

# Yield gaps and nutrients use efficiency of apple tree (golden delicious/MM106) in the middle Atlas Mountains of Morocco

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**Abstract**— *The main objective of this work was to evaluate use efficiency of nitrogen, phosphorus, potassium, calcium and magnesium in adult apple orchards in the Middle Atlas of Morocco and to establish preliminary reference norms for fertilizing this crop under local conditions. The study was based on soil and leaf analysis and data with regard to farming practices and yield on forty apple orchards (cv. Golden delicious/MM106) where nineteen are growing on silty-clay soil and twenty-one on sandy-loam soil. The results showed significant correlations between leaf content for each nutrient and yield level following polynomial equations, thereby indicating local reference norms for apple leaf analysis. Moreover, correlations were significant between leaf and soil contents that permitted to determine apple needs in nitrogen fertilizer and references norms for soil richness in phosphorus, potassium, calcium and magnesium to obtain yield potential in the study region. However, the found norms are less than international standards because of feebleness of yield level in the study region, largely related to deficient cultural practices adopted by farmers. In addition, investigation of leaf nutrients ratios N/K, N/Ca, K/Ca, K/Mg and Ca/Mg showed that there was disharmony in uptake of these nutrients originating particularly from high soil richness in Ca and Mg. Taking into account these considerations, the found references norms can be applied only under the adopted farming practices. Nevertheless, by improving local practices, reference values may change.*

**Keywords**— *apple tree, leaf analysis, macronutrients, Morocco, soil analysis.*

## I. INTRODUCTION

In order to be more competitive and ensure the sustainability of quality of their soils, farmers should constantly improve fertilization efficiency of their crops [1]. This objective would be achieved through determination of critical level for each nutrient that designates its concentration in soil above which crops does not respond to a supply of this nutrient [2].

Determining this level usually based on trials, with a single factor, of escalating doses of a nutrient on crop yield at different levels of soil richness [3, 4].

In fruit trees, precise determination of the nutrient requirements is particularly difficult. Indeed, nutrients and metabolites may be stored in wood for use them at the next year by growing shoots [5]. To these difficulties are added those related to nutrients migration in soil and to particularity of tree root system [6]. Soil analysis permits to quantify soil richness in nutrients and to estimate fertilizer requirements but they provide no indication as their use by trees. However, leaf analysis is an effective tool for assessing nutritional status of trees and for readjustment of fertilizer requirements taking into account factors that may affect nutrients availability and their uptake by roots [7]. Thus, a deficiency in phosphorus would be explained by a low concentration of this nutrient in soil, an inhibition of its uptake caused by a high concentration in active limestone, or by combined effect of these two conditions [8]. Leaf analysis reveals also deficiencies induced by some fertilization practices. For example, a deficiency in potassium would be induced by nitrogen fertilization in soil containing a low concentration in potassium because the vegetative growth resulting from nitrogen generates important requirements in potassium [9]. Leaf analysis provides information about fertilizers assimilation and for this reason it complete soil analysis [10].

In Morocco, works on this topic, in particular for apple tree, are limited. Until now, interpretation of soil and leaf analyses for the Moroccan apple orchards based on reference norms established on others countries such USA, France, Netherlands, United Kingdom and South Africa. Establishment of norms under local conditions is therefore necessary for an efficient management of fertilization in Moroccan orchards taking into account local practices and production performances. The present work aims to establish recommendations for an efficient fertilization of adult apple tree in the region of Imouzzer Kandar in the Middle Atlas of Morocco, which constitutes a concentration area for apple production in

northern Morocco. It is also a contribution to identify the Moroccan norms of soil and leaf analysis for apple tree concerning nitrogen, phosphorus, potassium, calcium and magnesium.

## II. MATERIALS AND METHODS

### 2.1 Cultural conditions

Study was carried out in farmer's fields in the region of Imouzzar Kandar in northern Morocco. The climate of this region is characterized by cold winters with a minimum temperature of -10 °C and hot summers with a maximum temperature of 40 °C. The annual average of precipitations is 500 mm concentrated in autumn and spring. However, summer is characterized by a rainfall deficit (fig.1).

The experiment consisted in characterization of nutritional status and production of forty adult apple tree orchards (cultivar *Golden delicious* in association with *Starking delicious* as pollinator and grafted on *MM 106* rootstock) 12-15 years old and planted at a density of 667 trees/ha (5x3m) among farmers orchards in relation to their usual farming practices. The forty orchards were selected from all parts of the study area in which nineteen orchards were planted on silty-clay soils and twenty-one orchards on a sandy-loam soil. The orchards were irrigated by submersion every week from flowering to

fruit harvest (April – October) and practically pruned following the same manner, but differently fertilized. For all orchards, the intakes of nutrients concerned only nitrogen, phosphorus and potassium with amounts ranged from 6 to 165 kg/ha for nitrogen, from 0 to 135 kg/ha for phosphorus and from 0 to 112 for potassium. Weighed yield ranged from 8 to 26 t/ha.

### 2.2 Measurements

#### 2.2.1 Soil analysis

Soil analysis was realized during dormancy period of apple tree in November on two soil horizons: 0-35 cm and 35-70 cm. Analysis were performed by the following methods: particle size by pipette method [11], total and active limestone by Drouineau method [12], pH by titration [13], organic matter by Walkley and Black method [14], total nitrogen by kjeldhal method [15], available phosphorus by Joret and Hebert method [16], exchangeable potassium using ammonium acetate [17] and exchangeable calcium and magnesium by complexometry [18].

Physical and chemical characteristics of soil, both silty-clay and sandy-loam, are indicated in Table 1 showing that the soil for all experimental orchards was alkaline, moderately calcareous, rich in organic matter and little charged in rocks.

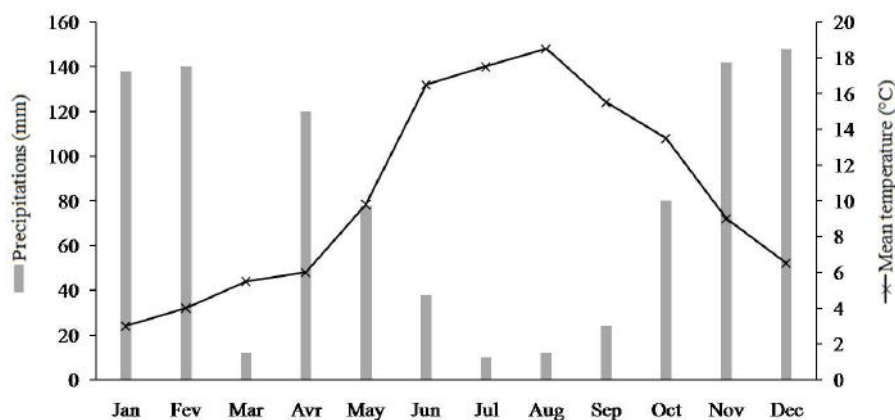


Fig.1: Monthly values of precipitation and mean temperature in the study region

Table 1. Physical and chemical characteristics of soil in the experimental orchards

	Orchards on silty-clay soil		Orchards on sandy-loam soil	
	0-35 cm	35-70 cm	0-35 cm	35-70 cm
Fine soil (%)	88.42	85.75	88.36	85.35
Total limestone (%)	33.45	31.71	35.30	33.04
Active limestone (%)	11.58	10.50	11.53	10.98
pH	7.81	8.02	7.83	8.04
Organic matter (%)	2.93	1.47	2.91	1.48

### 2.2.2 Leaf analysis

Leaves were taken with their petioles during the last decade of June 65 to 75 days after full flowering stage, from middle portion of growing shoots. At this period, nutrients content of apple leaves are relatively stable and for which references norms have been previously established [19]. Leaves samples were conveyed immediately to the laboratory where they were placed in a hydrochloric acid solution 0.1%, washed thoroughly with distilled water, dried at 70 °C for 48 hours and finely grinded.

Analysis concerned leaf content in nitrogen, phosphorus, potassium, calcium and magnesium following methods described by Rayan *et al.* [15]: nitrogen by kjeldhal method, phosphorus by spectrophotometer, potassium by flam photometer, calcium and magnesium by complexometry.

### 2.3 Statistical analysis

Data was used to evaluate significance of correlations established between soil richness in nutrients and nutritional status of apple tree based on leaf analysis and the obtained fruit yields. The significance of correlations was evaluated following Pearson test using SPSS software (version 17.0).

## III. RESULTS AND DISCUSSION

### 3.1 Reference norms for leaf analysis

Apple yield varied with leaf nutrients contents following significant polynomial equations. According to determination coefficients of the found equations, apple yield was more determined by leaf potassium and nitrogen better than phosphorus, calcium and magnesium. This result is in line with the findings of Cheng and Raba [19] on Gala apple tree, of Raina *et al.* [20] on pear tree and of Kumar *et al.* [21] on kiwi tree. The curves of these equations indicated that reference norms of leaf analysis for high apple yield in the study site were 2.80-3.10 for nitrogen, 0.20-0.22 for phosphorus, 1.90-2.10 for potassium, 1.30-1.45 for calcium and 0.25-0.28 for magnesium (figure 2). These norms are higher than those recommended by Mahhou [22] in Sais plain in Morocco on *Golden delicious* grafted on rootstock *MM 106* for nitrogen and phosphorus that are respectively 2.35 and 0.14, but they are similar for potassium. These differences may be related to a variation in agricultural situations, especially to a difference in apple yield potential which is lesser in Sais plain compared to the mountainous region of Imouzzer Kandar because mainly of an insufficiency in chilling availability [23]. In comparison to other

countries, these norms are similar to those adopted in France regarding all the analyzed macronutrients except nitrogen [5]. For this nutrient, the found norms are similar to the United Kingdom norms [24]. While in comparison with the American norms, the concordances were found only for phosphorus and calcium [25].

The found norms imply that the optimal ratios between leaf nutrient concentrations should be ranged from 1.38 to 1.63 for the ratio of N/K, 2 to 2.38 for N/Ca, 1.31 to 1.61 for K/Ca, 6.55 to 8.40 for K/Mg and 4.48 to 5.80 for Ca/Mg. These ranges values of ratios are in line with the France norms for N/K, K/Mg and Ca/Mg and with United Kingdom norms for N/Ca, K/Ca and Ca/Mg [5, 24].

Our results showed that the optimal values of ratios of N/K and Ca/Mg were effectively recorded in the most productive orchards where yields are higher than 22 t/ha, thereby indicating that there was a harmony in uptake of these nutrients in soil [26]. However, ratios values of N/Ca, K/Ca and K/Mg in these orchards were generally lesser than the optimal ranges (table 2). This disharmony between these nutrients is originating from an excessive uptake of Ca and Mg since their concentrations in leaf are higher, exceeding the optimal values by an average of 0.14% for Ca and 0.02% for Mg. The origins of excesses in Ca and Mg are related primarily to their high concentration in soil [27]. However, other factors may induce excess in Ca and Mg uptake such as the use of nitrogen as nitrate (NO<sub>3</sub>), high contents in phosphorus and low amounts of potassium [28].

Nevertheless, the recorded excess in leaf Ca and Mg did not induce a reduction in apple yield. In fact, these two nutrients are not toxic for plants even at high concentrations, but they induce indirect effects [29]. The high soil contents in Ca and Mg generate an increase in pH, which reduces the uptake of certain nutrients such as boron, iron, manganese and zinc. Because they are cations, they compete therefore with the uptake of other cations such potassium (K<sup>+</sup>) and ammonium (NH<sub>4</sub><sup>+</sup>) and may cause a deficiency of these nutrients [30].

### 3.2 Reference norms for soil analysis

The relationships between soil and leaf nutrient content were tested by logarithmic regression analysis regarding phosphorus, potassium, calcium and magnesium taking into account both the initial soil richness and the applied amount of fertilizers. However, for nitrogen, relationship was tested for nitrogen fertilizer only because of a lack of indications concerning mineralization of organic nitrogen (table 3).

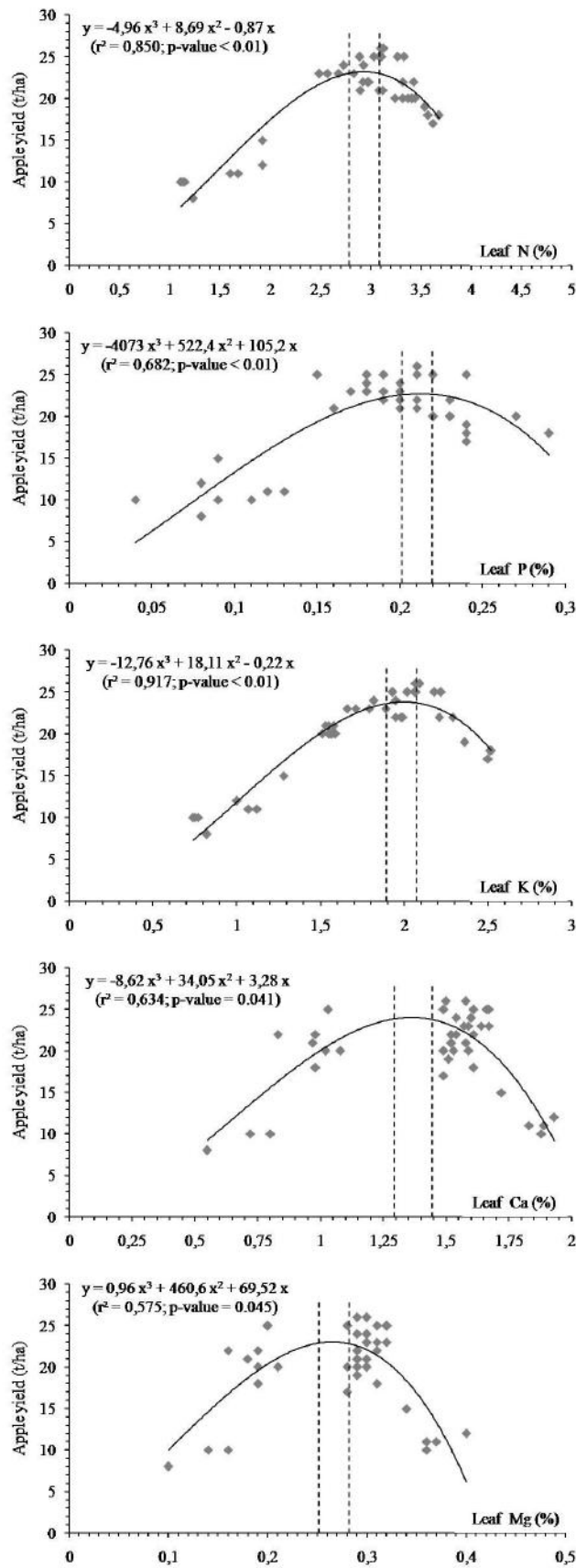


Fig. 2. Relationship between leaf nutrients content and apple yield

Table.2. Ratios of different leaf nutrients in the productive apple orchards compared to the optimal values

Ratios	N/K	N/Ca	K/Ca	K/Mg	Ca/Mg
Min	1.49	1.56	1.04	5.51	5.21
Max	1.50	1.69	1.13	5.96	5.30
Mean	1.50	1.63	1.08	5.73	5.26
Optimal values	1.38 - 1.63	2 - 2.38	1.31 - 1.61	6.55 - 8.40	4.48 - 5.80
French norms	1.13 - 1.57	1.13 - 1.68	0.75 - 1.43	4.29 - 9.09	4.00 - 9.09
United Kingdom norms	1.50 - 2.15	1.50 - 2.80	0.81 - 1.60	4.33 - 6.40	3.33 - 6.40

Table.3: Relationship between nutrients content in soil and apple leaf following soil texture

Correlated factors	Regression equation	r <sup>2</sup>	Optimal level in soil	
Silty-clay soil	Fertilizer N (kg/ha) vs. Leaf N (%)	$y=0.526\ln(x)+0.53$	0.58**	74 - 130
	Soil P <sub>2</sub> O <sub>5</sub> (ppm) vs. Leaf P (%)	$y=0.064\ln(x)-0.09$	0.71**	92 - 126
	Soil K <sub>2</sub> O (ppm) vs. Leaf K (%)	$y=1.187\ln(x)-5.06$	0.77**	350 - 415
	Soil Ca (meq/100g) vs. Leaf Ca (%)	$y=0.552\ln(x)-0.15$	0.83**	14 - 18
	Soil Mg (meq/100g) vs. Leaf Mg (%)	$y=0.109\ln(x)+0.19$	0.71**	1.7 - 2.2
Sandy-loam soil	Fertilizer N (kg/ha) vs. Leaf N (%)	$y=0.634\ln(x)-0.07$	0.76**	92 - 146
	Soil P <sub>2</sub> O <sub>5</sub> (ppm) vs. Leaf P (%)	$y=0.074\ln(x)-0.13$	0.87**	82 - 106
	Soil K <sub>2</sub> O (ppm) vs. Leaf K (%)	$y=0.809\ln(x)-2.78$	0.57*	320 - 410
	Soil Ca (meq/100g) vs. Leaf Ca (%)	$y=0.481\ln(x)-0.05$	0.86**	13 - 18
	Soil Mg (meq/100g) vs. Leaf Mg (%)	$y=0.107\ln(x)+0.19$	0.85**	1.7 - 2.2

The results show that leaf contents in N, P, K, Ca and Mg are significantly correlated with their corresponding soil contents both in silty-clay and sandy-loam soils. Such correlations were reported in several previous works [31-33]. However, other trials reported that correlation is particularly low for phosphorus because of its low mobility in soil, thereby making its uptake limited at few millimeters from the hairy root [22, 34]. The significance of the found correlation for this nutrient under the cultural conditions of the present study may be related to the submersion irrigation, which was able to increase the mobility of phosphorus in soil and making it more available for roots.

Furthermore, data show that the correlation coefficients in sandy-loam soil are higher than those found in silty-clay soil except for potassium. This result is in agreement with those of Fan and Yang [35] who indicated that uptake ability is higher in sandy soil for majority of nutrients owing to their increased mobility. Particularly, the high

value of correlation coefficient found for nitrogen in sandy-loam soil indicates that there was no considerable leaching of this nutrient that is known to be important in sandy soil [36]. In clay soil, the uptake ability is particularly higher for potassium as result of its high fixation on clay particles and clay-humic complexes that ensure exchange of this nutrient in soil [37].

For each nutrient, the corresponding soil contents to ensure the leaf reference norms are considered as optimal soil contents to get high apple yield (table 2). The found optimal soil content for P, K, Ca and Mg may be considered as reference norms for soil analysis for apple orchards in the study region. While for nitrogen, the found values constitute the optimal amounts of nitrogen fertilizer for a high apple production with an average of 88 kg/ha for apple orchards growing in silty-clay soil and of 130 kg/ha for orchards in sandy-loam soil. These nitrogen doses are near of those recommended in Morocco by Mahhou [22] for *Golden Delicious* 30 years



old and producing 40 t/ha. They are also near amounts generally recommended in Western USA and Eastern Canada [38, 39]. However, they are higher than France recommendations averaged at 50 kg/ha for an apple yield of 26 t/ha [40]. In fact, nitrogen dose vary following orchard situations. There is a significant disagreement in data on nitrogen amount used and removed by apple tree that is related to the differences in location, requirements of varieties and cultural practices [41]. Taking into account these considerations, the found optimal nitrogen doses concerns only the year of study and should be regarded as approximate for fertilizing apple tree in the region study for the next years.

Compared to the interpretation norms for soil test of Soltner [42], the found optimal nutrient contents in silty-clay soils are arranged in low level for P, sufficient level for K and high level for Ca and Mg. In sandy-loam soils, the optimal values are moderate for P and high for K, Ca and Mg. This disagreement may be related in large part to

differences in yield level that is low compared to the production potential of the used variety that can reach 40 t/ha under optimal conditions [43]. This result imply that there were other factors that affect apple yield in the region study such as spring frosts, hail falls and inadequate cultural practices (irrigation, pruning, pests and diseases, etc.). Indeed, in previous diagnostic works carried out in the study region, it has been noted the existence of such factors that affect severely apple production [44, 45]. Nevertheless, for an apple yield of 26 t/ha, the found optimal nutrient contents may be used as soil reference norms for the region study. By comparing these norms to soil analysis data, it appears that the soil richness in K, Ca and Mg is able to satisfy the apple needs in these nutrients for all the tested orchards, thereby indicating that no intake in these nutrients is required. However, the intake of P is required since soil P content is low compared to found reference norms both in the silty-clay and sandy-loam soils (table 4).

*Table.4: Recommended amounts of fertilizers (kg/ha) for an apple yield of 26 t/ha*

	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Ca	Mg
Orchards in silty-clay soil	88	75	0	0	0
Orchards in sandy-loam soil	130	84	0	0	0

#### IV. CONCLUSION

In adult apple orchards growing in the middle Atlas of Morocco, there is an amply variation in yield level, applied amounts of fertilizers, soil richness in nutrient and their concentration in leaf. These variations originate from differences in cultural practices, especially fertilization since relationships between apple yield and nutrient content in soil and leaf were significant. The relationship between yield level and leaf nutrient content served to determine the reference norms for leaf analysis with regard to nitrogen, phosphorus, potassium, calcium and magnesium required to ensure a high apple yield under local climate, soil and cultural practices. Furthermore, relationship between leaf and soil nutrient content brought out local apple nitrogen needs and reference norms of soil analysis for P, K, Ca and Mg. However, it should be highlighted that the found results are in preliminary order since the study was conducted during one year. The results are also in elementary order for establishment of the Moroccan reference norms for leaf and soil analysis in apple orchards.

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