#7835 SPATIAL VARIABILITY OF SOIL AND PLANT NUTRIENT STATUS IN RELATION TO THE OCCURRENCE OF BITTER PIT IN APPLE ORCHARDS IN THE SAIS PLATEAU, MOROCCO

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ABSTRACT

Bitter-pit is a nutritional disorder that affects apple fruit quality and post-harvest cold storage aptitude. In many Moroccan orchards, this disorder causes substantial yield loss on the field and upon cold storage. It is attributed to several factors, mainly the Ca-K-Mg nutrition equilibrium. Soil, leaf and fruit analyses can help assess the nutritional status and vulnerability to such a disorder. However, conventional methods relying on few samples cannot inform about the spatial variability of soil and tree conditions across the field, especially in large farms. The present study aims at assessing the spatial variability of soil, leaf and fruit K-Ca-Mg in an apple orchard using a high-density grid sampling in order to get a better understanding of the incidence of bitter bit and propose site-specific nutrient management. The study was conducted on a 30-ha field and targeted the Golden Smoothee variety. Composite samples of soil and leaf were taken at 130 regularly spaced points (50 m). Soil analyses concerned mineral N, exchangeable K, Mg and Ca. Leaf analyses included N, K, Mg and Ca. Spatial variability maps were elaborated for each nutrient and for the (K+Mg/Ca) ratio using spatial interpolation to identify the most vulnerable areas to bitter-pit. The results revealed important spatial variability for all nutrients, with K buildup on a major part of the field, thus causing a high (K+Mg)/Ca ratio incriminated for bitter-pit incidence. Leaf K content was normal to high with a N-S gradient, while leaf Ca was low on a large part of the field despite the high levels of exchangeable Ca in the soil. Leaf (K+Mg)/Ca ratio showed also similar trends to that of soil with values greater than 1.2 considered as a threshold for bitter pit development. Based on cut-off levels of 1.25 and 1.5, the map shows that about 35% of the field is of moderate risk and about 25% is of high risk to bitter-pit incidence. The spatial variability maps can serve as a decision support for site-specific management of fertilizers application to the soil, mainly K and N, as well as foliar applications of Ca in order to balance tree nutrition, avoid bitter pit occurrence and ensure better fruit quality, and profitability.

Keywords: bitter-pit, apples, Golden Smoothee, soil test, foliar analysis, potassium, calcium magnesium, spatial variability

INTRODUCTION

Bitter pit is a nutritional disorder, related directly or indirectly to calcium nutrition, and affects apple fruits. It manifests as brown spots on the apple skin with a bitter taste of the underneath tissue. It can develop at fruit maturity, but develops even more after periods of cold storage (Rui-Luiz, 1985; Lotze, 2005), therefore, affecting fruit quality and market value. Its occurence is attributed to various factors that impacts calcium (Ca) levels in the fruits (Ferguson et Watkins 1989). Moreover, potassium (K) and magnesium (Mg) are particularly involved in the Ca-K-Mg equilibrium, as both are considered antagonists to Ca (Faust and Shear, 1968; Ferguson and Watkins, 1989). Fruits with bitter pit expression are of low Ca contents. However, a high (K+Mg)/Ca ratio of leaf or fruit have been reported as a better indicator of bitter pit occurrence compared to Ca alone (Boon, 1980). The incidence can exceed

30% when leaf (K+Mg)/Ca ration is greater than 1.15 (Boon, 1980). Soils with high exchangeable K concentrations may lead to bitter pit even when soil exchangeable Ca is adequate or high. Excess nitrogen (N) absorption in the fruit can cause an increase in fruit size, and therefore a consequent Ca flesh dilution (Rui Luiz, 1985; Saure, 2005). Some varieties have been reported to be more susceptible than others (Ferguson and Watkins, 1989; Cheng and Sazo, 2018). Bitter-pit has been observed on many apple orchards in the Sais and Mid Atlas mountain regions of Morocco (Faraj, 2006), with fruit loss exceeding 50% of the yield after cold storage. Soil testing and foliar analysis are often used to assess soil fertility and tree nutrition. However, few composite samples are insufficient to reveal orchard nutrient spatial variability and depict the vulnerable areas to bitter-pit. The objective of this study was to assess the spatial variability of K, Ca and Mg in the soil and leaf in an apple orchard in the Sais plateau in NW Morocco in order to gain a better understanding of the occurrence of bitter-pit and propose site-specific nutrient management as a precision farming practice.

MATERIALS AND METHODS

The study was conducted on an apple orchard farm near the city of Meknes, in northwestern Morocco. The farm experienced repeated important losses of fruit quality due to bitter pit, mainly after cold storage periods. A 30-ha apple orchard (12 years old) with a density of 1250 tree/ha, was selected. It houses 3 varieties (Lyse Golden, Golden Smoothee and Ozark Gold), but the study focused on the Golden Smoothee only. The fertilizer program varies from one year to another and consists of 100-120 kg/ha N, 80-100 kg/ha P_2O_5 and 180-240 kg/ha of K_2O, in addition to K, Ca and boron (B) foliar sprays.

Composite samples (consisting of 9 subsamples) were collected at 130 geopositioned grid points (50x50m) for soil (3 weeks before bud) and leaf (80 days after full flowering). At each point, soil samples were taken at 2 depths (0-30cm and 30-60cm) and leaf samples were taken from 4 nonboring trees and comprised 160 leaves. Soil samples were prepared and analyzed for mineral N, available P and exchangeable K, Ca and Mg. Leaves were analyzed for N, P, K, Ca and Mg contents. Analysis were done according to Estephan et al. (2013).

Spatial variability maps of individual nutrients and (K+Mg)/Ca ratios in the soil and the leaves were derived by surface interpolation using Inverse Distance Weight (IDW) method under geostatistical analyst of ArcGIS software. In the case of soil data, only the maps of the surface layer will be presented.

RESULTS AND DISCUSSION

The orchard field shows a moderate NW-SE gradient in terms of soil depth (60 to 80 cm), soil texture (clayey to clay loam), organic matter content (1.8 to 2.7%), active lime (15.6% to 10.0) and pH (8.3 to 7.9).

Soil Exchangeable K, Ca and Mg

Exchangeable potassium showed an important spatial variability, with values ranging from 122 to 780 ppm in the surface layer and 100 to 452 ppm in the sub-surface layer, with means of 452 and 237 ppm respectively. Surface and subsurface K were significantly correlated (R^2=0.58). The map for the surface layer (Figure 1) shows that more than 2/3 of the orchard has high K content, considered rich to excessive for apples orchards, and may cause antagonistic effect on calcium nutrition for apple trees.

For exchangeable Ca, values ranged from 6372 and 12084 ppm in the surface layer (cv= 10%) and from 6482 to 10094 ppm in the subsurface (cv = 9.2%). These values are typical of calcareous soils containing important levels of active $CaCO_3$. A small, but significant, correlation exists between surface and subsurface Ca (R^2= 0,32). The surface layer Ca map (Figure 1) shows a clear N-S gradient, but variations are due mainly to inherent soil conditions than to management practices. Despite high Ca levels, Ca deficiencies can be observed as a result of K and Mg antagonisms and/or imbalance. Excess Ca absorption by plants does not occur and is believed to be physiologically controlled compared to other nutrients such as N and K.

Soil exchangeable Mg showed values ranging from 508 and 2156 ppm with a mean of 1588 (cv= %) in the surface and from 628 et 2608 ppm with a mean of 1800 ppm (CV= %) in the subsurface. Magnesium content in the subsurface were higher than those at the surface compared to calcium. Surface and sub-surface Mg were highly correlated (R^2=0.84). The surface layer Mg map (Figure 1) shows less variability compared to K and Ca. The high Mg levels add up to potassium and therefore impact Ca absorption by the apple trees, making them more vulnerable to bitter pit development.

The soil (K+Mg)/Ca ratio (eq/eq) varied from 0.1 to 0.5 with an average of 0.31 (CV=25.8%). The corresponding map (Figure 1) shows a net N-S gradient that reveals an important imbalance of Ca-K-Mg across the field. It is suggested that a cut-off value of 0.3 be considered for this ratio as a threshold for Bitter pit incidence.

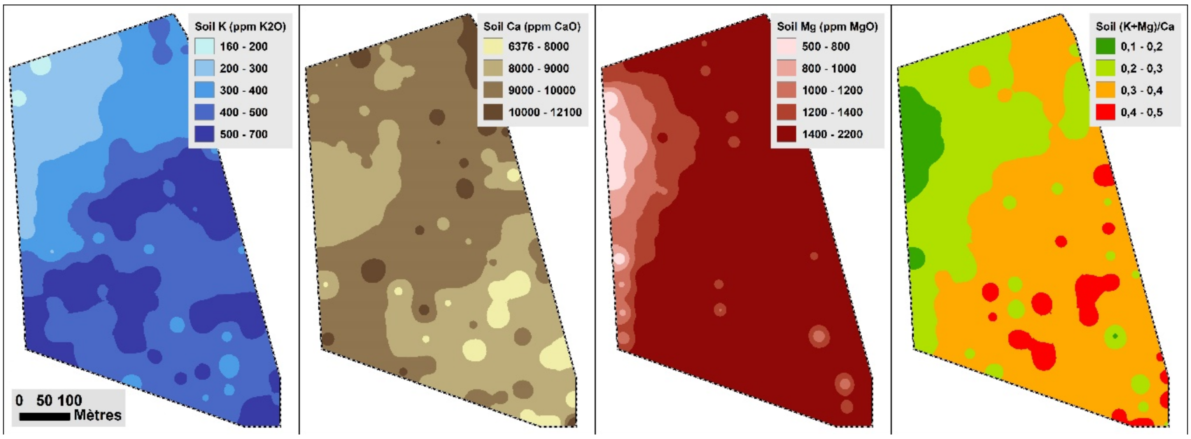

Figure 1. Spatial variability maps of exchangeable K, Ca, Mg and (K+Mg)/Ca ration in the surface (0-30cm) layer of the apple orchard field studied.

Leaf K, Ca and Mg

Leaf K contents varied from 1.45% to 3.17%, with an average of 2.3% (CV=17%). These levels are considered satisfactory to moderate high. The leaf-K map (Figure 2) shows a net N-S gradient, with about a third of the trees being over-fertilized with K. A leaf K content greater than 1.5% can be favourable to Bitter pit if leaf Ca content are lower than 1.6% (Van Der Boon, 1980). A highly significant correlation (R^2=0.62) was observed among soil-K and leaf-K contents.

Leaf Ca contents ranged from 0.89% to 1.45%, with an average of 1.16% (CV=11.2%). In general, these values are considered relatively low for apple trees (the optimum being about 1.5 to 1.8%), especially in the southern part of the field (Figure 2) which is more vulnerable to bitter-pit. Terblanche et al. (1988) reported that bitter pit occurred over 30.7% of an apple orchard field (var. Golden Delicious) with an average of 0.92% leaf Ca content.

Leaf Mg contents ranged from 0.28% to 0.46%, with an average of 0.35% (CV=11,4%). These levels are considered optimum. The leaf Mg map (Figure 2) shows a significant heterogeneity despite the lower heterogeneity in the case of soil exchangeable Mg. This could be attributed to the antagonistic effect of other nutrients such as K and NH_4, which is often assessed by looking at the K/Mg ratio.

The leaf (K+Mg)/Ca ratio (eq/eq) varied from 0.98 to 2.16 with an average of 1.55 (CV=18,7%). Despite the important heterogeneity, the corresponding map (Figure 2) shows an overall N-S gradient that depicts the K-Mg-Ca leaf nutrient imbalance across the field. Van der Boon (1966) reported that apple trees with a (K+Mg)/Ca >1.2 (eq/eq) presented a high risk of bitter-pit development. Based on cut-off levels of 1.25 and 1.5, the map shows that about 35% of the field is of moderate risk and about 25% is of high risk to bitter-pit incidence, respectively. Leaf (K+Mg)/Ca ratio was significantly correlated to that in the soil (R^2=0.65).

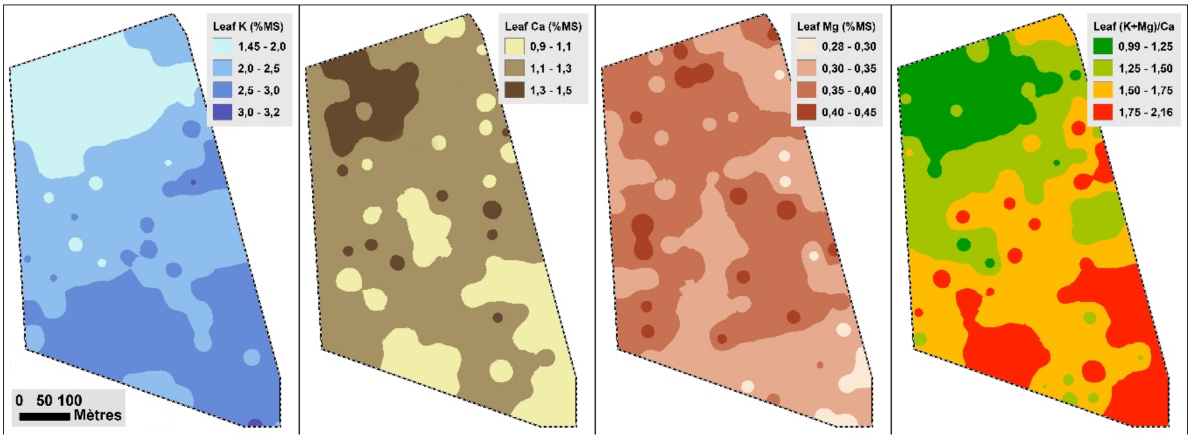

Figure 2. Spatial variability maps of leaf K, Ca, Mg and (K+Mg)/Ca ratio in the apple orchard field studied.

Leaf N content can also inform about the risk of bitter-pit vulnerability. High nitrogen can lead to increased fruit size, and therefore cause Ca dilution which results in lower tissue cohesion and bitter-pit development (Wilson and Cline, 2000, Saure, 2005). Measured leaf N ranged from 2.05 to 3.34% with average of 2.66 (CV=14,7%). The corresponding map (not shown) revealed also that a large part of the field had high N content and could contribute to the aggravation of bitter-pit.

Field observations, showed that apple fruits expressed symptoms of bitter-pit in the southern part of the field in early maturity stage. These observations confirm the results revealed by the maps and call for a rigorous site-specific management of the duo K-Ca, with a drawdown of soil K fertilization ratio and an increased Ca-foliar fertilisation in the high (K+Mg)/Ca. In addition, N should be reduced to avoid high-size fruits that causes fruit Ca dilution. Val et al. (2000) reported that when apples (Golden Smoothee) show symptoms of bitter-pit in the field, about 80% of the fruits are likely to develop bitter-pit after 2 months of cold storage. Furthermore, it is recommended to sort apples harvested from the moderate to high-risk areas and subject them to soaking in a 1% $CaCl_2$ or $Ca(NO_3)_2$ solution (for about 2 minutes) prior to cold storage (Boon, 1968).

CONCLUSIONS

The K, Ca and Mg nutrient levels in the soil and in the leaves of apple orchard were assessed to determine its vulnerability to bitter-pit. Spatial variability was approached using a 130 grid sampling points over a 30-ha field. Maps of K, Ca as well as that of the (K+Mg)/Ca ratio showed that the apple field presented a high risk of bitter-pit development that explains the substantial yield loss observed after apples undergo a period of cold storage exceeding four weeks. About 60% of the field is at risk, with 35% of moderate risk and 25% of high risk. These findings help explaining the high incidence of bitter-bit. The spatial variability maps allowed and identifying the most contributing areas would orient site-specific nutrient management including both soil and foliar fertilization. Appropriate cost-benefit soil and foliar testing tools can be used for soil fertility and three nutrient status assessment as a precision agriculture practice to avoid post-harvest loss of yield due to bitter-pit.

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