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Effect of the Phosphate Fertilization on the Production of Apple Trees Planted in Calcareous Alluvial Soil

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Abstract

To test the effect of phosphate fertilization on the production of the Tunisian local apple variety "Llorca" planted on alluvial, highly carbonated and silty to silty clay soil, an experimental protocol consisting of a test block with 5 treatments and three repetitions has been applied. The five treatments are doses of bi-ammonium phosphate (DAP) varying between 0 and 200 kg/ha, spaced 50 kg/ha of each other. They have been applied by plowing on three rows located in the middle of the studied orchard. At the end of the cropping season, analyzes on available P_2O_5 (Olsen) under each tree and P content of dry matter of fruits were conducted. The results showed that the yield is strongly correlated with fertilization of DAP, but no effect was detected on the P concentration of fruits. Export of P by fruits was also variable and is not clear linked with increasing fertilizer doses. Values, despite their weakness, appear in the standards, compared to results from other regions. The conclusion is that the yield responded more to increasing the contribution of nitrogen to that of phosphorus. P, initially abundant in the soil by precedent fertilizations, had no detectable effect on production. Fertilization of the crop should be balanced by reducing phosphorus doses to the just annual crop needs and incorporating nitrogen and potassium fertilizers.

Keywords*: Apple Trees, Export, Fruits, Phosphorus, Soil, Treatments.*

Introduction

The apple tree (*Malus pumila*) is a fruit culture often established on calcareous soils of north and west of Tunisia. Its yields are relatively weak and generally vary between 10 and 15 tons of fruits per hectare. The well led orchards can reach yields of 25 tons per hectare (GIFruit, 2008). Among the principal constraints contributing to the weak productions, we note the calcareous soils with alkaline pH in which the orchards of apple trees are established. Under these conditions, nitrogen and potassium can be assimilated without problems, but it is the phosphorus which, from its characters of low mobility and demotion with calcium of limestone (Dutil, 1976; Arvieu, 1980; Morel, 1988; Burden and Conesa, 1994), can have a depressive effect on the production by insufficiency of the quantities absorbed by the trees. However, this element fulfills many important physiological functions within the plant organism, which in its deficiency, affects negatively the production. It takes part indeed, with respiration, energy transfers, proteins synthesis; it accelerates the maturation and the conservation of fruits; it supports growth, development of roots, precocity and fecundation; it increases the strength of the trees, the yield, the coloring of the fruits and their firmness after storage (Magny and Baur, 1982; Hopkins, 2003; Wojcik and Wojcik, 2007). By fulfilling these many functions, phosphorus supports the final production, which depends on the edaphic conditions and phosphorus brought (Lafarge and Gault, 1985).

Given the soil requirements of apple trees which prefer soil pH near 6.0 to 7.5 (Mahhou, 2008), the roles of P on the production, but also the risks of its insolubilization by limestone, it was considered useful to study firstly its impact on yield and fruit export and secondly to evaluate the relevance of the farming practice of mono-phosphate fertilization on soil and culture. In this context, an experimental protocol has been implemented on a selected part of an orchard and the study was applied during the 2013 crop year.

Material and methods

Field activities

The studied orchard covers a surface of 2.5 ha on left bank of Mejerda which is the principal river with permanent flow, crossing North of Tunisia and joining the Mediterranean Sea at the eastern coast. The soil occupied by the orchard is an alluvial plain filled by the recent deposits of Mejerda floods. The materials from which the soils occur are thick, highly carbonated and often of fine texture.

Table 1 Soil analysis results before the phosphate fertilization

Depth cm	Particle size (%)					pH 1/2,5	EC* dS/m	$CaCO_3$ (%)		OM* (%)	Available P_2O_5 ppm	Exch.* K_2O ppm
	C*	FS*	CS*	fs*	cs*			Total	Active			
0-20	7	39	8.4	34	6	8.4	1.2	38	19	0.8	65	90
20-40	18	30	8.3	36	2	8.3	1.6	43	21	0.6	54	50
40-60	26	41	8.3	24	1	8.3	3.6	57	27	0.3	38	50
60-80	16	42	8.34	32	1	8.34	4.7	43	21	0.2	18	70

* C: clay; FS: fine silt; CS: coarse silt; fs: fine sand; cs: coarse sand; EC: electric conductivity; OM: organic matter; Exch: exchangeable

T_2	T_4	T_1	T_0	T_3
T_4	T_1	T_0	T_3	T_2
T_0	T_2	T_3	T_4	T_1

Figure 1- Random arrangement of treatments (doses of DAP) in 3 blocks

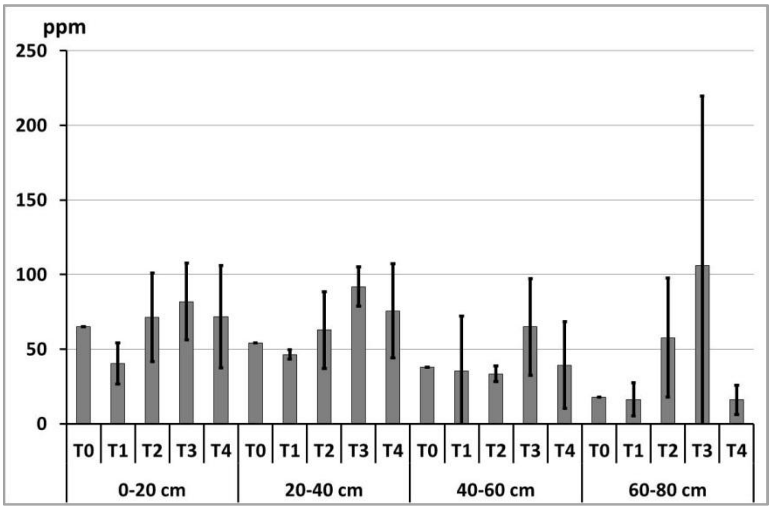

Figure 2 - Means of soil available P_2O_5 (ppm) of three replicates for each treatment, arranged according to the sampling horizons

The climate is Mediterranean with upper semi-arid stage; annual rainfall presents an average ranging between 450 and 500 mm, distributed essentially over the period September-April of each cropping season.

The trees are arranged in rows, with a density of plantation of 4 m × 4 m, which makes a number of 625 units per hectare and around 1560 trees for the total surface of orchard. The local cultivated variety is called "Llorca". It produces yellow fruits with big caliber, resembling those of "Golden delicious".

The experimental protocol consisted of the addition to soil of increasing doses of binary phosphate fertilizer (Di-amino-phosphate: DAP) containing 46% of P_2O_5 and 18% of N, for three rows of trees chosen in the medium of the orchard (Figure 1). The doses varied between 0 and 200 kg/ha of DAP, which made 5 increasing levels of 50 kg one compared to the other. The three lines constitute randomized repetitions what made an experimental layout in blocks including 5 treatments and 3 blocks. Contributions of fertilizer were hidden under the trees concerned, by ploughing, in February 2013, just before the buds stage. No other mineral or organic manure was brought.

A first sampling operation was carried out at the beginning of February just before the fertilization, on 4 thicknesses ranging between 0 and 80 cm: a sample every 20 cm. It is intended to characterize the orchard soils before the experimentation by the following analyses: particle size, pH, electric conductivity of saturated paste extract, active and total limestone, organic matter, available phosphorus, exchangeable potassium.

The second sampling operation was carried out at the end of May 2013 just fifteen days before the maturity of the fruits.

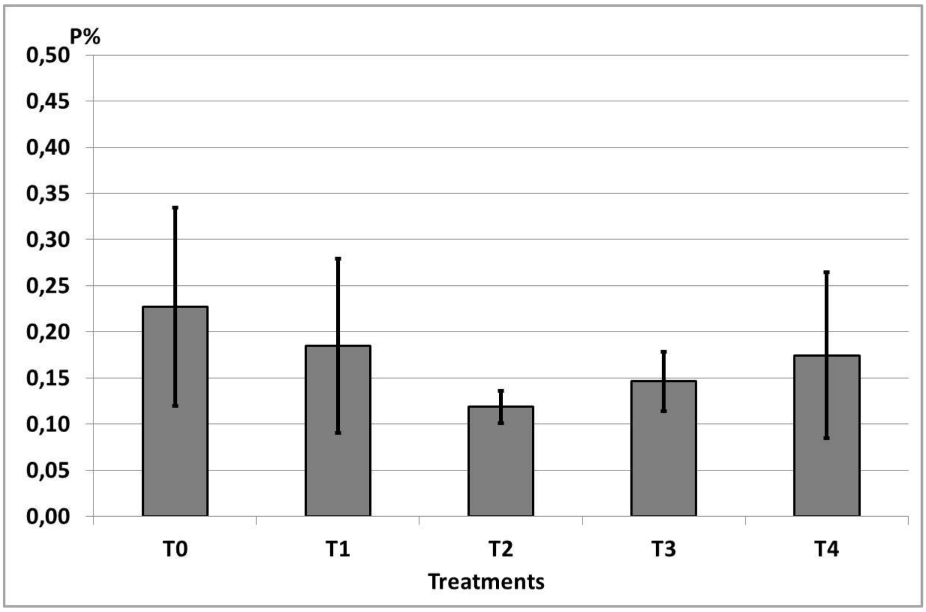

Figure 3 - Concentrations of P (%) in the dry matter of fruits for each treatment

Table 2 Dry matter content (DM%), yield of fruits in kg/tree and in T/ha and exported P by fruits in kg/ha and in kg/ton of fresh fruits

Treatments	Dry matter (DM) content (%)		Yield (kg fruits/tree)		Yield ton/ha	DM kg/ha	P export		
	Mean	SD*	Mean	SD*			P kg/ha	P_2O_5 kg/ha	P kg/ton
T_0	15.89	1.27	12.49	3.16	7.806	1240.15	2.82	6.45	0.36
T_1	14.80	0.08	13.47	1.13	8.421	1246.56	2.30	5.28	0.27
T_2	14.48	0.61	18.97	1.57	11.856	1716.79	2.04	4.67	0.17
T_3	15.28	0.26	18.87	2.52	11.794	1801.69	2.63	6.03	0.22
T_4	14.58	0.48	24.00	4.18	15.000	2187.5	3.81	8.73	0.25

*SD: standard deviation

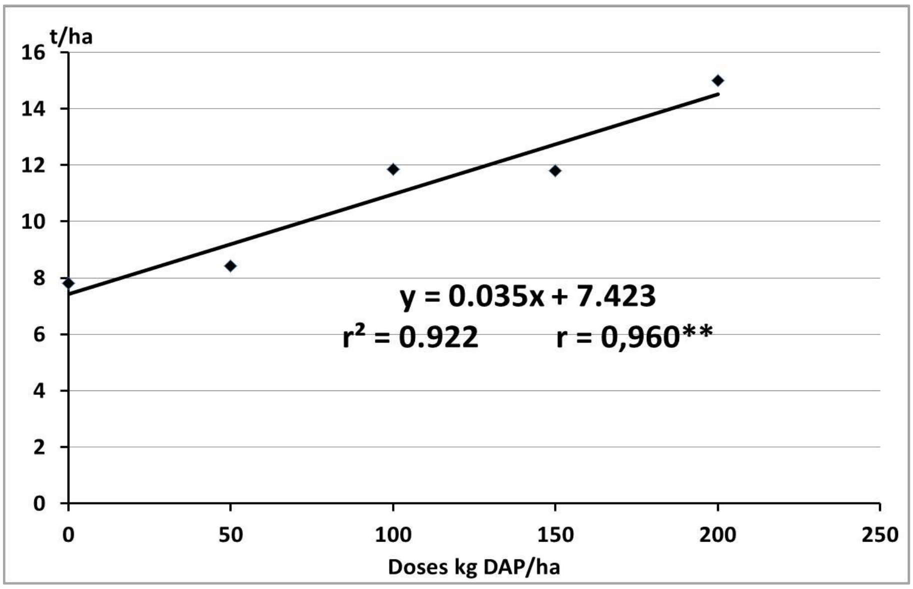

Figure 4 - Right correlation between phosphate fertilizer doses (DAP kg/ha) and the yield of fresh apples in tons/ha (**: p = 0.01)

Under each fertilized tree, four samples representing the four levels of depths (0 to 80 cm) were taken which made a total of 48 samples. There was no sampling under T_0 which is the control point. These samples are intended to only analyze available parameter P_2O_5.

From each tree of the device in blocks, 5 fruits were taken in June 2013. They were weighed in a fresh state then dried and weighed again in a dry state. Their dry matter was crushed and was used to analyze the phosphorus exported by the fruits. At the same time, a counting of the number of fruits of each tree was carried out in order to estimate the apples yield per tree and per hectare.

Methods of soils analyses

The methods employed are those diffused by Naanaa and Susini (1988).
– Particle size analysis: method of pipette of Robinson.
– pH: measured with the pH-meter in 1/2.5 suspension.
– Electric conductivity: measured with the conductivimeter in dS/m, in a saturated paste extract.
– Total limestone: method of the calcimeter of Bernard.
– Active limestone: extraction with ammonium oxalate 0.2 M, dosage of the oxalate excess per manganimetry.
– Organic matter: method of Walkley and Black, colorimetric dosage at the wavelength 600 nm.
– Available phosphorus: extraction with sodium bicarbonate 0.5 M (Olsen method), colorimetric dosage at the wavelength 660 nm.
– Exchangeable potassium: extraction with ammonium acetate 1M, dosage of K^+ by flame photometry.

Methods of fruits analyses

– Determination of the dry matter rate: weighing the fruits in a fresh state, drying with the ventilated oven at 70-80 °C until obtaining constant weight and weighing dry matter (DM).
– P extraction (method of Saint Amand and Cas (1967) modified) : crushing the dry matter, calcination of 1 g of the vegetal powder at 550 °C during 5h30 mn, moistening in HCl 1/5, filtration with 100 ml of distilled water. Dosage of P by colorimetry at the wavelength 660 nm.

Results

Initial characterization of the orchard soils

As the orchard soil is homogeneous, only one sampling point was used to identify the physicochemical properties of this soil. The analysis results (Table 1) show that texture is silty, that mineral matter is highly carbonated, with active limestone rates exceeding almost always the 20% and that the pH is alkaline with values close to 8.5. The organic matter is of low content reflecting the characters of the cultivated soils of the semi-arid zones. The electric conductivity of the saturated paste extract increases in-depth to exceed even 4 dS/m what explains that salinity would have for origin an underground water level, or an accumulation of salts by successive leaching operations.

The contents of P_2O_5 extracted according to the Olsen method seem significant explaining the high annual fertilization of phosphate by the farmer. The reserves persist and were not immobilized in spite of the strong proportions of limestone in the mineral fraction. Exchangeable K is with relatively low contents and this would be related on the small clay fraction and the abundance of limestone.

The P_2O_5 reserves in soil at the end of the crop season

The contents of available P_2O_5 of the four horizons of the orchard soil increase according to the doses of fertilizer brought. This is visible on the treatments T_3 and T_4 especially in the horizons 0-20 cm and 20-40 cm which are more affected by the fertilization since fertilizer was hidden on the surface. For the whole of the profile, it is especially the treatment T_3 (150 kg/ha of DAP) which is characterized by its higher mean values (Figure 2).

The value of the control sample T_0 is rather high in horizon 1, this is explained by the fact that all the plot soil would have been strongly fertilized during the seven preceding crop years and it kept high reserves in spite of the absence of fertilization during this crop; horizon 2 (20-40 cm) is influenced also enough by the significant contents of the overlying horizon. We must note the high value of standard deviation of the mean of T_3 in the deepest horizon.

Concerning the impact of DAP doses on the reserves of P_2O_5 in the soil, it was evaluated by the correlation test. The values of the correlation coefficient r between the doses in kg/ha and the means of the reserves per horizon, were 0.5568 and 0.7785 for the horizons 0-20 cm and 20-40 cm, respectively. These values indicate non-significant correlations to n-1 degrees of freedom, in spite of the rapprochement of r to 1, relating to the horizon 20-40 cm. After a few months of burying, phosphorus would have been mobilized either by root absorption or by fixing on the solid particles of the soil and in particular its precipitation with limestone.

The export of P by the fruits

Contents of P (%) in dry matter vary between 0.119% for T_2 and 0.227% for T_0 (Figure 3). The increasing amounts of P in the soil did not have an effect on the concentrations of this element in the fruits since the highest value corresponds to the point T_0 not having received a fertilization; weakest contents of P are in fruits of T_2 having received a dose of 100 kg/ha of DAP.

The means of the dry matter rates are close to 15% for the five treatments and there is no obvious link between doses of fertilizer and these values (Table 2). Their standard deviations are weak and reflect the homogeneity of the fruit concentrations and the weak margin of error in measurements.

The average yield varied between 12.49 kg for T_0 and 24 kg for T_4 of fresh apples by tree, which is equivalent to 7.806 t/ha for T_0 and 15 t/ha for T_4. Such a production exported between 2.04 kg for T_2 and 3.81 kg for T_4 of P per hectare. The concentration of P per ton of fresh apples varied between 0.17 for T_2 and 0.36 kg/ton for T_0 (Table 2).

The yield is highly correlated (**: p = 0.01 with 3 (n-2) degrees of freedom) at the fertilizer doses brought as figure 4 indicates it. The coefficient of correlation r is indeed equal to 0.960. For the relation fertilizer doses – export of P in kg/ha, it is non-significant owing to the fact that r is equal to 0.539.

The soil reserves of P_2O_5 at the end of the crop season aren't correlated neither at the yield nor at the P contents in the dry matter of fruits; however, the coefficients of correlation r indicate, with values of 0.598 and 0.689, a certain dependence between the yield in tons/ha and the reserves of the horizons 0-20 cm and 20-40 cm, respectively.

Discussion

Plants retained by the study benefited from the phosphate and nitrogenized contribution by the DAP; there was no potassium fertilization. The DAP contains 46 % of P_2O_5 and 18 % of N. The fertilizer provided thus for soil 0, 9, 18, 27 and 36 kg/ha of N, for T_0, T_1, T_2, T_3 and T_4 respectively. For potassium (K_2O), the soil reserves (Table 1), calculated with a mean of bulk density of 1.5 are about 780 kg/ha in thickness of 80 cm.

The DAP fertilization in increasing doses, had a positive impact on the yield explained by a highly significant positive correlation. Its effect on the soil reserves after four months of the fertilization date was partially observed in the horizons 0-20 cm and 20-40 cm and in particular in this last horizon for which the coefficient of correlation r was 0.779.

In spite of the large fertilizer doses especially for T_3 and T_4, but also of the significant reserves of P inherited from the fertilizations of the preceding years, the phosphorus exported by fruits was firstly relatively weak and secondly not growing with the increase of the contributions. The P concentrations in the dry matter of the fruits varied between 0.12% for T_3 and 0.23% for T_0; such concentrations make that export by tree varied between 3.26 g of P for T_2 and 6.10 g for T_4. These values are slightly higher than that found by Yan'an and Fan (2007) which is of 2.84 g/tree. Such a figure corresponds to 1.775 kg of P or 4.065 kg of P_2O_5 per hectare. Mahhou (2008) announced that a production of 40 tons of fruits would export 35 kg of P_2O_5 distributed in the following way: 13 kg for the fruits, 6 kg for the leaves, 9 kg for the branches, the trunk and roots, 3 kg for various taking away (buttons, falls of fruits) and 4 kg for the prunings. The production in the studied orchard, whose trees are only 7 years old, varied between 7,8 and 15 T/ha and exported between 4,67 and 8,73 kg/ha of P_2O_5, it is far below the 40 tons produced by an adult orchard and exporting 13 kg/ha of P_2O_5 (Mahhou, 2008). If the production were 40 tons/ha, the studied orchard would have exported between 15.75 and 23.28 kg/ha of P_2O_5 by the fruits.

Finally, the P contents of the dry matter do not differ too much from those which were identified by various authors on the leaves: 0.15 to 0.4% (Ministry of agriculture and food of Ontario, 2012-2013; Ankerman and Large, 2001); 0.184 to 0.390% (Eaton and Robinson, 1977); 0.12 to 0.40% (Zatylny and St-Pierre, 2006).

Consequently, the phosphate nutrition of the apple trees in highly carbonated soils and with silty texture, in spite of an in-depth relatively high salinity and a low content of organic matter, concentrated the element P in the fruits in ordinary contents which did not vary according to the treatments. Phosphorus is sufficiently abundant in all the treatments and would not have had a direct effect on the variation of the yields. Those would be more sensitive to the increase of N contents which is also provided by the DAP. Indeed, the producer did not bring any other fertilizer in addition to the DAP. Potassium would not have constituted a constraint since its reserves are significant on 80 cm thickness, volume normally explored by the roots of the apple tree, even if a good production requires 150 kg/ha of K_2O (Mahhou, 2008). The nitrogenized mineral fertilizer should not be limited to a mixed manure bringing of the incomplete requirements in N, it should reach 100 kg/ha of N (Mahhou, 2008) for a variety like the "*Golden delicious*"; this nitrogenized fertilization should not, in no case, to be neglected as announced by Kleiber (1995).

The abundance of the phosphorus, evaluated by the Olsen method considered to be interesting in calcareous soils (Burden *et al.*, 1988), did not make possible to detect a variation on the P concentration of the fruits; the tree would have reacted to increasing contributions of DAP especially for the nitrogen which would be defective in this type of soil slightly provided of organic matter. The same practices of fertilization which are repeated in each crop year charged the soil of important quantities of phosphorus in spite of the high presence of calcium carbonates in the mineral fraction. The threshold of 28 ppm of P_2O_5 identified by Morel *et al.* (1992) as the level allowing 95% of the maximum production in wheat grains, would be also a sufficient level for the apple tree which does not export as much P than wheat. The fertilization by only one fertilizer creates an imbalance in the soil which does not provide a well-balanced flow of elements to the roots and the plant would undergo the effects on its metabolism and finally on its production. It was shown that phosphorus appears only in third position, after potassium and nitrogen, like element absorptive by several varieties of apple trees such as the

"Gala", "Golden delicious" and "*Fuji*" (Nachtigall and Dechen, 2006). Too much phosphorus in soils, even in the form of insoluble solid particles, with pH alkaline, constitutes a risk for the eutrophication of continental and marine waters.

Conclusion

The experimentation carried out in mode of blocks with 5 treatments consisting of increasing doses of phosphate and nitrogenized fertilizer (DAP) and 3 repetitions, on three rows of 7 years old apple trees, led to note that the fertilization acted positively on the yield but it did not have obvious impact on the P concentration of the fruits. Export of P by the fruits is variable from one treatment to another and is not proportional to the added quantities of fertilizer. Its quantity seems ordinary compared to the obtained productions which varied between 7.8 and 15 tons/ha of fresh fruits per hectare.

The phosphorus abundance in soil does not concentrate it in the fruits which take only their needs. The reaction of the yield to fertilizer seems to have due a response to the increasing quantities of N brought by the DAP in the form of ammonium (NH_4^+). A good production can be only the result of a well-balanced fertilization with the three major elements N, P and K brought in quantities evaluated according to the importance of the production considered and to other parameters relating to the age of the plantation and the soil reserves especially in P and K. To reach good productions in an orchard of apple trees, the contributions of trace elements should not be forgotten, especially in calcareous soils where the pH with values always close to 8.5 precipitates almost the totality of these elements and the plant would be deprived by them what should be reflected negatively on the yields.

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