petiole-P concentration at harvest. The inflection petiole concentration associated with optimum P nutrition was 0.413 % P at flowering, which corresponded to 0.133 % P in petiole and blade at harvest time.

K e y w o r d s : leaf analysis, petiole, blade, mineral nutrition, recycled water.

Introduction

The nutritional status of vineyards can be evaluated by soil or plant tissue analysis. In Israel, and many other countries leaf tissue analysis is perferred to soil analysis (SAMISH *et al.* 1960; COOK 1966, 1978). There is however some disagreement with regard to the type of tissue and the best time for leaf sampling. Following a leaf analysis survey carried out by SAMISH *et al.* (1960), a procedure of sampling the blade tissue opposite a cluster, close to harvest, was adopted by the extension service in Israel as a routine practice. In other countries, petioles are analysed at flowering (COOK 1978; ROBINSON *et al.* 1978). In recent years leaf blade analysis close to harvest was questioned, since changes in nutrient concentration in the leaf blade close to harvest are small compared to changes in the petiole. HEPNER and BRAVDO (1985) considered the petiole at flowering time to be a preferable tissue for N and P diagnosis. However, diagnosis of K at flowering was found to be inadequate (HEPNER and BRAVDO 1985).

The appropriate tissue and sampling time for the nutritional diagnosis of two adjacent experimental plots was evaluated by sampling blades and petiole tissues at flowering and harvest. The two experiments were carried out to evaluate the effect of irrigation-fertigation levels on yield and vine quality in a semi-arid environment, and to explore the feasibility of recycled water for vineyard irrigation. The mineral analyses of the experiments are presented here, together with some limited data on yield. Detailed results of yield in relation to growth and wine quality will be presented elsewhere. The data derived from the two experiments enabled to draw conclusions with regard to the nutritional diagnosis of P and K in grapes.

Materials and Methods

A field experiment, evaluating three pan A irrigation coefficients of wine grapes was set up in 1992 in a commercial vineyard (planted in 1989 and located in the semi-desert region of the Arad Plateau (31°18' N, 35 ° 08' E;

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500 m above sea level). Rainfall in this region is very low (ca. 150 mm·year^{-1}). Winters are cold enough to enable sufficient chilling for normal grape development in the spring. Average daily temperatures in summer are 34 °C in June-August while night temperatures are moderate 14-18 °C. The relative humidity during the long dry summer is low, imposing a high evaporative demand (ca. 11-12 mm·day^{-1} of pan A in June-August). Irrigation treatments included either a 0.3, 0.4 or 0.5 pan A coefficient of irrigation. Vineyards in other regions of Israel are routinely irrigated with the intermediate level of a 0.4 pan A coefficient, which equals ca. 250-320 mm of irrigation in the coastal plane of Israel applied during summer (in addition to winter precipitation of 400-800 mm). A coefficient of 0.4 treatment in the Arad Plateau equals ca. 450 - 500 mm of irrigation. The various irrigation coefficients were applied by adjusting the dripper discharge rates within a commercial vineyard. Therefore, treatments were fertigated in proportion to the irrigation rate (Tab. 1).

Annual fertigation started usually in mid-April, at bud break to the end of May, applying two third of the annual fertilizer dose. The remaining one third was applied during October. Nitrogen was applied every year. Phosphorus application started in 1995, after P deficiency was diagnosed.

Irrigation treatments were replicated 4 times, in a randomized block design, in Sauvignon blanc, Merlot and Cabernet Sauvignon. Each replicate consisted of 3 adjacent rows of 40 vines each, spaced 3.0 x 1.5 m. Data and samples were collected from 10 designated vines in the center row. The commercial vineyard was drip-irrigated with 4 l h^{-1} inline drippers, spaced 1 m along single laterals. The vineyard was clean cultivated. The experimental plots received standard maintenance practices, as the commercial vineyard.

In the same vineyard, in a separate experiment, the application of recycled water was compared to fresh water, applying an irrigation coefficient of 0.4 Pan A to Merlot and Cabernet Sauvignon, during 1995-1997. Recycled water contained on the average 46 mg·l^{-1} N, 5.3 mg·l^{-1} P and 44 mg·l^{-1} K (Tab. 1). The recycled irrigation experiment included a comparison of surface and sub-surface drip irrigation. Experimental layout in the recycled irrigation treatment was similar to the fresh water irrigation experiment. Only details of petiole and blade mineral analysis of the recycled irrigation experiment are presented here, mainly to extend phosphate analysis to the extreme tissue-P concentration levels.

Leaf samples were collected annually at flowering (beginning to mid-May) and a few days before harvest (ca. end of July for Sauvignon blanc and mid-August for Merlot and Cabernet Sauvignon). At each sampling date 30 leaves, from opposite the first or second cluster, were collected and blades and petioles separated. Fifteen blades and all 30 petioles were washed with soap, tap water and three times with distilled water. Blade and petiole samples were dried at 80 °C and ground to pass 30 mesh. Ground samples were digested with concentrated sulfuric acid and clarified with H_2O_2 for total N analysis, or extracted with 1N HCl for nitrate analysis. Phosphate and K were analyzed after digestion with nitric acid. Total N was analyzed by the Nesler color reaction, nitrate by the salicylic acid color reaction and all the other elements from the nitric acid digestion by plasma emission (ICP).

Results

Intensity of P nutrition as reflected by tissue-P concentrations: Each year leaf analyses were repeated at flowering and close to harvest. The N irrigation rate and recycled water irrigation did not affect consistently tissue nitrate and ammonium concentrations (data not presented). Until 1994 only N was fertilized at a proportional rate to the irrigation coefficient (Tab. 1). In 1993, P concentration of the blade close to harvest was ca. 0.1% in all three cultivars (Fig. 1). The P level in the petiole was very low at flowering and harvest, indicating marginal intensity of phosphate nutrition. In 1994, phosphate concentration further declined, reaching a deficient level of <0.1 % P in the blade close to har-

Table 1

Annual N-P fertigation in the irrigation experiment and NPK input in the recycled water irrigation experiment (kg·ha^{-1} year^{-1}) in the Arad Plateau

	Pan A Irrigation Coefficient						
Cultivar	0.3	0.4	0.5	0.3	0.4	0.5	0.4
		N			P*		K
Fresh water irrigation experiment (N-P fertigation)							
Sauvignon blanc	49	65	81	5.6	7.5	9.3	
Merlot	71	95	119	8.2	10.9	13.7	
Cabernet Sauvignon	53	70	88	6.0	8.1	10.1	
Recycled water irrigation experiment, Merlot and Cabernet Sauvignon (NPK input)							
Fresh water	---	95	---	---	10.9	---	---
Recycled water	---	240	---	---	24.0	---	202

* P fertigation in the fresh water irrigation experiment started in 1995

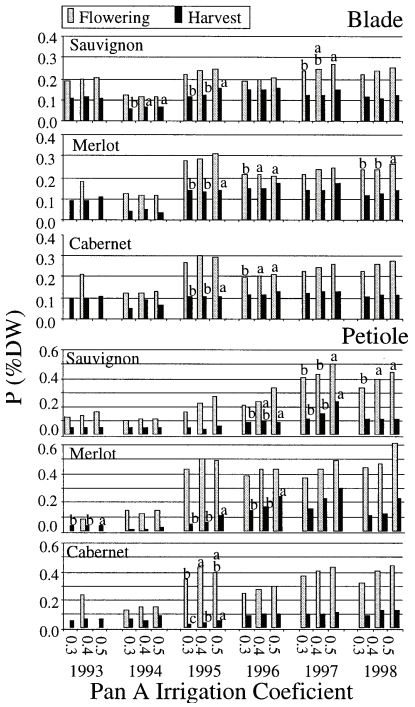

Fig. 1: Phosphate concentration in leaf petioles and blades, at flowering and harvest for Sauvignon blanc, Merlot and Cabernet Sauvignon irrigated with three coefficients of Pan A.

vest. After the diagnosis of P deficiency, the fertilizer formulation was changed in 1995 to a compound liquid fertilizer of 19:5:0 composition. Since irrigation treatments were achieved by adjustment of the dripper discharge rates, the various treatments received N-P fertigation rates proportional to the irrigation rates (Tab. 1). Phosphate fertigation raised petiole and blade P concentration already in the first year of application (Fig. 1). It has been shown previously that grapevines takes up phosphate readily (HAESELER *et al.* 1980; HEPNER and BRAVDO 1985, CONRADIE and SAAYMAN 1989; JANAT *et al.* 1990; STROEHLEIN *et al.* 1990). Overall phosphate concentration in the blades of all three cultivars was raised immediately at flowering and harvest, and was maintained at a fairly steady level during subsequent years of fertigation. The P concentration of the Merlot and the Cabernet Sauvignon petiole at flowering was raised immediately to a high level similarly to the blade. However, Sauvignon blanc petioles at flowering and the petiole-P at harvest of all three cultivars were raised only gradually from year to year. The rise in tissue-P was generally proportional to the fertigation rate, with a greater impact of the fertigation rates on tissue concentration in the petiole as compared to the blade. Overall the Merlot received slightly more P (Tab. 1) and its petiole acquired more P both at flowering and harvest, as compared to the other two cultivars (Fig. 1).

Petiole- and blade-P concentrations at flowering and harvest, averaged for all three cultivars in the fresh water irrigation experiment showed a shift in relative P concentration between petiole and blade as the vineyard shifted from a deficient P nutritional status (1993-1994), through build-up years (1995-1996) to years of steady P levels (1997-1998, Tab. 2).

At low P nutrition the blade-P concentration was higher than the petiole concentration, at both flowering and harvest. After fertigation started, during the years of tissue-P build-up (1995-1996), petiole-P at flowering was higher than blade-P, but it lagged behind the blade-P at harvest. Only after two years of fertigation, soil- and tissue-P reached a fairly steady concentration and then petiole-P exceeded blade-P at flowering and at harvest. There were minor differences in response between cultivars. Petiole-P build-up of Sauvignon blanc was slower than the build-up in the other two cultivars (Fig. 1), and there were slight differences eventually in tissue-P concentrations. As an average for 1997-1998, the blade-P concentration in the 0.4 irrigation coefficient, close to harvest, was 0.114, 0.132 and 0.120 % in the Sauvignon blanc, Merlot and the Cabernet Sauvignon, respectively, These differences in concentration may have resulted from differences in the dose of fertigation (Tab. 1).

In an adjacent plot within the vineyard, a recycled effluent irrigation experiment was conducted with the Merlot. The recycled water effluent contained an average of 5 mg l^{-1} P, supplying an annual rate of ca. 24 kg ha^{-1} phosphate. According to our calculations, P concentration in the 0.4 Pan A treatment of the fresh water irrigation experiment was similar to the P concentration of the recy-

Table 2

Phosphate concentration (% DW) of petiole and blade, at flowering and harvest, averaged for Sauvignon blanc, Merlot and Cabernet Sauvignon during years of low P nutrition (1993-1994), build-up years (1995-1996), and years of steady tissue-P levels (1997-1998) (±SE)

Sampling time	Tissue	1993-1994	1995-1996	1997-1998
Flowering	Petiole	0.133 ± 0.034	0.339 ± 0.097	0.430 ± 0.066
	Blade	0.142 ± 0.039	0.225 ± 0.049	0.244 ± 0.021
	Petiole/blade	0.94	1.51	1.76
Harvest	Petiole	0.047 ± 0.015	0.096 ± 0.055	0.152 ± 0.061
	Blade	0.080 ± 0.025	0.131 ± 0.022	0.129 ± 0.018
	Petiole/blade	0.59	0.73	1.18

Table 3

The effect of recycled effluent irrigation on Merlot petiole- and blade-phosphate concentration (% DW) at flowering and at harvest

Year	Irrigation Water	Petiole Flowering	Petiole Harvest	Blade Flowering	Blade Harvest
1995	Fresh	0.374 b	0.130 b	0.269 b	0.125 b
	Recycled	0.603 a	0.277 a	0.361 a	0.163 a
	% Enrichment	161	213	134	130
1996	Fresh	0.397 b	0.199 b	0.227 b	0.160 b
	Recycled	0.807 a	0.689 a	0.470 a	0.249 a
	% Enrichment	203	346	207	155
1997	Fresh	0.501 b	0.227 b	0.238 b	0.175 a
	Recycled	0.663 a	0.546 a	0.293 a	0.172 a
	% Enrichment	132	241	123	98
Avg.	Fresh	0.424	0.185	0.245	0.153
	Recycled	0.691	0.504	0.375	0.195
	% Enrichment	165	267	154	127

cled effluent, but the application lasted only for several weeks (ca. 8 weeks during spring and fall), rather than the entire season. Fertigation with P and K was found to maintain an elevated concentration of these nutrients in the soil solution, as long as it was applied continuously (KLEIN and SPIELER 1987). Therefore, the recycled irrigation contributed a larger cumulative dose over a longer period of time, as compared to the fresh water irrigation treatments, and consequently raised tissue-P beyond the level achieved by the highest dose of fertigation with fresh water irrigation (Tab. 3).

At flowering the average P enrichment of the petiole (165 %) and the blade (154 %) by recycled effluent irrigation was similar (Tab. 3). Phosphate concentration of the petiole and the blade declined from flowering to harvest, both in recycled and fresh water irrigation. The relative decline, however, in the petiole was less than that in the blade. Close to harvest the relative enrichment of the petiole was twice as much (267 %) than that of the blade (127 %). The considerable P enrichment of the petiole at flowering by recycled water irrigation caused only a moderate increase in the blade concentration at harvest (0.194 % P by recycled water irrigation *vs.* 0.153 % P, using fresh water irrigation).

Intensity of potassium nutrition as reflected by tissue-K concentrations: Potassium concentration in petioles and blades of all three cultivars, when averaged for all irrigation treatments, was high in 1993 and declined gradually, with some yearly fluctuation, until 1998 (Fig. 2). The tissue-K decline resulted from lack of K fertigation and soil K depletion from the limited soil volume explored by the root system under drip irrigation. Initially, the intensity of K nutrition was luxurious, as evidenced by the large difference between K concentration of petiole and blade, at flowering as well as at harvest time. With time, as K concentration of petioles and blades declined, the difference between petiole- and blade-K narrowed, particularly at harvest time in Sauvignon blanc

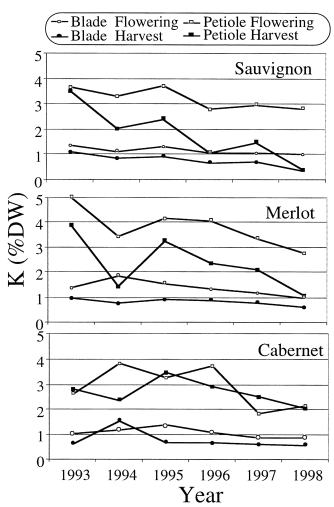

Fig. 2: Potassium concentration in leaf petioles and blades, at flowering and harvest for Sauvignon blanc, Merlot and Cabernet Sauvignon, averaged for three irrigation coefficients of Pan A.

and Merlot. At harvest, petioles and blades of Sauvignon blanc reached an equal (deficient) concentration of 0.38 % K in 1998 (Fig. 2). At harvest in 1998 average petiole-K concentration of Merlot (1.07 %) approached the blade concentration (0.56 %) while at harvest the average Cabernet Sauvignon petiole-K (2.05 %) remained higher than the blade-K (0.59 %). At flowering and harvest the average petiole-K concentration of Cabernet Sauvignon did not differ significantly, although the concentration declined from year to year (Fig. 2).

Close to harvest K concentration in petioles and blades increased as the rate of irrigation was raised, particularly in the last three years, when the nutritional intensity of K declined (Fig. 3). At flowering Merlot and Cabernet Sauvignon showed an opposite trend of lower tissue-K for the higher rates of irrigation, (*i.e.* Cabernet Sauvignon and Merlot petiole during flowering of 1996-1998). At flow-

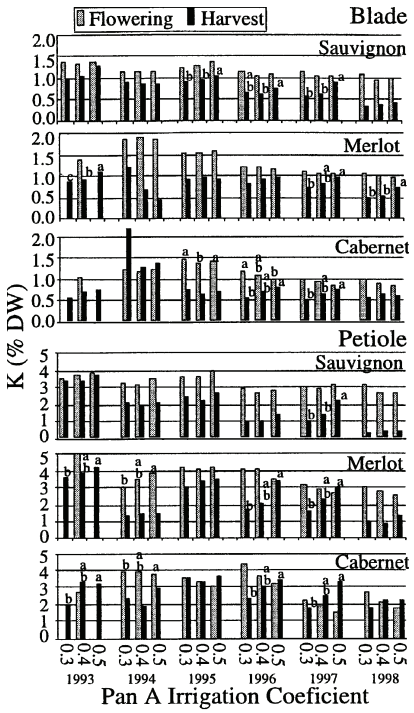

Fig. 3: Potassium concentration in leaf petioles and blades, at flowering and harvest for Sauvignon blanc, Merlot and Cabernet Sauvignon irrigated with three coefficients of Pan A.

ering petiole- and blade-K content of Sauvignon blanc did not decline with increasing irrigation rates, as it declined in the two other cultivars. K was not fertigated, therefore, the increase in tissue-K close to harvest at the higher irrigation rates was probably the result of greater dissolution of K from clay particles and enhanced diffusion in the soil solution, which facilitated greater uptake. The irrigation rate effect was manifested mainly under low K nutritional intensity, during the last three years, and close to harvest, after several months of soil moisture facilitated K uptake during the growing season.

Grape yield: Irrigation-fertigation at the reduced rate of 0.3 Pan A coefficient (with the lowest N-P fertigation rate), as compared to the standard 0.4 Pan A irrigation, reduced the yield significantly in all three cultivars (Tab. 4). The highest rate of irrigation-fertigation increased slightly but insignificantly the yield of Sauvignon blanc, had no effect on the yield of Cabernet Sauvignon, but increased significantly the yield of Merlot. Average yield of each cultivar irrigated with the 0.3 Pan A coefficient during the three consecutive pairs of years (1993-1994, 1995-1996 and 1997-1998) was fairly steady. The positive effect of the elevated irrigation-fertigation rates on yield was greater during 1995-1996, as compared to the previous or the subsequent pair of years (Tab. 4).

Discussion

In a vineyard in Israel petiole and blade analysis in a drip irrigation experiment revealed a deficient P and high K nutritional status. The nutritional status of the three grapevine cultivars Sauvignon blanc, Merlot, and Cabernet Sauvignon, initially fertigated with N only, reflected the fertility of an arable soil in a semi-arid region which was not cultivated previously. Following the diagnosis of phosphate deficiency, P was incorporated in the fertigation scheme of the irrigation experiment, resulting in three gradually increasing N-P irrigation rates (Tab. 1).

There are numerous approaches to leaf analysis of grape, in terms of the preferable tissue, time of sampling and interpretation of data. Originally, 3-4 annual samplings, at specific phenological stages (*e.g.* flowering, veraison, maturity), were proposed for diagnosis (see discussion in Cook 1966, and more recently Janat *et al*. 1990; Stroehlein *et al*. 1990). Currently sampling for routine diagnosis is usually restricted to either petiole (Cook 1978; Robinson *et al.* 1978) or blade (Samish *et al.* 1960; Beyers 1962) at a single date, because of practical considerations, assuming that it is adequate if standardization of sampling

Table 4

Grape yield ($t \cdot ha^{-1}$) of Sauvignon blanc, Merlot and Cabernet Sauvignon during years of low P nutrition (1993-1994), build-up years (1995-1996), and years of steady tissue-P levels (1997-1998) (±SE)

Cultivar	Pan A Irrigation Coefficient	1993-1994	1995-1996	1997-1998
Sauvignon blanc	0.3	14.9 ± 1.6	16.9 ± 2.4	13.3 ± 1.1
	0.4	22.4 ± 1.7	27.0 ± 2.3	18.7 ± 1.0
	0.5	23.8 ± 2.3	32.3 ± 1.2	20.1 ± 0.7
Merlot	0.3	13.3 ± 0.7	13.5 ± 1.1	13.5 ± 1.1
	0.4	17.5 ± 0.8	18.7 ± 0.8	18.9 ± 1.1
	0.5	21.1 ± 1.5	24.2 ± 1.5	22.2 ± 1.7
Cabernet Sauvignon	0.3	17.5 ± 0.8	17.7 ± 1.6	18.2 ± 1.3
	0.4	21.7 ± 0.3	23.4 ± 0.9	18.4 ± 1.1
	0.5	20.7 ± 0.9	24.0 ± 1.0	18.1 ± 1.2

is followed rigorously. For research, however, it appears to be appropriate to sample at least twice (*e.g.* at flowering and at veraison, SKINNER *et al*. 1987; at flowering and at harvest, HEPNER and BRAVDO 1985) and to compare leaf and blade tissues (ULRICH 1942; ATALY 1978; ROBINSON *et al.* 1978; CONRADIE 1981 a; CHRISTENSEN 1984; HEPNER and BRAVDO 1985; JANAT *et al.* 1990; STROEHLEIN *et al*.1990).

The petiole- and blade-P content was enriched readily by phosphate fertigation, starting from the first year of application. Blades had priority for phosphate, therefore close to harvest they had higher P concentrations under deficiency as compared to the petiole, and were enriched to their full potential immediately after fertigation started. The petiole, which is a conducting and storage tissue was enriched close to harvest more gradually, eventually reaching a higher concentration than the blade when the P nutritional intensity improved after several years of phosphate fertigation. SKINNER *et al.* (1987) considered the leaf lamina to be a better indicator of phosphate status, since extractable P accumulated preferably in lamina. The data in Fig. 1 indicate that excess P accumulates in the petiole and to a lesser extent in the blade. Nutrient acquisition in leaf blade is sink driven and lamina phosphate accumulation is probably feedback inhibited by soluble P. Such a mechanism, integrating shoot and root regulation of nutrient uptake (COOPER and CLARKSON 1989) can explain the fact that there is a limit to nutrient accumulation by the leaf lamina and therefore, nutrient concentration levels off eventually at high nutritional intensities.

Comparing leaf petiole and blade at flowering, it was recognized that petiole-P concentration is lower than blade-P at low intensities of phosphorus nutrition while the opposite is true at high intensities (COOK and KISHABA 1956; SHIKHAMANY and SATYANARAYANA 1971; ATALY 1978; CHRISTENSEN 1984; JANAT *et al.* 1990; STROEHLEIN *et al*. 1990). The same trend was found also close to harvest (Tab. 2). ATALY (1978) assumed that the critical P level in petiole at flowering is at the transition point, when petiole and blade concentrations are equal (0.215 % in Thompson Seedless in Turkey). The petiole- and blade-P concentration declines from flowering to harvest (Fig.1, Tabs. 2 and 3). Thus, the concentration at harvest (peak cumulative demand), in relation to flowering (the time of least demand) should be a better indicator of the nutritional status than the concentration at either flowering or harvest alone, or the ratio between petiole and blade at flowering (COOK and KISHABA 1956; ATALY 1978, JANAT et al. 1990; STROEHLEIN *et al.* 1990). The relation between petiole-P at flowering and harvest, at a wide range of intensities of P nutrition (Fig. 1, Tabs. 2 and 3), was found to be polynomial ($r^2 = 0.8038$, Fig. 4). At low intensities, P was depleted from the petiole between flowering and harvest. At increasing nutritional intensities of phosphorous, P was retained in the petiole at harvest, at increasing concentrations. Petiole-P at flowering was linearly related to blade-P at harvest ($r^2 = 0.6532$, Fig. 4). Petiole and blade at harvest reached equal concentrations of 0.133 % P (intersection of the polynomial and linear lines of Fig. 4) when petiole concentration at flowering was 0.413 %. Phosphorus was retained in the petiole between flowering and harvest 2-3

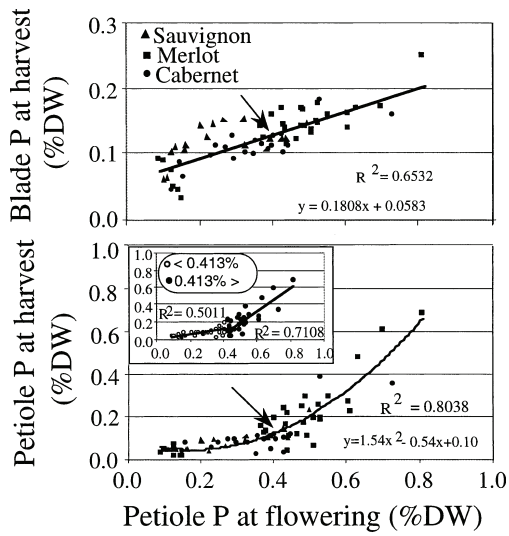

Fig. 4: The relationship between petiole-P concentration at flowering and petiole- and blade-P at harvest in Sauvignon blanc, Merlot and Cabernet Sauvignon. Equations of regression lines in the inset were y = 0.31x and y = 1.33x - 0.45, for regression lines below and above the concentration of 0.413 % of petiole P at flowering, respectively.

times more at high intensities of P nutrition (when petiole P at flowering was above 0.413 %) as compared to low intensities (inset Fig. 4). A petiole concentration of 0.413 % P at flowering, corresponding to 0.133 % P of both, petiole- or blade-P at harvest, can be considered as the optimal phosphorus level of the cultivars Sauvignon blanc, Merlot and Cabernet Sauvignon under the growing conditions of the present experiment (Fig. 4). The P concentrations during the transition years 1995-1996 (Fig. 1), when blade-P was raised almost to its maximal level (0.225 ± 0.049 % and 0.131 ± 0.022 % at flowering and harvest, respectively) and petiole-P was still building up (0.339 ± 0.097 % at flowering but only 0.096 ± 0.055 % at harvest), can be considered as a suboptimal P level. A clear-cut deficiency of P was associated with 0.133 ± 0.034 % and 0.047 ± 0.015 % of petiole-P at flowering and harvest, respectively, and 0.142 ± 0.039% and 0.080 ± 0.025 % of blade-P at flowering and harvest (Tab. 2). Thus, the best diagnosis for a suboptimal level of P was identified by the ratio of petiole-P to blade-P at harvest (≤0.6: deficient, >0.6-1.0: suboptimal, >1.0: optimal, Tab. 2). Contrary to previous reports (HEPNER and BRAVDO 1985; BRAVDO and HEPNER 1987) which considered the petiole at harvest to be the preferable tissue and time for N-P diagnosis, our data indicate that the blade and the petiole are equally suitable for diagnosis of P, if only a single tissue (petiole or blade) is analyzed.

Initially the K supply in the experimental vineyard was abundant, but declined thereafter, reaching in 1998 a deficient level in Sauvignon blanc and in the lower irrigation rates of Merlot and Cabernet Sauvignon (Figs. 2 and 3). The vineyard was established in an arable land, which had not been cultivated before. The native soil had apparently sufficient K to support growth and fruiting for 7-8 years without K fertigation. The high availability of K in the first

few years was evident from the abundance of petiole-K both at flowering and close to harvest. Two thirds of total vine K is removed annually by the fruit and part of it is remobilized from leaves, shoots and roots when demand exceeds uptake (Conradie 1981 b). Remobilization between flowering and harvest was more conspicuous in the petiole than in the blade. Petiole at flowering (Cook 1978; Robinson *et al.* 1978), petiole at harvest (Hepner and Bravdo 1985), and blade at harvest (Samish *et al.* 1960; Beyers 1962) were used and suggested as the appropriate tissue for K diagnosis. An early (flowering) sampling is incapable of taking into account the effects of crop load and soil water shortage on tissue K concentration (Cook 1966), nevertheless it is used in many places around the world. Furthermore, as Hepner and Bravdo (1985) pointed out, the bloom time-K is positively correlated to crop load, rather than negatively correlated, as would be expected from the heavy K removal by the crop (Conradie 1981 b). At limited K supply flowering- and harvest-K concentrations of Merlot and Cabernet Sauvignon petioles and blades were affected in an opposite way by the irrigation rate (Fig. 3). This is similar to the opposite way that crop load affects flowering- and harvest petiole-K (Hepner and Bravdo 1985). Potassium availability and uptake is limited under condition of limited soil water (Cook 1966; Dundon and Smart 1984), and an increasing rate of irrigation is expected to increase tissue K content, as was found at harvest time (Fig. 3).

The petiole-K concentration of Sauvignon blanc at flowering was highly correlated with the K concentration of its blade at flowering and harvest time (Tab. 5). In contrast, the Merlot and Cabernet Sauvingon petiole-K at flowering had low correlations to their respective blades at harvest. The flowering petiole-K of Merlot had also a low correlation to its blade-K at flowering time. Therefore, a reliable diagnosis of K from petiole at flowering time, can be carried out successfully for Sauvignon blanc, but not with the other two cultivars. At harvest, the petiole-K concentration of all three cultivars are highly correlated to the blade-K (Fig. 5 and Tab. 5), and thus the best time for K diagnosis is at harvest.

Surprisingly, a comparative (quantitative) study of K nutrition of different vine cultivars, other than in surveys (Cook and Lider 1964; Christensen 1984) is rare. Correlations of petiole and blade K at harvest showed significant differences between the three cultivars in the irrigation experiment (Fig. 5). At intermediate and high K nutritional intensities, the expected blade K concentration of the three cultivars at harvest, at an equal petiole concentration, can be ranked in the following order: Sauvignon blanc > Merlot > Cabernet Sauvignon. From the slopes of the regression lines in Fig. 5 it can be calculated that the blade-K concentration change in Sauvignon blanc, Merlot, and Cabernet Sauvignon at harvest is 0.235, 0.140 and 0.095 %, respectively, for each 1 % change in petiole-K. The cultivar ranking and regression slopes (Fig. 5) fit well with the intensity of K status measured in 1998 (Figs. 2 and 3).

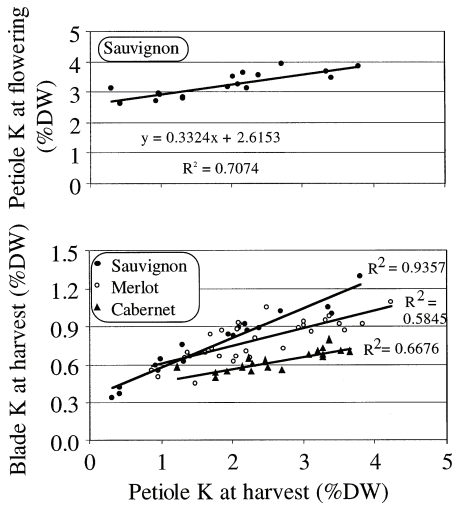

Fig 5: The relationship between petiole- and blade-K concentration at harvest for Sauvignon blanc, Merlot and Cabernet Sauvignon, and between petiole-K at harvest and petiole-K at flowering for Sauvignon blanc. Equations of regression lines for petiole- and blade-K at harvest were: y = 0.24x + 0.35, y = 0.14x + 0.47, and y = 0.10x + 0.38, for Sauvignon blanc, Merlot and Cabernet Sauvignon, respectively.

Contrary to the interpretation of the P nutritional status, where an optimal petiole- and blade-P concentration of 0.133 % (at harvest) could be deduced from the relation between the petiole content at flowering and harvest (Fig. 4), no conclusive interpretation can be drawn from the linear relation presented in Fig. 5, regarding the optimum K concentration in either the petiole or the blade. The optimum K concentration requires careful calibration of production parameters (growth, yield and fruit quality)

Table 5

Linear correlation coefficients (r^2) of phosphate and potassium concentrations between petiole and blade at flowering and harvest time, for three grape cultivars

		Sauvignon, blade		Merlot, blade		Cabernet, blade	
	Petiole	Flowering	Harvest	Flowering	Harvest	Flowering	Harvest
P	Flowering	0.7935	0.5825	0.7894	0.8702	0.9426	0.8149
	Harvest		0.4915		0.8010		0.7912
K	Flowering	0.9136	0.8266	0.3625	0.4791	0.7147	-0.0654
	Harvest		0.9673		0.7645		0.8171

in relation to tissue K concentration. Such a calibration could not be carried out from the present experiment, since several variables (N, P and irrigation rate) were modified simultaneously. It should be pointed out, however, that increasing N-P irrigation rate increased the yield (Tab. 4). The higher tissue-K content at higher irrigation rates, therefore, was associated with increased K removal by fruit and was not a consequence of reduced yield. Blade-K concentrations at harvest rarely exceeded 1 % K, even under luxurious K supply. Assuming that the required (threshold) blade-K concentration at harvest is 0.5 %, the calculated (Fig. 5) petiole-K concentration at harvest should be 0.65, 0.22 and 1.28 % for Sauvignon blanc, Merlot and Cabernet Sauvignon, respectively, and the Sauvignon blanc petiole-K at flowering 2.83 %.

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