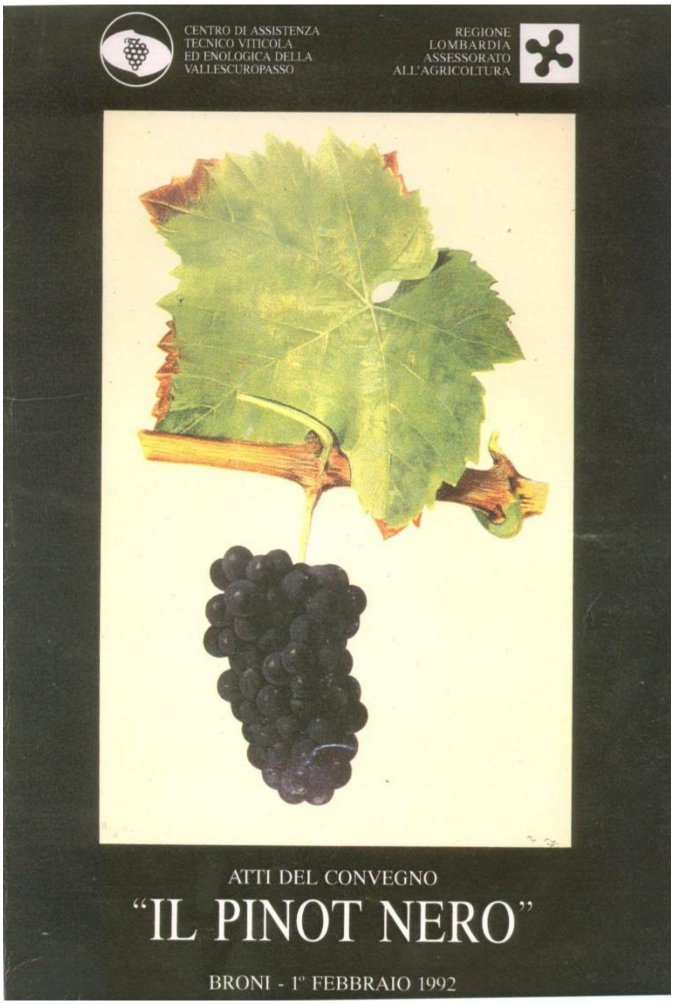

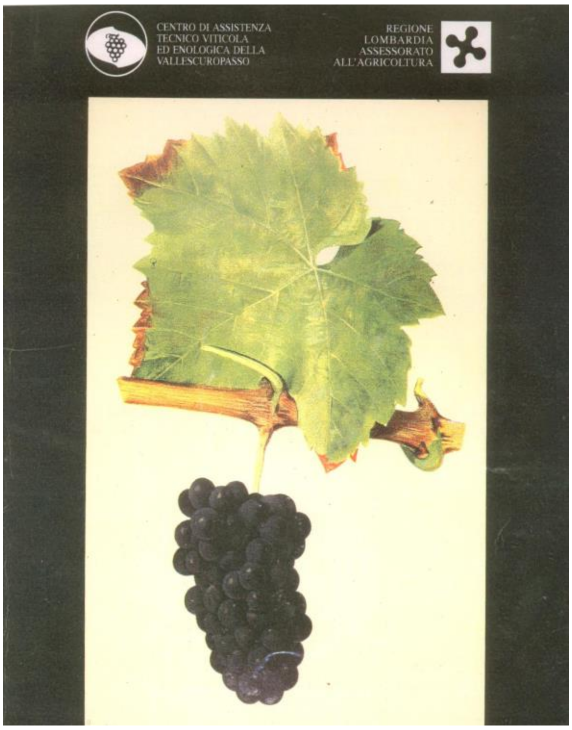

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STUDY OF MINERAL NUTRITION (LEAF DIAGNOSTICS) OF PINOT NOIR IN THE SCUROPASSO VALLEY

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INTRODUCTION

Nutrition

Nutrition of the grapevines consists in the series of procedures by which the grapevine takes from the environment around it those elements that, once assimilated, allow it to grow, to preserve itself and to reproduce, and to develop; that is to say all its fundamental vital functions. As far as weight is concerned, the greatest part of the vine is made up of water (apart from the seeds). In fact, water represents approximately 70-85% of its total weight. The remainder non-water element is called the dry matter. If we consider the leaves, the dry matter is mainly made up of nine elements: carbon, C; oxygen, O; hydrogen, H; nitrogen, N; phosphorus, P; sulphur, S; potassium, K; calcium, Ca; magnesium, Mg. These elements each amount to on average over 0.1% of the dry matter (TABLE 1). These nine elements are defined as macro-nutritional and altogether they make up 99.8% of the dry weight. Other elements are present in smaller quantities, e.g. iron (Fe) 0.021%, boron (B), 0.003%, even though this does not mean that these elements are any less important, above all in viticulture.
The first three macro-nutritional elements indicated (C, H, O) on their own represent over 93% of the total dry weight. The others (N, P, S, K, Ca, Mg) together make up approximately 6.5%. The total amount of carbon and almost the total amount of oxygen are obtained from the carbon dioxide in the air and water by photosynthesis. Photosynthesis, therefore, is an essential process. It is through photosynthesis that the epigeous green portions of the plant develop. Compounds of a sufficiently basic composition as to allow them to be used as the starting point to construct the plant (called glucides) are formed; these have a high energy content and are obtained from easily available low energy substances, i.e. carbon dioxide and water (TONZIG, 1968). This process is made possible by the particular chlorophyllian pigment offered to the plant to use as solar radiation energy source.
The other macro-nutritional elements (N, P, S, K, Ca, Mg) and those micro-nutritional (B, Fe, etc.) mainly come from the soil. These are absorbed through the roots and together with the carbon matrix synthesized in the foliage they make up those complex substances that contribute to the construction of the different organs of the plant and their function. If we develop a mechanical example, we could say that, with few exceptions, the macro-nutritional are the working parts of an internal combustion engine. In contrast, the micro-nutritional elements provide the lubrification. This underlines the huge importance even of the micro-nutritional elements, even though they contribute less to the total weight.
The mechanisms through which these abovementioned nutritional procedures (epigeous and hypogeal) act and influence each other represent an important part of the process by which the quantity and the quality of the production of the species of wine are determined.

Main factors influencing nutrition

The environment (climate and soil and their interactions) has an important influence on the nutrition of the combination of species of wine and stock.
The conditions of the soil and climate are largely defined by the location under study and can only be modified in part. Of the macroclimatic considerations, particular attention should be given to the type of solar radiation exerted on the study site (NOGGLE, 1978), as well as to rainfalls and their distribution through the year. The incidence of edaphic factors is often interpreted above all as an

interaction with the climate (temperature and rainfall) and includes their chemical and physical characteristics. Often it is these latter characteristics that have the most influence.
Man can have a greater or lesser influence through the choice of varieties and cultivation strategies in order to put the quantity-quality potential of the environment to best use, through the choice of an appropriate training system that allows the foliage to absorb the most solar radiation thus optimizing the photosynthesis (SCIENZA *et al.,* 1985) and appropriate soil treatment (fertilizers, tillage, weeding, grassing), once the most suitable stock has been chosen according to the characteristics of the terrain under consideration.

Importance of mineral fertilizers for the quantity and quality of grapevine production
The substances used by the plant for the development of its vital functions are mainly synthesized in the green parts of the grapevine, and in particular in the leaves. The glucides are particularly important for this and these act in two important parts of the grapevine: the tips of the growing shoots and the grape clusters. These two parts compete with each other and this can lead to a change in the equilibrium to which the plant can be governed by the environment and/or Man.
Mineral nutrition can be directly controlled by the amount of appropriate fertilizers distributed to the soil and/or the leaves. This can modify the physiological equilibrium and, therefore, the competition between the growing shoots and the bunches resulting either in a greater vegetative growth in the shoots or a higher deposit in the bunches (FREGONI, 1985). All this is closely related to the climate, and above all to the temperature. In fact, the temperature is the main factor in regulating the growth of the grapevines, while rainfall is the key factor responsible for their size.
The habit of applying mineral fertilizers to the soil and to the leaves is just one of the possible techniques of grapevine cultivation. This can most directly and consistently influence the vigor and the productive performance of the combination of species of wine and stock in a given environment. This can also have an impact on any unwanted nutritional imbalance that can be such as to result in a diseased grapevine.
There are also other important links between the extent and type of nutritional interaction provided by the different minerals, not only with the quantity of grapes produced but also with their quality and good health (sugar levels, extent and type of must acidity, health of the grapes at harvest, proteic and aromatic characteristics of the wines). These relationships suggest a careful use of mineral fertilizers, above all given the current almost complete lack of natural fertilizers, to maximize production quality and to reintegrate soil fertility after long periods of cultivation.
The use of fertilizers can be optimized through the study of the effective cultivation requirements and through limiting their use as far as possible in order to reduce and control any resultant risk to the environment that could be caused by an excessive and imprudent exposure to minerals.

Nutritional requirements of the grapevines
To identify the real nutritional requirements of the grapevines in relation to the qualitative enological objectives, and given the huge range of factors that can influence their performance, it is important to use study methods that examine the nutritional phenomenon as a whole. This involves designing studies that investigate the links between the different possible nutritional settings and the characteristics of the quantity-quality performance of the vineyards under the different environmental conditions.
At the beginning of the 1970s, Fregoni proposed his Nutritional Guidelines. This is an integrated approach that considers the consumption and the losses reported in the different vineyards together with the nutritional status demonstrated by leaf diagnostics. It also takes into consideration the characteristics of the terrain and the enological objectives established. The aim of these Guidelines is to optimize the calculation of the most appropriate mineral fertilizing formula to be used. So far,

approximately 160 subzones of grapevine cultivation have been studied using this method, including that of Rovescala in the Oltrepò Pavese.
The possibility of using the analyses of the terrain to evaluate its nutritional potential for grapevine cultivation is of great importance when the grapevine is planted (LOUÈ, 1990). It is then that, according to the results of such analyses, any imbalance inherent to the soil must be corrected. When the vineyard is in full production, analyses of the soil surrounding the roots are less informative and must be integrated with samples taken directly from the grapevines in order to estimate their nutritional status and to identify what elements reach the leaves from the soil and to what extent.
A similar evaluation of the vegetal-productive performance of the vineyards provides a series of information on the different components of the viticultural agrosystem. These can widen our knowledge of the dynamic processes that result in quantity-quality characteristics of the viticultural production of a specific area and of the role of mineral nutrition in this context. The interpretation of the findings of these analyses (relating to the leaves, terrain and grapes produced) and their interactions provides a more rational approach to the use of mineral fertilizers in relation to the vitivinicultural objectives proposed by the grower. An analysis of epigeous vegetal tissues (leaf, petiole and grape diagnostics) is an efficient method to check the nutritional potential of the terrain according to the climate of a particular area for the various varieties (COOK *et al.,* 1956; FREGONI, 1980; DELAS, 1990; BERTONI, 1991; CRISTENSEN, 1984; LOUÈ, 1990; DELAS, 1991).

Study objectives
The objective of the current research is to improve our knowledge on the nutrition of the Pinot Noir cultivated in the Scuropasso Valley (Oltrepò Pavese) mainly for the production of sparkling wines *méthode traditionnelle*. The study aims to identify any possible link between the mineral nutrition that develops in the vineyards in the area and some of the main quality characteristics of the grapes produced. This will help develop a rationale for the use of mineral fertilizers considered as part of the overall management of vineyards for the production of better quality grapes.

MATERIALS AND METHODS
Climate: seasonal temperatures and rainfall
During the three years studied, overall temperatures and rainfall were to lesser or greater degrees drier than the average for the area (TABLE 3). Above all, 1988 and 1990 were drier, with less than 350 mm of rainfall in the most important period for the vegetal-productive development of the grapevines (March-September). Furthermore, 1990 followed one of the mildest winters of recent years with temperatures only going slightly below 0°C on a few days.
During 1989, rainfall in the period from March to September was much higher (by almost 100 mm) than the other two years, above all with much more intense rainfall in July. In 1988, June was the month with the highest rainfall (130 mm). The next two years saw the most intensive rainfall in April as is more usual (157 mm, 1989; 170 mm, 1990). Apart from 1989, July was the month with the least rainfall. Rainfall for August was always below 50 mm, with a minimum of 17 mm in 1989.

Characteristics of the vineyards and the sampling
Over the three years 1988-1990, 20 vineyards were studied at different locations considered to be representative of the viticultural production for sparkling wines *méthode traditionnelle* in the Scuropasso Valley (Oltrepò Pavese).
The vineyards studied were all cultivated with Pinot Nero and were located at between 107 and 460 m a.s.l. with moderate slopes and characterized by different exposures (TABLE 2).

The training system adopted was a Guyot with two opposite canes or, more rarely, one over the other. The spacing patterns provide grapevine density of between 2,200 and 2,700 grapevines *per* ha with production frequently reaching approximately 10 ton *per* ha, corresponding to vine yield of 4-6 kg. Soil samples were taken from the vineyards under study using a hand auger at a depth between 15 to 65 cm, approximately 70 cm from the vines.
The soil analysis involved the following variables:
-sand (%)
-silt (%)
-clay (%)
-organic matter (%)
pH
active limestone (%)
cationic exchange capacity C.E.C. (meq/100 g soil)
total nitrogen (‰)
exchangeable potassium (ppm)
exchangeable calcium (ppm)
exchangeable magnesium (ppm)
assimilable phosphorus (ppm, Olsen extraction).
In the three years under study, both at the setting and at the veraison, on a sample of grapevines demonstrating an average vegetative development with respect to the vineyard as a whole, close to the areas used for soil analyses, 20-40 leaf blades samples were taken (without the petiole) opposite the basal grape cluster of shoots of average vigor. During the second phenological phase (veraison), the studied samples were taken when at least 50% of the grapes had turned red.
On the dry matter obtained from the vegetal samples collected, we evaluated the percentage of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg). At harvest of the three years under study the following analyses were carried out on a sample of 12-15 vines:
-number of buds left after pruning;
-number of grape clusters;
-weight of grape production *per* vine (kg)
-average weight of gapes (g).

The following analyses were carried out on the must obtained from pressing a sample of 2-4 bunches considered representative of the level of maturation of the grapes of every vine studied:
-sugar content (°Brix);
-titratable acidity (g/L, expressed in equivalents of tartaric acid)
-tartaric acid (g/L)
-pH.

The correlations between the variables found for the soil, the leaves and the grapevines for the different years were then checked. In interpreting the results, we took into consideration the data for temperature and rainfall recorded for the three years 1988-1990 by the six meteorological stations of the *Rete Agrometeorologica del CI.VI.FRU.CE.* of the Region of Lombardy located in the rural centers of Vicomune, Pietra de Giorgi, Bosco Casella, Lirio, Canevino, Montalto Pavese (Scuropasso Valley).

RESULTS AND DISCUSSION

Characteristics of the soil

Even though overall, during the edaphic evaluation, we observed that most of the fine soil samples contained large quantities of clay, in the more northern areas of the valley (medium-low altitudes) silt was the main component with a smaller amount of exchangeable potassium.
Soil analyses always showed medium-low levels of organic substance (often near to 2%).
Correlations between the different variables observed in the layers of soil with the majority of the roots (TABLE 5) were evaluated. These showed that the percentage of silt was negatively and significantly correlated with clay (r=-0.60) and the cationic exchange capacity (r=-0.80), and also with K (r=-0.65), Mg (r=-0.73) and Ca (r=-0.64), evaluated as exchangeable. The amount of silt was positively correlated with active limestone (r=0.47). In certain aspects, the opposite was seen observed with clay, that correlated positively with cationic exchange capacity (CEC, r=0.61), with K and Ca (r=0.66 and r=0.57, respectively). The CEC was also negatively correlated with active limestone (r=-0.62) and positively with the exchangeable fractions of K (r=0.49), Mg (r=0.60) and Ca (r=0.92).
It was seen that the amount of organic substance had a significant influence on the amount of N and P, with a positive and significant correlation between them (r=0.84). A further positive correlation was found between K and Mg (r=0.43), elements evaluated as exchangeable.

Presence of mineral macro-nutritional elements in the leaves and correlations with soil characteristics

We evaluated the different amounts of the principle macro-nutritional elements studied (N, P, K, Ca, Mg) as percentage of dry matter of the leaf blade. Among the three years under study, significant variations were seen for all elements except nitrogen in relation to the average results at the setting and at the veraison (TABLE 6). In particular, on average, N, P and K acquired values that can be considered to correspond to an average soil fertility profile (TABLE 7), with a minimum of 2.02% in 1989 and a maximum of 2.15% in 1988 for N, 0.14% in 1988 and 0.18% in 1990 for P, 0.87% in 1989 and 1.14% in 1990 for K. Ca and Mg showed moderate soil fertility profiles in 1988 and 1989, while quite high levels were found in 1990.
The summation of the five principal macro-nutritional elements (overall amount) was over 5 (5.31% of dry matter) in 1988, just under 5 (4.95%) in 1989, and 6.61% in 1990. The smallest percentage of N and the largest percentages of Ca and Mg in the overall summation were seen in 1990. At the setting, no substantial differences were seen in the amount of N, while variations in the amount of the other macro-nutritional elements studied were significant. There was significantly less P in 1988 (0.14% vs. 0.19% and 0.20% in 1989 and in 1990, respectively), while K, Mg and Ca reached significantly higher percentages in the leaf dry matter in 1990.
At the veraison, significant differences were seen between the three years studied in the amount of all the macro-nutritional elements studied, apart from K. There was significantly more N in 1988 (1.87% vs. 1.55% approximately for the next two years) while there was significantly more P, Mg and Ca in 1990. The only elements that showed an almost constant reduction from the setting to the veraison were N and Ca in 1988 and in 1989. In 1990, N showed an even more consistent decrease while Ca showed a clear increase.
In the leaves (TABLE 11), N was positively correlated with K in 1988 and in 1990, both at the setting and at the veraison. However, in 1989, this correlation was only seen at the veraison. In 1988, N was positively correlated also with Mg in both the phenological phases considered. Ca was positively correlated with Mg at the setting in the two years 1989 and 1990 but in 1988 it was positively correlated with P. At the veraison in 1989 and 1990, Ca was positively correlated with K and Mg, respectively.
The correlations found at the veraison between the various macro-nutritional elements were checked by evaluating the percentages of the individual elements that make up the summation (TABLE 12). In this summation, K was the most important and Mg and Ca were the least important. Significant negative correlations were also observed between the amount of N and the amount of

Mg and Ca, and the same was seen between P and Ca. Significant positive correlations were seen between the amount of Ca and Mg, and the same was seen between N and P.
An analysis of the interrelationships between the chemical-physical characteristics of the soils under study and the presence of minerals in the leaves showed a series of significant correlations even though these differed over the three years.
In 1988, at the setting, some characteristics of the soils had an appreciable influence on the presence of P, K, and Mg in the leaves. Above all the Mg contained in the leaf blade was negatively correlated with the organic matter, nitrogen and phosphorus in the soil. The amount of Mg at the setting was correlated with the percentage of sand although these values only just reached significance and positivity. Also at the setting, the leaf nitrogen was positively correlated with the pH of the soil (TABLE 8).
In 1989 the leaf N was positively correlated with the pH of the soil both at the setting and at the veraison. The Mg of the leaf blade was, at both phenological phases, positively correlated with silt and negatively correlated with clay and K; there was also a negative correlation with the CEC but only at the veraison. The K in the leaves was positively correlated with its presence, as an exchangeable element, in the soil for both of the phenological phases; at the setting it was positively correlated with edaphic amounts of N and P, while at the veraison it was negatively correlated with the amount of silt (TABLE 9).
In 1990, at the setting, we observed positive correlations between N, P and K in the leaves with the total N in the soil, just as between K in the leaf blade and the organic matter in the soil. In the same phenological phase, the exchangeable Mg in the soil and the P in the leaves were negatively correlated. At the veraison, the presence of K on the dry matter of the blade was negatively correlated with the silt and positively with organic matter, CEC and N, P and K content in the soil. Again at the veraison, Mg content in the leaves was negatively influenced by the CEC and by the presence of exchangeable K in the soil, while it was positively correlated with active limestone (TABLE 10).
More frequently, N was positively correlated with the pH in the soil; when there was greater availability of water in spring (at the setting in 1990, 270 mm of rain, from March to mid-June vs. just over 200 mm in 1988 and 1989) significant positive correlations were found between the N, P and Ca content in the leaves and in the soil, and a significant synergy between N and P.
The amount of potassium in the leaves in both 1989 and in 1990 was positively related to its presence in the soil, just as to the N and P content, and negatively correlated, at the veraison, with the silt fraction of the soil.
It is interesting to observe (TABLE 15) that the content of K at the veraison over the 3-year period of study was positively correlated with the amount of exchangeable K in the soil and with the Kexc. : CEC ratio, while the leaf Mg, negatively correlated with the amount of P and N in the soil, in its absolute percentage of the total leaf dry matter, was also negatively correlated with K, CEC and the Ks : CEC ratio, in its percentage of the summation of the principal macro-nutritional elements of the leaf dry matter.

Correlations between leaf and edaphic variables and quantity-quality performance of the grapes at harvest

Analyzeing the linear correlations found between the vegetal-productive variables examined (yield *per* vine, sugar content, titratable acidity, malic acid, tartaric acid, pH) and the results of leaf and soil analysis carried out in the various vineyards. Some significant results were found (TABLE 13).
The yield *per* vine, higher in 1989 due to the greater availability of water (TABLE 3), seemed to have a significant correlation only with the quantity of Mg in the soil in 1990 and with no variable found

for 1988. However, in 1989, significant positive correlations were found not only with the quantity of exchangeable Mg in the soils, but also with the quantity of N in the leaves and the sand in the soil.
As far as the sugar content in the harvested grapes in concerned, the only significant correlation found was with the quantity of N in the soils at the setting; this was negative.
The titratable acidity of the grapes was, in 1988, negatively correlated with the sand and N at the veraison, and, in 1990, there was a positive correlation with N at the setting.
There was a positive correlation between malic acid and N of the soil in 1988 and 1990, and with leaf N at the setting in 1989 and 1990. There were negative correlations with the Mg at the veraison in 1989 and at the setting in 1990. There were positive correlations with P at the setting in 1989 and with K at the veraison in 1990.
There was a correlation between tartaric acid and N and P of the soil, and with leaf N at the setting only in 1989, and this was always negative.
For all three years of study, there was a positive correlation between pH of the grapes at harvest and the quantity of leaf blades K at the veraison. For 1988 and 1990, there was a positive correlation between pH of the grapes at harvest and leaf N at the veraison. In 1989, the year with the highest rainfall in the vegetative period of cultivation, the acid reaction of the musts (pH) was negatively correlated with the quantity of exchangeable potassium in the soil and with the quantity of silt. In 1990, there was a significant positive correlation between grape pH and the edaphic quantity of N and P, and likewise for leaf phosphorus at the setting.
Given that the Pinot Noir grapes in this study are destined for use in the production of sparkling wines *méthode traditionnelle*, and the fact that the acid reaction of the musts is extremely important, data were collected concerning the pH in the grapes at harvest (TABLE 16). Therefore, the differences of the variables measured in pH between 2.9 and 3.0, 3.1 and 3.2, between 3.2 and 3.4 were evaluated.
The highest titratable acidity was found in the intermediate class of pH where even higher values of tartaric acid (significantly higher than those typically correlated with the highest pH values) and malic acid were found. The lowest pH values, therefore, were found in relation to a higher ratio of the tartaric and malic component of organic acidity.
The evaluation of the main macro-nutritional elements in the leaf dry matter at the setting showed no significant variations as regards P, K and Ca, while significantly lower quantities of N and substantially greater quantities of Mg were found in the lower pH classes. Again at the veraison, quantities of nitrogen and potassium were significantly higher in the higher pH classes (1.9 vs. approx. 1.6 for N and 1.05 vs. approx. 0.87 for K).
Leaf Mg at the veraison was higher in the lowest pH class, and likewise for Ca.
In order to collect useful information about the possible correlations between the overall nutritional profile in all its complexities and the main qualitative variables measured in the musts at harvest, we checked the correlations of some indexes: i) the summation of the percentages of N, P, K, Ca and Mg in dry matter; ii) the ratio of the sum of N+P+K over the total quantity of Ca and Mg (N+P+K)/(Ca+Mg); iii) the K : Mg ratio at the veraison (TABLE 14).
The summation of the macro-nutritional elements at the setting was not correlated with any of the qualitative variables of the musts. In contrast, at the veraison, the correlations between the summation of the macro-nutritional elements and titratable acidity values, tartaric acid and malic acid were negative and significant, while the correlation with sugar content was positive and significant. The opposite was seen in the correlations relating to the (N+P+K)/(Ca+Mg) ratio, except for the correlation with tartaric acid, that lost significance, and for pH at the veraison, that was positively correlated. The K : Mg ratio at the veraison was positively correlated with the titratable acidity, malic acid and pH, resulting always highly significant.

As far as nitrogen is concerned, there were significant positive correlations between quantity of leaf N at the veraison and the pH of the grapes obtained in relation to the significant negative correlation with tartaric acid.
In order to better summarize the significant impact of the different variables analyzed in defining the pH of the harvested Pinot Noir grapes, we analyzed the multiple regression that linked some of the more important variables considered with the pH for the three years under study. We, therefore, also considered altitude and exposure. The different exposures were graded according to a numerical score (1-4) according to their greater or lesser influence on the degree of maturation of the grapes (1=north, 2=west, 3=east, 4=south) (TABLE 17).
The following resulted in significant coefficients: altitude(negative correlation) exposure, the exchangeable potassium : CEC ratio, the K : Mg ratio on the leaf dry matter at the veraison, yield *per* vine (positive correlation). The resulting coefficient of determination was 0.46.

CONCLUSIONS

The different soils that make up the Scuropasso Valley are nearly always characterized by high clay content. In the northern areas of the valley, at medium-low altitudes, quantities of silt are higher than in the other areas studied. The pH of the soils is always over 7.5 and in approximately 20% of the cases, is over 8. In 40% of cases, large proportions of total and active limestone are found. High or very high levels of CEC were nearly always found. The organic substance was very often below 1.5%. Medium values of total N were nearly always found, while assimilable P values were medium or very low (Olsen extraction). High quantities of Ca and exchangeable Mg were found. Medium-high quantities of exchangeable K were found, even though some cases had very low values (for cations, reference should be made to the CEC).
The quantities of N and P were positively correlated with the amount of organic substance, likewise, K and Ca are positively correlated with clay content. The quantity of Mg was negatively correlated with silt content (as for K and Ca) but no correlation was seen with clay (TABLE 5).
In the leaves, in almost all cases, medium quantities of the macro-nutritional elements studied (N, P, K, Ca, Mg) were found (TABLES 6 and 7).
Leaf N and leaf P were positively correlated with their respective quantities in the soil, and with a greater water availability in the soils. The quantity of potassium in the leaf dry substance seems to be conditioned by not just its edaphic quantity, but by the ratio established between the exchangeable K of the soil and the CEC (the higher the K value over the CEC, the greater the K content in the leaves) and with the K : Ca ratio, although this time this is negative. Magnesium was conditioned by the nutritional dynamic of the potassium (and not *vice versa*) showing itself to be subject to K antagonism both in the soil and in the leaves. In the leaves, this dynamic is not so much seen in its absolute quantity in the dry substance but as percentage relevance on the summation of the macro-nutritional elements (TABLES 9, 10, 12, 15).
The different nutritional profile was seen to be associated with the qualitative characteristics of the Pinot Noir grapes produced. Results of leaf diagnostics at the veraison were particularly interesting, where positive correlations were found between leaf potassium content, K : Mg ratio in the leaves, and the (N+P+K)/(Ca+Mg) ratio with the pH and the malic acid of the harvested grapes.
These ratios were also positively correlated with the titratable acidity, suggesting a substantial difference between the musts in their mineral cation content (TABLE 14).
Leaf N at the veraison was positively correlated with the pH of the harvested grapes, in relation to its negative correlation with tartaric acid. N was the only mineral studied to demonstrate any relationship with the tartaric acid content of the grapes, provably related to an indirect effect of the factors that define quantity at harvest (e.g. dilution for tissue growth).

In conclusion, this study shows that the mineral nutrition of Pinot Noir can modify the reaction, above all acidic, of production. The evolution of an abundant supply of potassium and nitrogen during the vegetative season favors the production of grapes with a higher pH; an undesired factor in the production of sparkling wines *méthode traditionnelle*. The quantity of potassium, on the one hand positively correlated with the quantity of malic acid, and sometimes also with the titratable acidity, favors the production of musts that are on the whole less acidity. It is, therefore, useful not to have excessive amounts of potassium in the soil and to check in advance their quantities with respect to the CEC. It is also advisable not to use excessive amounts of nitrogen fertilizers that can result in lower acidity levels of the harvested grapes (excessively high pH).

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Table 1 – Percentage of the chemical elements on the dry matter in the grapevine leaves (Fregoni el al., 1989).

Macronutrients		Micronutrients			
element	%	element	%	element	%
C, H, O	94.20	Cl	0.050	Mo	0.00005
Ca	2.61	Na	0.024	Co	0.00005
N	2.15	Fe	0.021		
K	1.02	Mn	0.014		
S	0.40	Zn	0.009		
Mg	0.31	B	0.003		
P	0.17	Cu	0.0005		

Table 2 – Localities of the experimental vineyards studied in the years 1988, 1989 and 1990. (a.s.l. = above sea level).

No. of vineyard	Locality	Altitude (m, a. s. l.)	Exposure
1	Cigognola	175	East
2	Pietra de Giorgi	320	South-East
3	Pietra de Giorgi	245	South-East
4	Cigognola	120	East
5	Pragone	200	North
6	Scorzoletta	120	West
7	Casa Barbieri	250	South
8	Bosco Casella	265	North
9	Ca Tessitori	274	North-East
10	Vallescuropasso	107	West
11	Finigeto	320	South-West
12	Rocca de Giorgi	425	South-East
13	Rocca de Giorgi	360	West
14	Rocca de Giorgi	250	West
15	Rocca de Giorgi	290	West
16	Canevino	460	South
17	Canevino	370	North-West
18	Montalto Pavese	185	East
19	Lirio	358	South-East
20	Pietra de Giorgi	235	North

Table 3 – Monthly rain (mm) from March to September. Average values from the meteorological stations of the Scuropasso Valley (CIVIFRUCE – Regione Lombardia).

year	March	April	May	June	July	August	Sept.	∑
1988	53	35	74	130	8	34	7	**341**
1989	33	157	23	42	89	17	77	**438**
1990	55	170	28	26	9	2	12	**349**

Table 4 – Abbreviations of the variables considered in the correlation and in the elaborations.

SA	Sand (%)
SI	Silt (%)
CL	Clay (%)
o.m.	Organic matter (%)
C.E.C.	Cationic Exchangeable Capacity (meq/100 g of soil)
a.l.	Active limestone (%)
Ns	Total nitrogen in the soil (‰)
Ps	Phosphorous in the soil (mg/kg, Olsen method, in P_2O_5)
Ks	Potassium in the soil (ppm = mg/kg, exchangeable, in K_2O)
Mgs	Magnesium in the soil (ppm = mg/kg, exchangeable, in MgO)
Cas	Calcium in the soil (ppm = mg/kg, exchangeable, in CaO)
Nlf, Nlv, Plf, Plv, Klf, Klv, Calf, Calv, Mglf, Mglv = nitrogen (N), Phosphorous (P), Potassium (K), Calcium (Ca), Magnesium (Mg), in the leaves (l), in the phonological phase of fruit-set (f) or of veraison (v); % of dry matter.	

Table 5 – Significant linear correlation coefficients (r) between some of the variables considered for the soil. F: * = significant for p<=0.05, ** = significant for P<=0.01.

Y	X	r	F
Sand (%)	Clay (%)	-0.71	**
	Active limestone (%)	-0.53	**
	pH (soil)	0.55	**
Silt (%)	Clay (%)	-0.60	**
	C. E. C.	-0.80	**
	Active limestone (%)	0.47	**
	K	-0.65	**
	Mg	-0.73	**
	Ca	-0.64	**
Clay (%)	C. E. C.	0.61	**
	K	0.66	**
	Ca	0.57	**
Organic Matter (%)	N	0.71	**
	P	0.64	**
C. E. C.	Active limestone (%)	-0.62	**
	K	0.49	**
	Mg	0.60	**
	Ca	0.92	**
N	P	0.84	**
K	Mg	0.54	*

Table 6 – Average values of the mineral elements considered in the leaves (% on dry matter = d. m.). Average values followed by different letters are different according to LSD test. * = for p<=0.05, ** = for p<=0.01, / = not significant.

Average between fruit – set and veraison (leaves, % on d. m.)						
years	N	P	K	Mg	Ca	∑
1988	2.15	0.14a	0.88a	0.18a	1.96a	5.31
1989	2.02	0.16b	0.87a	0.19a	1.71b	4.95
1990	2.09	0.18c	1.14b	0.33b	2.87c	6.61
	/	**	**	**	**	
fruit – set (leaves, % on d. m.)						
years	N	P	K	Mg	Ca	∑
1988	2.43	0.14a	0.85a	0.17a	2.07a	5.66
1989	2.52	0.19b	0.88a	0.19a	1.95a	5.73
1990	2.58	0.20b	1.23b	0.30b	2.53b	6.84
	/	**	**	**	**	
veraison (leaves, % on d. m.)						
years	N	P	K	Mg	Ca	∑
1988	1.87a	0.13a	0.89	0.19a	1.84a	4.92
1989	1.51b	0.13a	0.84	0.18a	1.46b	4.12
1990	1.59b	0.15b	1.00	0.35b	3.21c	6.30
	**	**	/	**	**	

Table 7 – Middle levels of the leaves (% on dry matter) inferred by the values observed in many different zones of the Italian viticulture, by Fregoni et al., from 1973 to 1986 (Vercesi et al., 1987). Average values between fruit-set and veraison.

elements	poor	scarce	medium	rich	very rich
N	<1.65	1.65-1.90	1.90-2.40	2.40-2.60	>2.60
P	<0.11	0.11-0.14	0.14-0.20	0.20-0.24	>0.24
K	<0.57	0.57-0.80	0.80-1.24	1.24-1.46	>1.46
Ca	<1.41	1.41-1.78	1.78-2.54	2.54-2.91	>2.91
Mg	<0.15	0.15-0.23	0.23-0.39	0.39-0.47	>0.47

Table 8 – Significant correlation coefficients observed ( ) between the variables measured in the soil and the leaf contents (% on dry matter) of the macronutrient mineral elements. F: * = significant for p<=0.05, ** = significant for p<=0.01.

Leaves contents	Phase of the grapevine	Year: 1988 …soil
N	fruit – set	-
	veraison	pH (0.61**)
P	fruit – set	active limestone (-0.42**)
	veraison	-
K	fruit – set	active limestone (0.44**)
	veraison	-
Ca	fruit – set	-
	veraison	-
Mg	fruit – set	Organic matter (-0.53**), N(-0.48**),P(-0.58**)
	veraison	Sand (0.43**)

Table 9 – Significant correlation coefficients observed ( ) between the variables measured in the soil and the leaf contents (% on dry matter) of the macronutrient mineral elements. F: * = significant for p<=0.05, ** = significant for p<=0.01.

Leaves contents	Phase of the grapevine	Year: 1989 …soil
N	fruit – set	pH (0.50*), S (0.41**)
	veraison	pH (0.49**)
P	fruit – set	-
	veraison	-
K	fruit – set	N (0.57**), P (0.55**), K (0.40*)
	veraison	Silt (-0.42*), Ks (0.43*)
Ca	fruit – set	-
	veraison	-
Mg	fruit – set	Silt (0.53**), Clay (-0.58**),K(-0.54**)
	veraison	Silt(0.54**), Clay (-0.52**), K (-0.53**)

Table 10 – Significant correlation coefficients observed ( ) between the variables measured in the soil and the leaf contents (% on dry matter) of the macronutrient mineral elements. F: * = significant for p<=0.05, ** = significant for p<=0.01.

Leaves contents	Phase of the grapevine	Year: 1990 …soil
N	fruit – set	N (0.50*)
	veraison	Sand (-0.44**)
P	fruit – set	N (0.62**), P (0.51**), Mg (-0.50**)
	veraison	-
K	fruit – set	N (0.62**), P (0.45**), dry matter (0.45**)
	veraison	N (0.66**), K (0.54**), Silt (-0.46**), dry matter (0.44**), CEC (0.42**)
Ca	fruit – set	Ca (0.42*)
	veraison	-
Mg	fruit – set	-
	veraison	Active limestone (0.54**), CEC (-0.50**), K (-0.43**)

Table 11 – Significant correlation coefficients ( ) among the mineral elements (% on dry matter) in the leaf. (> = versus). F: * = significant for p<=0.05, ** = significant for p<=0.01.

year	Phase of the grapevine	…leaf mineral elements
1988	fruit – set	N > K (0.51**) N > Mg (0.44**) P > Ca (0.52**)
	veraison	N > K (0.40*) N > Mg (0.42*)
1989	fruit – set	Ca > Mg (0.62**)
	veraison	N > K (0.49*) Ca > K (0.49*)
1990	fruit – set	N > K (0.65**) N > P (0.49*) P > Ca (0.50**) Ca > Mg (0.68**)
	veraison	N > K (0.65**) N > Ca (0.50**)

Table 12 – Significant linear correlation coefficients among the nutritional importance of the macronutrients elements (% of each macronutrient element on the sum of the total principal macronutrients elements). For example: %N = (N*100)/(N+P+K+Ca+Mg). F: * = significant for p<=0.05, ** = significant for p<=0.01.

	% K	% Mg	% N	% P	% Ca
% K	-				
% Mg	- 0.47**	-			
% N	/	-0.38**	-		
% P	/	/	0.30**	-	
% Ca	-0.49**	0.43**	-0.87**	-0.29*	-

Tab 13- Significant linear correlation coefficient between the variables measured in the soil (s) and in the leaf (l, f = fruit set, v = veraison), and the vegetative-productive performances of the grapevines. F: * = significant for p<=0.05, ** = significant for p<=0.01.

	1988	1989	1990
Yield / vine (kg)		Sand (0.46*) Mgs (0.45*) Nlf (0.51*)	Mgs (0.50*)
Sugar (°Brix)		Nlf (-0.45*)	
Titratable acidity (g/L)	Sand (-0.49**) Nlv (-0.50**)	Plf (0.65**) Mglv (-0.42*)	Nlf (0.51**)
Malic acid (g/L)	Ns (0.43*)	Ks (0.51**) Nlf (0.46*) Plf (0.59**) Mglv (-0.47*)	Ns (0.46*) Nlf (0.60**) Mglf (-0.59**) Klv (0.64**)
Tartaric acid (g/L)		Ns (0.44*) Ps (-0.46*) Nlf (-0.44*)	
pH	Nlv (0.53**) Klv (0.45*) Nlf (0.59**)	Silt (-0.46*) Ks (0.45*) Nlv (0.58**) Klv (0.51**)	Klv (0.52**) Ns (0.58**) Ps (0.70**) Plf (0.59**)

Table 14 – Significant linear correlation coefficients between some chemical parameters of the must and some indexes calculated with the leaf contents of the macro-nutrient mineral elements (NPKCaMg = N+P+K+Ca+Mg, elements in % of dry matter of the leaf, f = fruit set, v = veraison). F: * = significant for p<=0.05, ** = significant for p<=0.01.

Leaves / *Must*	NPKCaMg f	NPKCaMg v	NPK/CaMg f	NPK/CaMg v	K/Mg v	N v
Sugar (°Brix)	-	0.44**	-0.47**	-0.44**	-	-
T. acidity (g/L)	-	-0.45**	0.36**	0.37**	0.31**	-
Tart. ac. (g/L)	-	-0.37**	-	-	-	-0.42**
Malic ac. (g/L)	-	-0.25**	0.33**	0.52**	0.56**	-
pH	-	-	-	0.36**	0.43**	0.46**

Table 15 – Significant exponential growth regression coefficients between, some soil characteristics (X) and the veraison leaf (l) contents of potassium and magnesium (K l v and Mg l v respectively; in % on dry matter) or the % of the same elements (%K or %Mg) on the principals macronutrients whole considered (N+K+Ca+Mg) (Y). v = veraison, F: * = significant for p<=0.05, ** = significant for p<=0.01.

Soil (X)	**Leaves (Y)** Kl v	% K l v	Mg l v	% Mg l v
K / CEC	0.54**	0.56**	-	-0.45**
K /Mg	-	-	-	-
Ca/K	-0.56**	-0.58	-	0.48**
CEC	-	-	-	-0.35**
N / K	-	-	-	-
K	0.49	0.46	-	-0.59**
Mg	-	-	-	-
P	-	-	-0.30*	-0.31*
N	-	-	-0.29*	-0.29*
Ca	-	-	-	-

Table 16 – Average values of some different variables measured, according to the different classes of grape juice pH considered. Mineral elements in % on dry matter. Average values followed by different letters are different according to LSD test for p<=0.05, F: *= significant for p<=0.05, ** = significant for p<=0.01, / = not significant.

variables	pH must classes			
	2.9-3.1	3.1-3.2	3.2-3.4	F
Tit. acidity (g/L)	9.31a	10.00b	8.77a	**
Tartaric acid (g/L)	7.02a	7.12a	5.99b	**
Malic acid (g/L)	4.00a	5.12b	5.15b	**
Sugar (°Brix)	19.00b	17.54a	19.67b	**
N l f	2.38a	2.55b	2.60b	**
P l f	0.18	0.18	0.18	/
K l f	1.03	0.93	0.94	/
Mg l f	0.25a	0.20ab	0.18b	**
Ca l f	2.23	2.10	2.10	/
N l v	1.54a	1.63a	1.90b	**
P l v	0.14	0.14	0.13	/
K l v	0.86a	0.88a	1.05b	**
Mg l v	0.27a	0.21b	0.19b	*
Ca l v	2.47a	1.68b	2.13ab	**

Table 17 – Multiple regression used to study the pH of the grape must (Y): x1 = altitude = ALT, x2 = exposure = EXP (from 1 to 4: 1= North, 2=East, 3=West, 4=South), x3 = soil K exchangeable/CEC = Ks/CEC, x4 = potassium/magnesium leaf at veraison = K lv / Mg lv, x5 = yield /vine = kg / vine. F: *= significant for p<=0.05, ** = significant for p<=0.01; R^2 = determination coefficient.

			F R^2 = 0.46*
pH (grape) =	3.047		**
	- 0.000464	ALT	**
	0.022820	EXP	**
	0.012354	Ks/CEC	**
	0.006599	K lv / Mg lv	**
	-0.01521	kg /vine	**