SPATIAL AND VERTICAL DISTRIBUTION OF SOIL P, K AND MG CONTENT IN A VINEYARD OF THE DO Ca RIOJA USING GRID AND TARGET SAMPLING METHODS

Unamunzaga, O.; Castellón, A.; Besga G., Perez-Parmo R.
Aizpurua, A

Neiker-Tecnalia. Basque Institute for Agrarian Research and Development; 48.160 Derio, Spain ounamunzaga@neiker.net.

Gallejones, P.

Basque Centre for Climate Change
Bilbao, Spain

Usón, A.

Agricultural and Chemical Engineering School; University of Zaragoza
Huesca, Spain

Neiker-Tecnalia. Basque Institute for Agrarian Research and Development; 48.160 Derio, Spain ounamunzaga@neiker.net.

ABSTRACT

Knowledge of spatial variability of soil nutrient contents is very important to design a fertilization strategy based on the needs of the vine. Matching fertilization and nutritional plant needs is very important due to the influence of nutritional status of vineyards on productive and qualitative factors. The aim of this work was to study the spatial and vertical variability of P, K and Mg in a vineyard soil by two methods: (i) the grid sampling at three depth ranges (0-30, 30-60 and 60-90cm), and (ii) the target sampling based on the previous zoning of the parcel and the subsequent description and analysis of soil profiles. The study was conducted in a vineyard of 8 hectares, located in the town of Oyon (Northern Spain) in the Denominación de Origen Calificada Rioja. Although the surface soil P content was high (18-30 mg kg^{-1}) decreased to less than 3 mg kg^{-1} at 20-45 cm depth in sloping areas and 30-45 cm in depositional areas. As for K, the soil content at 0 to 30 cm depth was 160-240 mg kg^{-1} and decreased to values less than 82 mg kg^{-1}at 35 to 62 cm depth. However, the soil Mg content did not change with the depth (1.1-1.2 cmol kg^{-1}). Soil P content had the highest coefficients of variation in the depth of 30 to 60 cm (267%). Previous fertilization practices influenced the spatial distribution of P and K from 0 to 30 cm, while at 30 to 60 cm the effect of erosion was also observed. On the other hand, geological parent material had a great influence on soil Mg spatial distribution. By the grid sampling we were able to establish several areas according to the spatial distribution of the soil P and K contents, which can be specifically managed for fertilizer application. However, the target sampling was more adequate to evaluate the spatial variability of soil Mg content.

INTRODUCTION

Nutritional status is a key component of vineyard in order to obtain quality productions. Fertilizer management in the vineyard can influence fruit set, fruit quality as well as the quality of the end product (Rius, 2005). Among the essential nutrients for the vine are P, K and Mg. The occurrence of deficiencies or measurable responses to P in vineyard is rare (Christensen *et al*., 1978; Lalatta, 1992) because vine absorption of P is very low (0.08 to 0.35 kg per 100 kg of grape harvested) (Hidalgo, 2006), but when it happens the consequences are evident, reduction of vegetative growth and fruiting, and also may reduce fruit set. On the other hand, K is mobile in the plant and is essential to photosynthesis, respiration and many metabolic processes (Salisbury and Ross, 1992). the important roles of K in plants can be grouped into four physiological-biochemical areas: a) enzyme activation, in photosynthesis and respiration (Walke *et al*., 1998), b) cellular membrane transport processes and translocation of assimilates, c) anion neutralization, which is essential in maintenance of membrane potential, and d) osmotic potential regulation, which is one of the important mechanisms in the control of plant water relations (Mpelasoka *et al*., 2003; Hidalgo, 2006). Smolarz and Marcik (1997) reported that lack of K over a number of years decreases shoot growth, considerably, and sugar concentration in the berry and increases sensitivity to water stress (Champagnol *et al*., 1988). Besides, Morris and Cawthon (1982), Dundon *et al*. (1984), Rühl (1989), Brancodoro *et al*. (1994) and Delgado *et al*. (2004) have all reported a reduction in acidity as a result of K application. During winemaking process, high K increases the precipitation of tartrate in salt form hence decreases free tartrate. Therefore, high K can lead to reduce tartrate:malate ratio which is undesirable for high quality wines (Mpelasoka *et al*., 2003 and Rühl, 2000). Finally, Mg is an essential component of chlorophyll as well as plays a role on functional ability of ATP in many reactions. It is also involved in the activation of many enzymes in photosynthesis, respiration and the formation of DNA and RNA (Salisbury and Ross, 1992). Deficiencies normally occur in sandy soils with low cation exchange capacity (Delas, 2000). The effect of Mg application on grape juice composition was investigated by Rühl *et al*. (1992) who reported that the application of Mg significantly reduced the acidity in the same way that occurs with K.

Soils are characterized by a high degree of spatial variability due to the combined effect of physical, chemical or biological processes, which operate with different intensities and at different scales (Goovaerts, 1998). Variability in soil properties is a direct result of the occurrence of the five soil forming factors: climate, organisms, relief, parent material and time (Jenny, 1961). Of the five factors, topography can be most readily assessed (Mzuku *et al*. 2005). Changes in the field topography influence the distribution of soil properties and crop productivity across the field. However, soil properties also vary largely through depth due to active soil-forming processes of eluviation-illuvation down the soil profile (Wilding, 1984). In agricultural fields, modelling water flow and nutrient transport for efficient utilization of irrigation water and fertilizer require information on surface as well as on vertical variation of soil properties.

The aim of this work was to study the spatial and vertical variability of P, K and Mg in a vineyard soil by two methods: (i) grid sampling at three depth ranges (0-30, 30-60 and 60-90 cm), and (ii) target sampling based on the previous zoning of the parcel and the subsequent description and analysis of soil profiles.

MATERIAL AND METHODS

This study was carried out in an eight hectare vineyard, named Costanillas, planted with “Tempranillo” cultivar and located in Oyón (North of Spain), and it is within the “DOCa Rioja”. Vines are grafted on 41B rootstock and are trained in a double cordon. There are two different areas called “Main area” and “Arm”. Main area is further subdivided in 3 sub-areas: a) A sloping area facing South-West “SSW” b) A sloping area facing North-East “SNE” c) A flat area “Depositional area”, downslope at the convergence of the two areas above (Figure 2). Mean annual temperature is 13.5ºC and mean annual rainfall 399 mm.

The size of the field is very large compared to the average size typical of the area that is 0.5 ha, because of land consolidation done in 1975. Previously, Costanillas vineyard was divided into 20 small plots, separated by steep banks and by stone walls. Most of the small fields were with cereal crops, although there were olive trees and vines too (Figure 1). The vineyard was planted in 1980 with the exception of a small area situated in the lower left corner planted in 1990 (called new area). In the new area there were a lot of stones as a result of steep bank and stone walls elimination. Because of this, before planting the vineyard, firstly a bulldozer passed a ploughshare around one meter deep, breaking the stone and then with a scraper stones were removed. At the end of this operation, in the central part of the new area, ground level lowered more than desired, and therefore, the top soil layer was removed from the new land, buried the stone removed in order to raise the terrain and levelled off the terrain besides improving drainage.

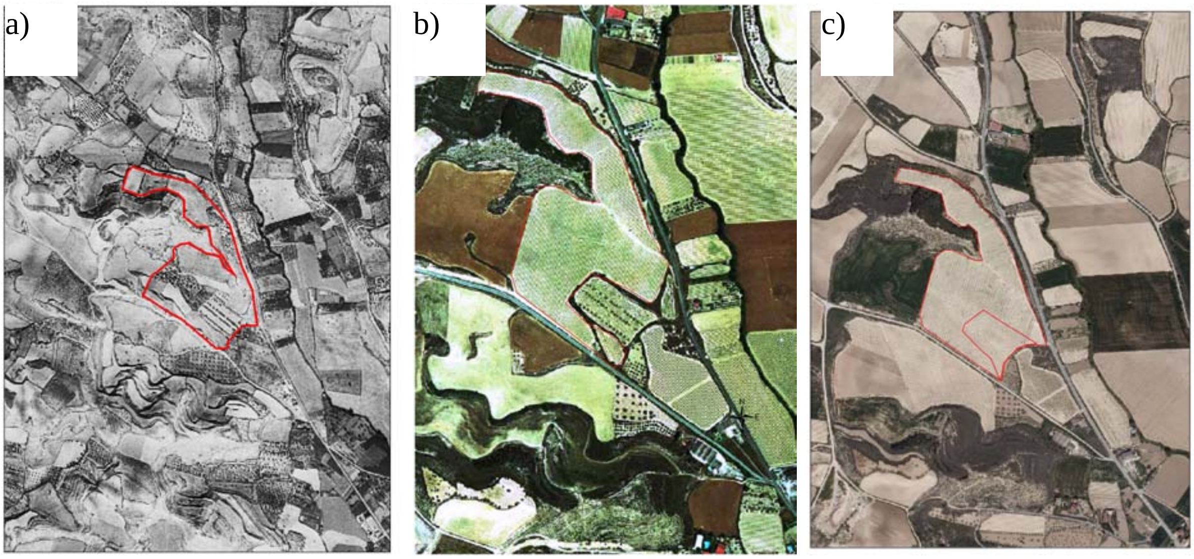

Figure 1. Aerial photography of the Costanillas vineyard, for the years 1956 (a), 1980 (b) and 2005 (c).

With regard to fertilization, from 1980 to 1995, 500 kg ha^{-1} of mineral fertilizer (9-18-27) was applied between rows, with a centrifugal spreader. Probably the cereal growing area before the land consolidation also was fertilized in this way, as the traditional dose in grain fields in the area. From 1995 to 2000 it ceased to apply mineral fertilizer and was used at first rabbit manure and then sheep manure, at an annual dose of approximately 5000 kg ha^{-1}. After spreading the manure on the surface a rotavator pass was made at 20 cm depth and then a cultivator to 20-30 cm. It is unknown the fertilization in the olive plots which were located in the arm before land consolidation, but probably were fertilized with lower dose than the cereal areas. From 2000 fertilizer was applied only to the middle of the slope “SSW” area and arm. To keep the soil free of weeds, every year five passes of cultivator are performed, two of them go down to 30-40 cm, and the other three to 20-30 cm.

Grid sampling

A regular grid was used with sampling points every 8 rows and 12 vines, resulting in 25 samples per ha (190 points). In this points soil samples were taken at different deeps (0-30, 30-60 and 60-90 cm).

Target sampling

Twelve profiles were described, divided by the different areas of the plot as topography, orientation and morphology of the plot (Figure 2).

The description of the profiles was carried out by the procedure Sinedares by the Spanish Ministry of Agriculture (Commission of the Database of Soil and Water, 1983). For each horizon, soil samples were taken for further analysis.

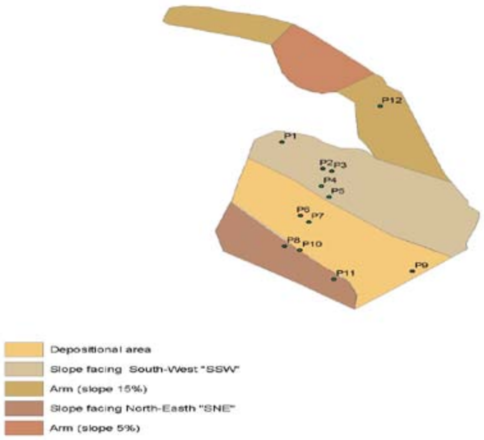

Figure 2. Costanillas vineyard with soil profiles and different areas.

Soil samples were air-dried and passed through a 2 mm sieve before analysis. Phosphorus was measured by the Watanabe and Olsen (1965) method, and K and Mg extracted with ammonium acetate 1N were measured by atomic absorption spectrophotometry. In P2 profile the mineralogy of the clay fraction <2 μm was analyzed by XRD using a Philips PW-1710 diffractometer equipped with Cu anticathode.

Statistical and spatial analysis

Within the descriptive analysis of the data were calculated coefficients of variation with the statistical program SAS (SAS, 1998).

The geostatistical analysis was carried out with the program ArcView (version 9.3, ESRI 2008). In the event that the data did not show a normal distribution the logarithmic transformation was performed. Once standarized the data, we proceeded to the realization of the semivariograms. In cases where there was strong or moderate spatial relationship, we proceeded to interpolation by ordinary krigging, using the spherical model. If the spatial relationship was low, the krigging was not considered appropriate. On maps of 0-30 cm of P and K ranges defined by the standards of reference of the Regional Advisory Service (DFA). For the map of distribution of P 30-60 cm were defined three ranges, <3 mg kg^{-1}, 3-6 mg kg^{-1} and> 6 mg kg^{-1}, because the method of analysis is not sufficiently accurate with values below 3 mg kg^{-1}. For the rest of the maps, we used the "small quartile" of the same program.

RESULTS

Grid sampling

Nutrients displayed differences in their spatial dependence (Table 1). Nugget-ratio indicated moderate spatial dependence for P and K at all depth ranges. However, Mg showed moderate spatial dependence at 0-30 and 30-60 cm but weak spatial dependence at 60-90 cm.

Tabla 1. Geostatistical parameters and coefficient of variation of P, K and Mg at different soil depths (0-30, 30-60 and 60-90 cm).

	Depth (cm)	**N**	**Sill**	**Range (m)**	**Nugget ratio (%)**	**CV (%)**
P	0-30	189	0,40	132	55	103
	30-60	181	0,60	103	40	267
	60-90	97	0,17	168	61	99
K	0-30	189	0,05	124	64	46
	30-60	181	0,04	167	72	62
	60-90	97	0,11	56	21	43
Mg	0-30	189	0,03	124	62	36
	30-60	181	0,09	48	47	58
	60-90	97	0,11	92	89	69

As Figure 3 (a) shows, soils at the middle of the SSW reaching to arm, and at the middle of this area, had the highest P content at 0-30 cm (30-179 mg kg^{-1}). However, the new area and western corner of the SSW presented the lowest P concentration (6-12 mg kg^{-1}). For the other areas, P level was high (18-30 mg kg^{-1}). The spatial map of K (Figure 3 b) content (0-30 cm) showed low levels (80-160 mg kg^{-1}) in the new area, in the middle of the SNE, in the west of the SSW and through most of the arm. In this case, as with P content, the highest K content areas are at the middle of the SSW (240-400 mg kg^{-1}), while in the other areas, the K level was intermediate (160-240 mg kg^{-1}). The highest content of Mg (1.5 to 3.5 mg kg^{-1}) (Figure 3 c) corresponded to the eastern areas of the SSW close to the arm, which coincided with the rich area in P and K. Moreover, the depositional area, the middle area of SSW and the west area of the SSW were poor in Mg (0.6 to 1.2 cmol kg^{-1}). As in the case of P and K, in the central area of the arm the Mg content (1.2 to 1.5 cmol kg^{-1}) was higher than at the end of this area.

The soil P decreased markedly at the 30-60 cm depth in comparison to the surface soil (0-30 cm). The dominant range at this depth (Figure 3 d) ranged between 3 and 6 mg kg^{-1}. Nevertheless, in the new area the decrease of the P content was lower (6-12 mg kg^{-1} at 0-30 cm and 3-6 mg kg^{-1} and even some focus with values higher than 6 mg kg^{-1} at 30-60 cm). The richest zone in P (> 6 mg kg^{-1}) at 30-60 cm was at the middle of the SSW close to the depositional area and at the eastern of the SNE. On the other hand, the lowest P contents were at the west corners of the two slopes (<3 mg kg^{-1}). With regard to K content, values at 30-60 cm (Figures 3 and 4) were also lower than at the first 30 cm, but in this case the difference of K content between surface and 30-60 cm was smaller than the difference of P content. Potassium content at 30-60 cm was highest in the middle-eastern area of the SSW (108-606 mg kg^{-1}). However, the arm and the corners of the slopes showed the lowest content of K (17-59 and 59-74 mg kg^{-1}) as well as the lowest values of P. The distribution of K in the new area was different from the other areas, because at 0-30 cm was the poorest area, while at 30 to 60 cm was one of the richest areas (89-108 mg kg^{-1}), although in this area the K content was very similar at the surface (80-106 mg kg^{-1}). Regarding the distribution of Mg (Figure 3 f), the slopes and the surrounding area of the arm were the richest with values between 1 and 6 cmol kg^{-1}, while in the deposition area and in the distal area of the arm Mg contents were lower (0.4 to 0.7 and 0.7 to 1 cmol kg^{-1}).

Spatial maps of P and K contents at 60-90 cm are presented in Figure 4. Phosphorus content was less than 5 mg kg^{-1} in all areas. Potassium content was higher (72-85 and 85-170 mg kg^{-1}) in the depositional area, in the SNE, in the middle and east corner of the SSW, but lower in the arm (16-40 and 40-56 mg kg^{-1}).

The nutrient with the largest variability according to the CV was P, ranging between 99 and 267%, with the lowest value at 60-90 cm and the highest value at 30-60 cm (Table 1). The CV of the K was also higher at 30-60 cm (62%) than at 0-30 cm (46%). In the case of Mg, the greater variation was at 60-90 cm (69%).

Target sampling

To study the soil profile distribution of P, values at the deepest horizons were taken as reference of contents, below to 3 mg kg^{-1}, because they are not affected by fertilizer application. Phosphorus distribution showed the same pattern in all profiles (Table 2-3). In the profiles located in the slope areas (P2, P4, P5, P8 and P12) at 20-30 cm, P showed the greatest decline to levels below 3 mg kg^{-1}. The profiles of the depositional area (P6, P7, P9 and P10) also had the same trend, but in this case the greatest decrease, up to 3 mg kg^{-1} P, was between 30 and 45 cm.

In the case of K (Tables 2-3), we consider the level of 82 mg kg^{-1}, as indicator of content not affected by fertilizer, since the deepest layer of all profiles is always below this level, except in those profiles with a change in the downward trend of K content, in which we consider the contents of the overlying layer. In general, K content reached up to 82 mg kg^{-1} at 35-62 cm. There is an exception in this trend, profiles P3, P5 and P11, which displayed a change in the decrease of K.

The distribution of Mg content in depth did not follow a consistent pattern (Tables 2-3). In the profiles P2 and P11 there was a sharp increase in deeper horizons. In the profiles P1, P7 and P9 from 60-100 cm there was a moderate increase, and at the profiles P3, P4, P6, P8, P12 declined slightly in depth. Finally, in P5 and P10 profiles remained constant. Thus, in the profile P2 at 60 cm Mg content increased from 1.5 to 2.4 cmol kg^{-1} and continued rising until 75 cm (2.7 cmol kg^{-1}). In the case of P11, at 74 cm Mg content increased from 1.2 to 4.1 cmol kg^{-1}. The results of mineralogical analysis of the clay fraction in the profile P2 (Table 2) highlighted the presence of vermiculite-type mineral with increasing smectite, from 60 cm on.

Table 2. Mineralogy of the clay fraction (<2 µm) of different horizont of the P2 profile.

Depth (cm)	Illite	Chlorite	Kaolinite	Smectite	Vermiculite	I/Vr	Goethite
0-21	58	5	15	11	-	8	3
21-28	54	7	16	12	-	4	8
28-42	37	7	22	13	-	11	9
42-48	45	5	18	16	-	8	9

48-60	45	5	20	13	-	11	6
60-75	37	5	17	20	16	-	5
75-85	30	6	20	24	16	-	4

I/Vr= interestratified illite/vermiculite.

DISCUSSION

Grid sampling

The spatial distribution of P in the first 30 cm of soil, is clearly defined by long-term (several decades) fertilization. Therefore, in east-central areas of the SSW and central arm, P contents are extremely high, being the areas most fertilized since 2000. On the contrary, in the new area, which until 1995 was an olive grove practically abandoned, the contents are lower. Similarly, the low levels of P in the western slope of the SSW, could be explained by the different fertilization strategy applied to the small field which was there before the vineyard plantation (Figure 1). Franzluebbers and Hons (1996), in a study on the distribution of nutrients in soils of South Texas, under different management treatments, both conventional tillage and minimum tillage, noted that the high content of P in the soil surface was likely due to long-term fertilization of the field. The low mobility of P (Delas, 2000) and the low extraction of the vine of this element (0.08 to 0.35 kg P per 100 kg of harvest) (Hidalgo, 2006) causes the P to be retained in the soil surface over time.

Phosphorus decreases rapidly from 0-30 cm to 30-60 cm (about 6 mg kg^{-1} at 30-60 cm and 30-179 mg kg^{-1} at 0-30 cm), which is shown in the soil profiles, that is, from 20 to 30 cm in sloping areas and 30-45 cm in depositional areas the P content is approaching levels characteristic of the soil horizons supposedly not affected by fertilization. Regarding the spatial distribution of P in this depth range (30-60 cm), on the one hand is still evident the effect of fertilizer, differentiating the central area of SSW, although it is also visible the effect of erosion. As a proof of the former the very low P content of the west corner of the SNE may be related to a shift of the surface soil layer, related to the floods of 1984, when according to the grapegrower a storm caused the overflow of a nearby canal at this end of the field, displacing the soil top layer from the extreme west to east. The spatial map of soil depth (Figure 4 c) shows erosion in this slope, because the depth is very low in the far west and higher in the middle of slope, indicating a lateral movement of the soil. Erosion induces displacement of surface soil from higher to lower parts of the field where the soil is deposited. Because of this displacement, there is a greater amount of nutrients in depositional areas. It was expected the same behaviour in the SSW slope, but these possible soil losses have been offset by manure application in recent years. De Gryze *et al.* (2008) reported that in areas of erosion, the P content was up to 40% lower than in the areas of deposition.

Potassium content exhibited a similar soil-profile distribution as that observed for P content, being the richest area in the middle of the SSW due to fertilization, but in this case the effect of fertilization reaches more depth (35-62 cm) than for P, due to leaching of K from the topsoil to the subsoil. The effect of soil preparation of the new areas on P and K vertical distributions is reflected at 30-60 cm, because this work led to a mixture of different soil horizons, and therefore the nutrient levels at 30-60 cm and soil surface are similar.

Phosphorus contents at 60-90 cm, with values of less than 3 mg kg^{-1}, are lower than P contents at the upper 30 cm. With regard to the distribution of K in this soil depth, the area with the lowest K content corresponds to the soils formed from sandstone. The low cation exchange capacity of soils formed on this parent material (Porta *et al.*, 1999) can be the reason for the lower K content of these soils. That is, there was some influence of geological materials on K contents in depth.

At 30-60 cm, the CV of P content is very high, due to the fertilization as well as the erosion effect. On the top layer, fertilizer compensates the loss of nutrients from eroded areas, resulting in similar values than in the other areas. The CV of P are higher than those of K, because P is less mobile in soil and also its uptake by the plant is also lower, therefore, most of the P applied remains in the soil surface. This makes that the fertilizer added decades ago still influences present soil surface P values. These results agree with those obtained by Rüth and Lennartz (2008) in rice fields in China, where soil surface P, has the greatest coefficient of variation present, about 55 and 78%, compared with those of texture and C content, and attributes this fact to erosion and fertilization. In our case the coefficient of variation of P is higher probably because fertilizer has been applied differentially, untill 1975 the various fields were planted to different crops, and since 2000 these differences have enlarged more, because the fertilizer is applied only in some areas.

The spatial distribution of Mg differs from that of P and K, because displayed weakly spatial dependence at 60-90 cm, what may be related to the appearance of a red clay layer (data not shown). The presence of this layer causes a sharp increase in Mg content, as seen in the profiles P2 and P11 (Table 2-3). The coefficient of variation, unlike those of P and K, is higher at 60 to 90 cm than at the upper 30 cm, because the clay layer is at 50-80 cm depth, causing large differences in Mg content. These results coincide with those of Franzluebbers and Hons (1996) and Wright *et al*. (2007) that find that macronutrients, such as Mg and Ca, are more closely related to natural factors as rock type that to management, occurring in general an increase in these nutrients at the bottom of the profiles. Similarly, Cambardella *et al*. (1994) found in one of the plots studied, where the management is similar to ours (tillage and fertilization), being also a plot on a slope, a non spatial relationship of Ca and Mg content, coinciding with our results in the layer of 60-90 cm.

Target sampling

When looking at the vertical distribution of P in depth it is observed a sharp decline from 20 to 30 cm in slope areas and from 30-45 cm in the depositional area, decreasing to levels below 3 mg kg^{-1}. In slope areas the depth at which P content decreases corresponds to the tillage depth indicating that P applied with the fertilizer, will be set at that depth. However, in the case of the depositional area, the jump occurs at a greater depth (30-45 cm). Gryze *et al*. (2008), in another study on the effect of conventional tillage compared with minimum tillage on P distribution in areas of erosion and deposition, reported a sudden drop at 20 cm in areas of deposition, while in slope areas slope the decline was more gradual. In our case, however, the decline is sharp in both areas, although occurs at different depths.

This study shows that, in general, K is leaching more easily than P. On the other hand, in some of the profiles there is a shift in the reduction of K content in depth (P3, P5, P7 and P11). This shift in the P7 profile, located in the depositional area, is related to the contributions it receives from the slope areas and which also coincides with an increase of organic matter at the same depth (data not shown), indicating that at 85 cm there is an accumulation of soil eroded from the adjacent slope areas. On the other hand, just in case of profiles P3, P5 and P11, this fact may be related to the parent material. Thus, the distribution of K, in addition to being influenced by the fertilizer management, also shows the influences of the rock (Wright *et al.*, 2007). Franznzluebbers and Hons (1996), reported that although the K content decreased in depth, this decrease is more gradual than that of the P because the extraction of K by the crop is greater than the extraction of P.

Magnesium distribution in the soil profile is strongly influenced by the presence of a vermiculite-rich clay layer. This effect is clearly seen in the profiles P2 and P11, in which the enrichment of clay took place at 60-74 cm, which coincides with a sharp increase in Mg content. Although other profiles show a similar phenomenon, the increase has not the same intensity. Also stands out the shift in the distribution of Mg in depth in the profiles P1, P3 and P5: where Mg decreases to 35-60 cm and increases from this depth down. This may indicate that in this type of soil there is also some vermiculite but not as much as in the areas of argillite, as in any profile of the area of deposition (P6, P7 and P9). In the profile P2, we performed a mineralogical analysis of the clay fraction; we detected the presence of vermiculite at 60 cm depth, which was not detected in the upper levels, as well as an increase in smectite content. The structure of vermiculite resembles that of mica originated by weathering, thus and can provide replacement of Fe^{3+} and Al^{3+} by Mg^{2+} (Porta *et al.*, 1993), what increases the Mg content in soil profiles in which the mineral has been detected.

Zonification

Using the information obtained by the two types of sampling, we have identified the following areas (Figure 5):

a) Two rich areas in P and K. One located in the middle-east SSW slope, near the arm, where the contents of P, and K at 0 to 30 cm are very high, even extremely high for P (30-179 mg kg^{-1}), and the K from normal to high (160-400 mg kg^{-1}). The second one is located in the middle of the arm, where the contents of P are the same as at the previous zone, but with a lower K content (160-240 or even 80-100 mg kg^{-1}). In fact, these areas belong to places that have received high rates of fertilizer. The effect of fertilization goes down until 20-30 cm in the slopes and until 30-45 cm in the area of deposition in the case of P, and until 35-62 cm in the case of K. At 60-90 cm the contents of P and K are lower in the whole plot.

b) East Zone, characterized by slightly lower contents of P and K in the soil surface and higher values at 30-60 cm compared with levels in the rest of the plot. Thus, P content in this zone range between 6-12 mg kg^{-1} at 0-30 cm and

3-6 mg kg^{-1} at 30-60 cm. Potassium content varies between 80-160 mg kg^{-1} at 0-30 cm and 74-108 mg kg^{-1} at 30-60 cm.

c) West corners of the two slopes, with lower contents of both nutrients at 30-60 cm than in the other areas.

d) Except for those areas, usually P levels at 0-30 cm, range from high levels to very high (18-30 mg kg^{-1}) at 0-30 cm. In the case of K usually varies between normal levels at the upper 30 cm (160-240 mg kg^{-1}).

e) It is further distinguished an area that coincides with the areas of soil with an argillite layer located at the east corner of the SNE with high Mg content (4.1 cmol kg^{-1}) in depth.

Differences between sampling methods

Grid sampling has allowed knowing the spatial distribution of the contents of P, K and Mg, which is more difficult to detect by target sampling. However, target sampling has allowed knowing at what depths there are sudden changes in nutrient contents. In the case of Mg, at 60 to 90 cm, due to its close relation to the composition of the clay layer, the variation is at a distance that has not been able to collect with the distance used in the grid sampling.

CONCLUSIONS

The nutrient spatial distribution at 0-30 cm was influenced by fertilization histories, differentiating areas where it has been applied more fertilizer with high nutrient contents and the areas in which historically has been applied lower amounts of fertilizer with lower nutrient contents. At 30-60 cm, besides the effect of the fertilization also appears the erosion effect, whereas the nutrient content is greater in depositional areas comparing to erodible areas. On the other hand, geological parent material had a great influence on soil Mg content at 60-90 cm, with a very high Mg content in areas of argillite.

REFERENCES

Brancodoro, L., L. Valenti, A. Reina, and A. Scienza. 1994. Potassium content of grapevine during the vegetative period: the role of the rootstock. J. of Plant Nutrition, 17 (12):2165-2175.

Cambardella, C.A., T.B. Moorman, J.M. Novak, T.B. Parkin, D.L. Karlen, R.F. Turco, and A.E. Konopka. 1994. Field-scale variability of soil properties in central Iowa soils. Soil Sci. Soc. Am. J. 58: 1501-1511.

Champagnol, F. 1988. Róle du potassium dans la physiologie de la vigne. Progrés Agricole et Viticole. 105 (19): 431-435.

Christensen, L.P, A.N. Kasimatis, and F.L. Jensen. 1978. Grapevine nutrition and fertilization in the San Joaquin Valley. 40 pp. Calif. Div. Sci. Publication 4087.

Comisión del Banco de Datos de Suelos y Aguas. 1983. SINEDARES, Manual para la descripción codificada de suelos en el campo (In Spanish.). Ministerio de Agricultura, Pesca y Alimentación, Madrid.

De Gryze S., J. Six , H. Bossuyt, K. Van Oost, and R. Merckx. 2008. The relationship between landform and distribution of soil C, N and P under conventional and minimum tillage. Geoderma. 144:180-188.

Delas, J. 2000. La fertilisation de la vigne. Collection des Usuels Féret de la Vigne et du Vin. Editions Féret.

Delgado, R., P. Matín, M. Álamo and M.R. González. 2004. Changes in the phenolic composition of grape berries during ripening in relation to vineyard nitrogen and potassium fertilisation rates. Journal of the Science of Food and Agriculture. 84: 623-630.

Dundon, C.G., R.E. Smart, and M.G. McCarthy. 1984. The effects of potassium fertilizer on must and wine potassium levels of Shiraz grapevines. Am.J. of enology and viticulture. 35(4):200-205.

ESRI (2008). Arcview 9.3. (Environmental Systems Research Institute: Redlans, CA, USA).

Franzleubbers, A.J. and F.M. Hons. 1996. Soil-profile distribution of primary and secondary plant-available nutrients under conventional and no tillage. Soil Till. Res. 39: 229-239.

Goovaerts, P. 1998. Geoestatistical tools for characterizing the spatial variability of microbiological and physico-chemical soil properties. Biol. Fertil. Soil, 27, 315-334.

Hidalgo Togores, J. 2006. La calidad del vino desde el viñedo. Mundi-Prensa (ed.).

Jenny, H. 1961. Derivation of state factor equation of soils and ecosystems. Soil Sci. Soc. Am. Proc. 25: 385-388.

Lalatta, F. 1992. Fertilización de árboles frutales. Ediciones CEAC (ed.).

Morris, J.B., and D.L. Cawthon. 1982. Effects of irrigation, fruit load, and potassium fertilization on yield, quality, and petiole analysis of Concord (*Vitis labrusca* L.) grapes. American Journal of Enlogy and Viticulture. 33(3):145-148.

Mpelasoka, B.S., D.P. Schachtman, M.T. Treeby M.T. and M.R. Thomas. 2003. A review of potassium nutrition in grapevine with special emphasis on berry accumulation. Aus. J. of Grape and Wine Res. 9: 154-168.

Mzuku, M., R. Khosla, R. Reich, D. Inman, F. Smith and L. MacDonald. 2005. Spatial variability of measured soil properties across site-specific management zones. Soil Sci. Soc. Am. J. 69: 1572-1579.

Porta, J., López-Acevedo, and C.Requero. 1999. Edafología para la agricultura y el medio ambiente. Ed. Mundi Prensa.

Rius, X. 2005. Apuntes de viticultura australiana. Agro Latino.

Rühl, E.H. 1989. Uptake and distribution of potassium by grapevine rootsocks and its implication for grape juice pH of scion varieties. Australian Journal of Experimental Agriculture. 29:707-712.

Rühl, E.H., A.P. Fuba, and M.T. Treeby. 1992. Effects of potassium, magnesium and nitrogen supply on grape juice composition of Riesling, Chardonnay and Cabernet Sauvignon vines. Australian Journal of Experimental Agriculture. 32:645-649.

Rühl, E.H. 2000. Effect of roostock and K^+ supply on pH and acidity of grape juice. Acta Horticulturae 512:31-37.

Rüth, B. and B. Lennartz. 2008. Spatial variability of soil properties and rice yield along two catenas in Southeast China. Pedosphere, 18(4): 409-420.

Salisbury, F.B. and C.W. Ross. 1992. ‘Plant Physiology’. 4th edition. (Wadswoth Inc.: Belmont, CA).

SAS Institute. 1998. SAS/STAT User´s Guide, version 8. SAS Institute, Cary, NC.

Sharpley, A.M. and S. Rekolainen. 1997. Phosporus in agriculture and its environmental implications. In: Phosphorus loss from soil to water. Tunney, H., Carton, O.T., Brookes, P.C. and Jhonston, A.E. (ed.). CAB International, Wallingford, UK. 1-54.

Smolarz, K. and S. Mercik. 1997. Growth and yield of grape in response to long term (since 1923) different mineral fertilization. Acta Horticulturae. 448, pp. 42-432.

Walker, D.J., C.R. Black and A.J. Miller. 1998. The role of cytosolic potassium and pH in the growth of barley roots. Plant Physiology 118, 957-964.

Watanabe, F.S. and S.R. Olsen. 1965. Test of an ascorbic Acid Method for determining Phosporus in water an $NaHCO_3$ Extracts from Soil. Sci. Soc. Proceedings: 677-678.

Wilding, L.P. 1984. Spatial variability: Its documeentation, accomodation and implication to soil surveys. In soil spatial variability (eds Nielsen, D.R. and Bouma, J.), Pudoc, Wageningen, 166-193.

Wright, A.L., F.M. Hons, R.G. Lemon, M.L. McFarland and R.L. Nichols. 2007. Stratification of nutrients in soil for different tillage regimes and cotton rotations. Soil & Tillage Research 96, 19-27.

Table 3. Phosphorus, K and Mg contents in different soil horizons of P1 to P10 profiles.

	Depth cm	P mg kg^{-1}	K mg kg^{-1}	Mg cmol kg^{-1}
P1	0-40	78	293	1.0
	40-60	2	64	0.7
	60-80	1	49	1.2
P2	0-21	183	709	2.0
	21-28	54	481	1.7
	28-42	2	224	1.1
	42-48	3	84	1.1
	48-60	2	77	1.5
	60-75	1	76	2.4
	75-85	1	68	2.7
P3	0-10	201	1585	2.8
	10-28	46	336	1.2
	28-43	5	173	1.0
	43-50	5	151	0.9
	50-55	7	147	0.8
	55-70	3	82	1.0
	70-85	2	96	1.2
P4	0-19	147	995	2.0
	19-35	20	479	1.5
	35-47	3	91	1.3
	47-80	3	56	1.2
P5	0-20	19	226	1.1
	20-35	3	94	0.9
	35-50	8	81	1.1
	50-73	9	101	1.1
	73-75			
P6	0-20	188	597	
	20-44	106	341	1.2
	44-55	2	133	0.9
	55-82	1	75	0.8
	85-90	1	58	0.8
	90-110	1	58	0.9
P7	0-15	95	346	1.5
	15-35	12	178	1.2
	35-55	3	99	1.1
	55-85	1	61	1.4
	85-115	1	76	1.8
P8	0-15	200	500	2.1
	15-25	196	638	2.1
	25-53	3	176	1.4
	53-70	1	64	1.2
P9	0-30	8	148	1.2
	30-100	3	72	1.3
	100-127	3	66	1.6
P10	0-10	224	799	2.1
	10-45	40	428	1.6
	45-62	2	89	0.8
	62-70	3	74	0.8
	70-78	1	64	0.8

Table 4. Phosphorus, K and Mg contents in different soil horizons of P11 to P12 profiles.

	Depth cm	P mg kg^{-1}	K mg kg^{-1}	Mg cmol kg^{-1}
P11	0-26	76	316	1.4
	26-74	12	67	1.2
	74-95	1	72	4.1
P12	0-20	88	257	1.0
	20-30	58	189	0.9
	30-45	6	114	0.9
	45-55	3	126	0.8

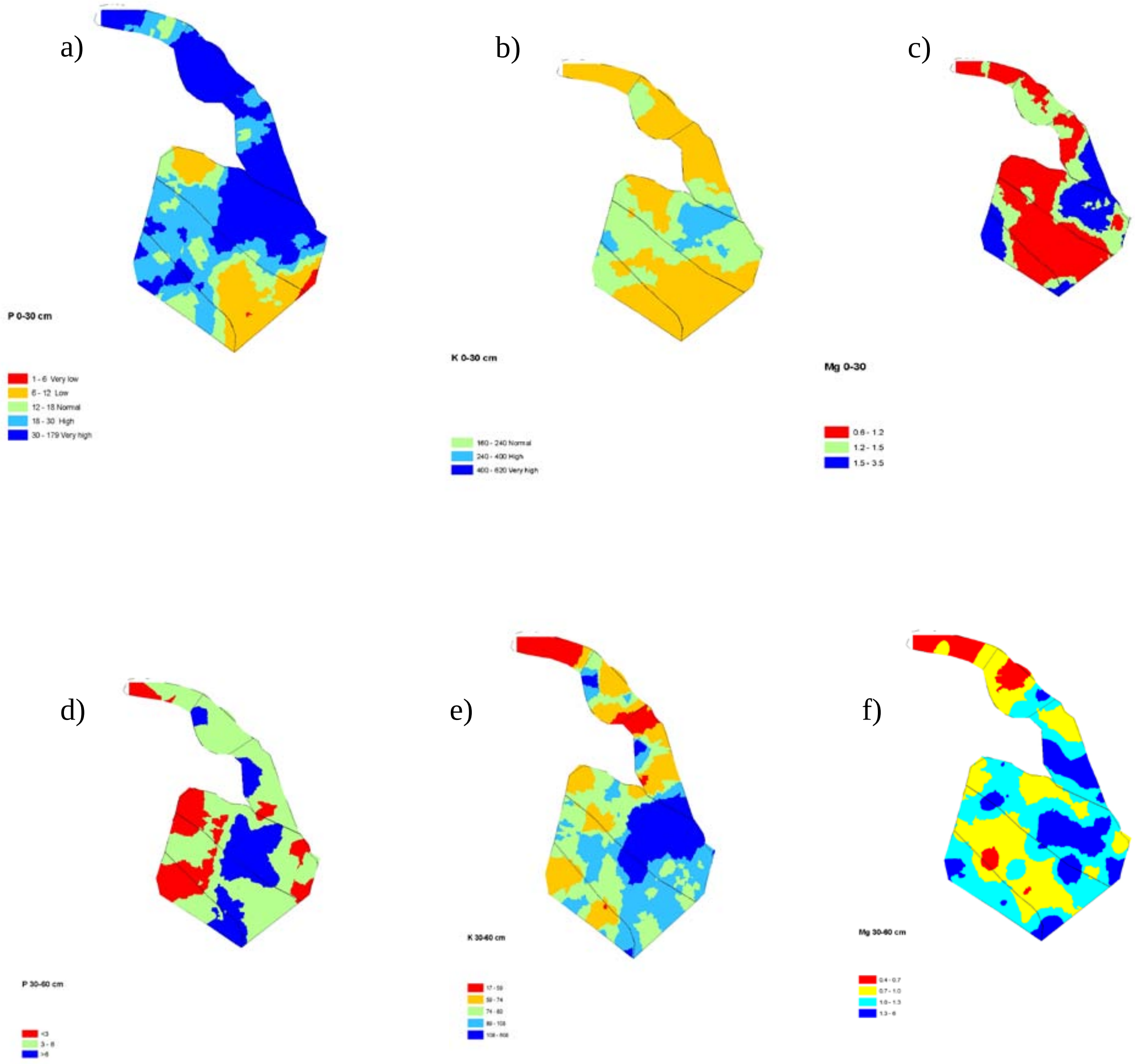

Figure 3. Spatial maps, a) P (mg kg^{-1}) at 0-30 cm, b) K mg kg^{-1}) at 0-30 cm., c) Mg (mg kg^{-1}) at 0-30 cm, d) P at 30-60 cm, e) K at 30-60 cm, f) Mg at 30-60 cm.

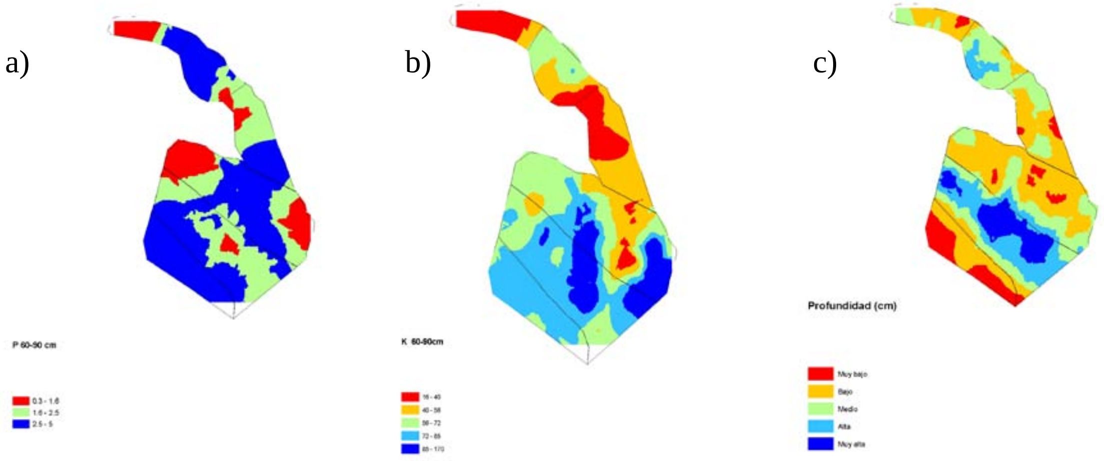

Figure 4. Spatial maps, a) P (mg kg^{-1}) at 60-90 cm, b) K (mg kg^{-1}) at 60-90 cm, c) Soil depth.

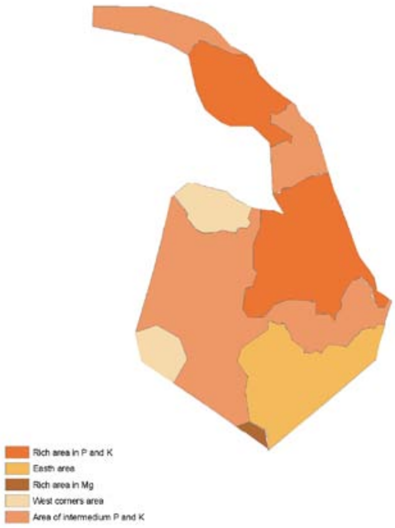

Figure 5. Zonification map of the Costanillas vineyard.