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# Injection Fertilization: A Full Nutritional Technique for Fruit Trees Saves 90-95% of Fertilizers and Maintains a Clean Environment

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## ABSTRACT

Several experiments were carried out in Egypt and Germany to study whether fruit shrubs and trees can be fertilized by injection through the trunk. Results showed that dicotyledonous vascular trees (mango and grapevine) can be fully fertilized by injection through xylem. Only 5-10% of the levels used in soil fertilization were sufficient for good growth and high yield. Growth of the injection-fertilized mango (*Mangifera indica* var. 'Sukkary white') trees was 20-25% higher than soil-fertilized plants while in grapevine (*Vitis vinifera* vars. 'White Riesling' and 'Spaet Burgunder') fruit yield increases were 32-49% higher compared to soil fertilization. Fruit quality of grapevine clusters assessed (juice °Brix, pH, reduced sugars, total acidity, grape vinegar, apple vinegar, ethanol and glycerin content) of the plants fertilized through injection was better than those fertilized through soil. Grapevine fresh juice content of the reduced sugars and ethanol increased by 7.5-11.9 and 41.4-50%, respectively while the total acidity decreased by 6.2-19.7%. Using injection fertilization, there was no need to control weeds because they never competed with tree roots for nutrient absorption. Since there is no soil fertilization, there was no use of herbicides or pesticides, nor leaching of these compounds to underground water, which was expected to be clean enough to be used as drinking water with no or less health hazards. This technique was registered as a patent in the Egyptian Academy for Scientific Research and Technology number 23750 in July, 2007.

**Keywords:** grapevine, growth, fruit quality, mango, nutrient status

## INTRODUCTION

The demand for food and other agricultural products is increasing in Egypt due to an increase in the population. Improved crop productivity is a continuous effort from both government and private sector. Fertilization is one of the most important agricultural practices for increasing crop productivity. Evaluation of the best source of nutrients, optimum rates of fertilization, suitable timing and proper fertilizer placement are necessary for efficient fertilizer management.

Conventional methods of plant nutrition depend upon fertilization through soil (broadcasting, splitting, dressing and fertigation). Foliar fertilization can only serve as a supplement in particular cases (high pH values of the soil solution, high $CaCO_3$ content, high salinity, etc.). Egypt currently consumes 1.25 million tones of fertilizers per year. Mango fertilizer rates range between 95-360 kg N, 55-70 $P_2O_5$ and 60-110 kg $K_2O.ha^{-1}$, while recommended fertilizer rates for grapevine varieties range between 95-300 kg N, 70-115 kg $P_2O_5$ and 60-110 kg $K_2O$ kg.$ha^{-1}$ (FAO 2005).

Previous studies proved that only a small portion of soil-added fertilizers is taken up by plant roots, especially those grown under sandy soil conditions, where high permeability allows fast leaching of fertilizers to underground water (Halliday and Trenkel 1992). Another portion of soil fertilizers is lost by volatilization, especially nitrogen. The lost portion of nitrogen was estimated to be as high as 62-85% of the added fertilizers (Dixon 2003). Fixation of other nutrients like phosphorus and micronutrients in the form of low dissolved compounds in the soil is responsible for another portion of the added fertilizers to be less available for absorption by the plant roots (Horesh and Levy 1981).

The present work assessed whether mango (tree) and grapevine (shrub) could be fertilized directly through the xylem in order to save fertilizers lost through soil application and to keep underground water free from chemicals.

## MATERIALS AND METHODS

Several experiments were performed in the greenhouse of the Micronutrients Project, National Research Centre, Dokki, Cairo, Egypt (2002-2007) with mango and in the farm of the Plant Nutrition Institute, Geisenheim, Germany (2006) with grapevine to investigate the possibility of full fertilization by injection into the trees' trunks. Since the detailed contents of these studies are the subject of an Egyptian patent (Egyptian Academy for Scientific Research and Technology No. 23750, July, 2007), they can not be described in detail below.

### Cultivation and agricultural practices

One-year old mango (*Mangifera indica* L.) var. 'Sukkary white' seedlings were purchased from the nursery of the Faculty of Agriculture, Suez Canal University, Ismailia, Egypt. The seedlings were transplanted into a plastic container filled with 100 kg

**Table 1** Physical and chemical characteristics of mango soil ($n$ = 3).

| Physical characteristics | Nutrient concentrations |
|---|---|
| pH 7.6*** | Exchangeable macronutrients |
| $CaCO_3$ (%) 1.2* | (mg.100g$^{-1}$ soil) |
| O.M. (%) 0.35* | P 2.0* |
| Sand (%) 87.0 | K 7.7* |
| Silt (%) 2.1 | Mg 16.0* |
| Clay (%) 10.9 | |
| Texture: Sand | |

* = low; ** =Adequate; *** = High (Ankerman and Large 1974)

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**Research Note**

**Table 2** Physical and chemical characteristics of grapevine soil ($n$ = 3).

| **Physical characteristics** | **Nutrient concentrations** |
|---|---|
| pH 7.8*** | Exchangeable macronutrients |
| $CaCO_3$ (%) 14.5*** | (mg.100g$^{-1}$ soil) |
| O.M. (%) 1.5** | P 14.0*** |
| Sand (%) 57.3 | K 16.0* |
| Silt (%) 40.1 | Mg 9.0* |
| Clay (%) 2.6 | |
| Texture: Sandy loam | |

* = low; ** =Adequate; *** = High (Ankerman and Large 1974)

washed sand (**Table 1**) in the greenhouse of the project Micronutrient and Plant Nutrition Problems, National Research Centre, Dokki, Cairo, Egypt. Every container has only one seedling and the containers were organized to keep 3 m distance between seedlings. Irrigation was performed once a week in spring, summer and autumn, but stopped during winter season. Average maximum temperature during the course of the study was 37.4°C while average minimum temperature was 7.6°C. Average relative humidity of the cultivation area ranged between 48 and 64.7% and the light intensity ranged between 533 and 899 W.m$^{-2}$. No pest control was performed, where the trees were healthy throughout the course of the study.

Experiments were performed with grapevine (*Vitis vinifera* L.) vars. 'White Riesling' and 'Spaet Burgunder' (2-30 years old) plants that already existed in permanent soil (**Table 2**) of the farm of the Soil Science and Plant Nutrition Institute, Geisenheim, Germany. The distance between plants was 3 m. Irrigation was rainfed, except in relatively hot weather in summer in which the plants were irrigated once a week. Average maximum temperature during the course of the study was 14°C while average minimum temperature was 5.9°C. Average relative humidity of the cultivation area was 45.75% and the average light intensity during the fruiting season was 330 W.m$^2$. No pest control was performed during the course of the study.

## Injection system

Fertilizers were injected through a 2-4 cm deep and 0.6-1.6 cm wide pore in the trunk (using an electric poring machine-ZIJ-13-China) after removing a circular bark piece of about 2-3 cm in diameter. A hard plastic tube (injection needle) of 3-5 cm length and 0.5-1.5 cm in diameter was tightened in the pore using hot plastic material which has the advantages of sterilizing the pore opening, stop sap bleeding and prevent fertilizer solution from flowing out from the injection site. The injection needle was tightly connected to a tank containing fertilizer solution by a plastic tube (**Figs. 1-3**). The tank was located 1 m higher than the injection site and the fertilizer solution was continuously applied throughout the growth season.

## Fertilizer solutions

The fertilizer solutions were composed from highly dissolved compounds and contained balanced concentrations of N, P, K, Mg, Ca, S, Fe, Mn, Zn, Cu and B. Solutions' chemical composition including pH, nutrient concentrations and ratios are changeable according to the tree's variety and age.

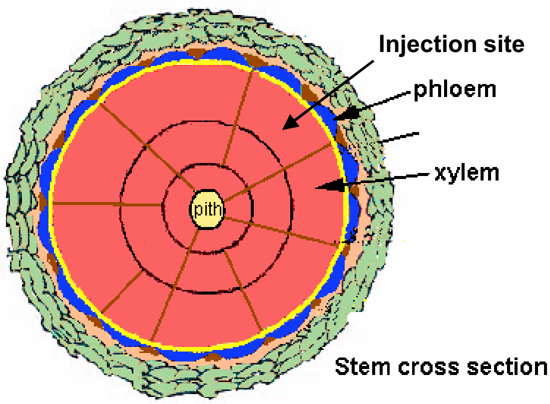


**Fig. 1 Injection site in the trunk of dicot trees.**


**Fig. 2 Mango shrubs injection fertilized through the trunk.**

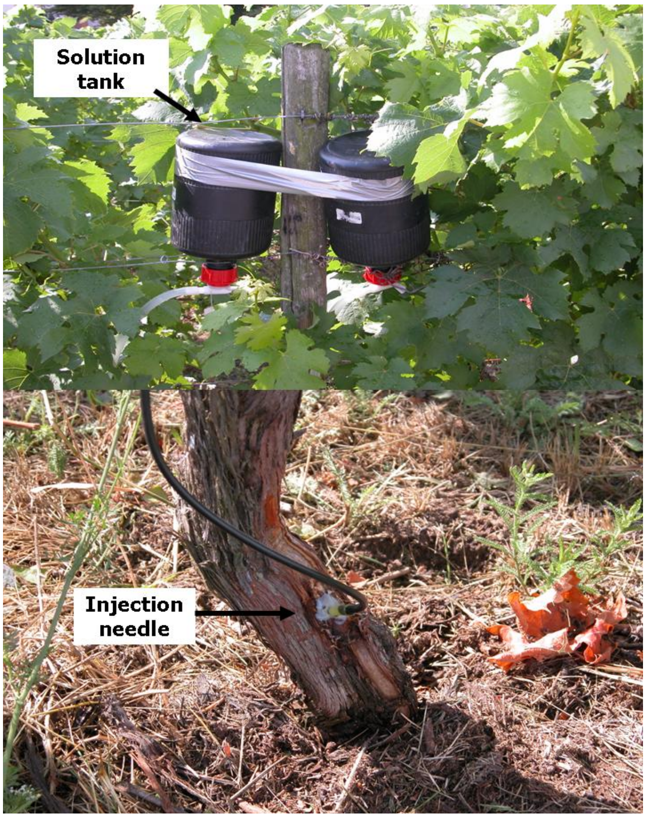


**Fig. 3 Grapevine trees injection fertilized through the trunk.**

## Treatments

Mango trees were injected using four fertilizer formulas different in their chemical composition, while soil fertilized trees received the recommended fertilization program. Every treatment contained 3 replicates.

Soil-fertilized grapevine trees received the recommended fertilizer program, while the injection-fertilized plants received two formulas differed in their chemical composition, each in three replicates.

## Sampling and analysis

***Soil***: A representative soil sample was taken from the experimented units, air dried and analyzed according to the methods of Chapman and Pratt (1978).

***Vegetative tissue***: recent mature leaf samples of mango were taken in June, while petioles opposite to the bunch cluster of grapevine trees were taken in the flowering stage. Samples were washed with tap water, 0.01 N HCl and double-distilled water, respectively, dried at 70°C for 24 hrs, weighed and ground. A part of mango plant material was dry-ashed in a Muffel furnace at 550°C for 6 hrs. The ash was digested in 3 N $HNO_3$ and the residue was then suspended in 0.3 N HCl (Chapman and Pratt 1978). Grapevine dry material was wet-ached using a mixture (0.49 g Se + 14.0 g $Li_2SO_4$ + 420 ml $H_2SO_4$ + 330 ml $H_2O_2$) according to the method described by Schaller (1993).

***Fruits***: Ripened grape-clusters from every replicate were washed with tap and double-distilled water and crushed. Fruit quality parameters (soluble solids concentration (°Brix), reduced sugars, pH, acidity, ethanol and glycerin content) in the fresh juice were determined using FTIR (Fourier-Transformed IR Spectroscopy) according to Schaller (1993).

***Nutrient measurements***: N was determined in dried mango leaves using the Kjeldahl-method; P was photometrical determined using the molybdate-vanadate method (Jackson 1973). K and Ca were measured using a Dr. Lang M8D Flame Photometer. Mg, Fe, Mn, Zn and Cu were determined using an Atomic Absorption Spectrophotometer (Perkin-Elmer 1100 B).

***Growth and yield measurements***: Growth of mango trees was measured as plant height (cm), while grapevine yield was determined as kg.tree$^{-1}$.

***Evaluation of the nutrient status***: Soil nutrient concentrations were evaluated according to the values of Ankerman and Large (1974). Leaf and petiole nutrient status was evaluated according to Robinson (1988).

## Statistical analysis

Data were statistically analyzed using the method described by Snedecor and Cochran (1980).

## RESULTS AND DISCUSSION

## General results

Results showed that mango and grapevine trees (representing dicots/vascular plants) could be fully fertilized by injection through the xylem. Only 5-10% of the recommended soil fertilizers injected into trees' trunks were sufficient for good growth and higher yields with better fruit quality.

## Response of mango trees

Mango shrubs fertilized through injection grew better than control plants fertilized through soil. 5-10% of the fertilizers added as soil application were adequate for a good growth throughout the season. Height of the injection-fertilized plants through the first year's growth season was nearly 25% higher than control plants (**Fig. 4**). Plant height at the end of the 3rd year's growth season of the continuously injected plants was 23.3% higher than soil fertilized plants (**Fig. 5**). Vigorous growth of the injection-fertilized plants may be attributed to nutrient integration and balance occurring within plant tissues, which led to better physiological expression of the nutrients. Nutrient balance and integration within plant tissues is a key factor for healthy growth and good crop yield (Marschner 1995; Shaaban 2001; Shaaban *et al*. 2004). This is obvious from **Figs. 6** and **7**, where macro- and micronutrient concentrations in the leaves were in the adequate range with all injected fertilizer compounds. Unfortunately, there is no available data about yield thus far.

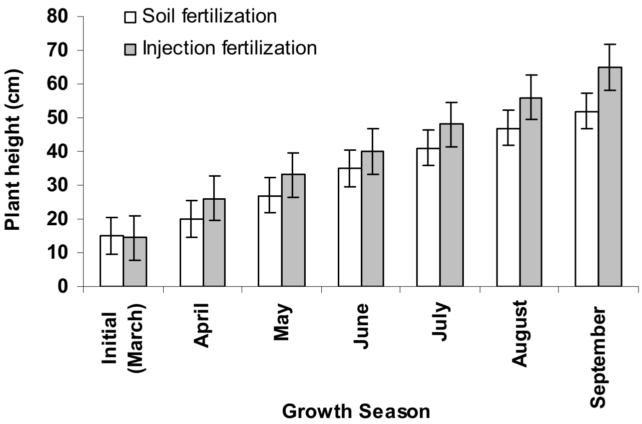


**Fig. 4 Growth of mango shrubs in the 1st season as affected by fertilization method.** Values represent means ± Standard Error.

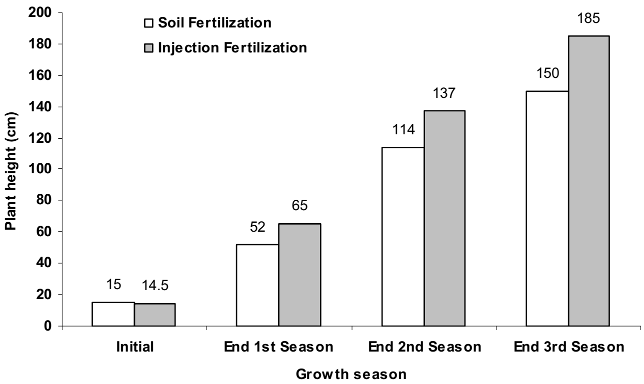


**Fig. 5 Growth of mango shrubs through 3 seasons as affected by fertilization method.**

## Response of grapevine trees

Grapevine trees fertilized by injection showed better growth than others fertilized through soil. Only 8-10% of the fertilizers added as soil fertilization were enough to fertilize grapevine trees throughout the whole growth season. **Figs. 8** and **9** show that macro- and micronutrient concentrations in the petioles of the injected plants are within the adequate range while N concentration was excess in petioles of the soil fertilized plants which suggested plants tend to vegetative growth at the expense of fruit set. K, Zn, and Mn concentrations were higher in the injected plants compared to soil-fertilized plants.

Balanced nutrition by injection fertilization led to higher yields and better yield quality of grapevine trees. **Fig. 10** shows that yield of clusters increased 32 and 49% for 'White Riesling' and 'Spaet Burgunder', respectively than soil-fertilized plants. Soluble solids concentration (°Brix), reduced sugars (glucose and fructose) as well as ethanol concentration in the fresh juice of injection-fertilized plants significantly increased, while total acidity and vinegar concentrations were reduced (**Table 3**). This may attributed to excess N and less K, Mn and Zn in tissues of soil-fertilized plants. Grapevine fruits produced by plants receiving adequate P and K had a higher sugar content and better taste than others supplied with lower levels (Mengel and Kirkby 1987). Since K is essential for photosynthesis and activates the enzymes of carbohydrate metabolism while the role of Mn and Zn is as enzyme activators (Mengel and Kirkby 1987; Marschner 1995), adequate concentrations of these elements realized by injection fertilization could explain the higher fruit yield and quality.

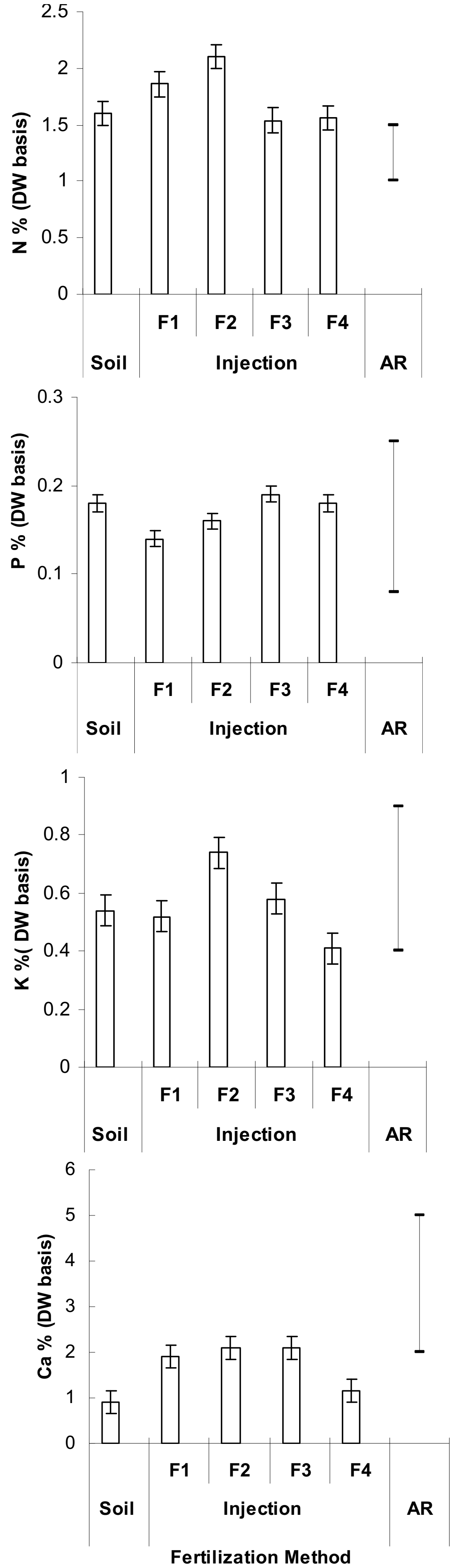


**Fig. 6 Macronutrients concentration in mango leaves (% DW basis) as affected by soil and injection fertilization methods.** F = formula, AR = adequate range, values represent means ± Standard Error.

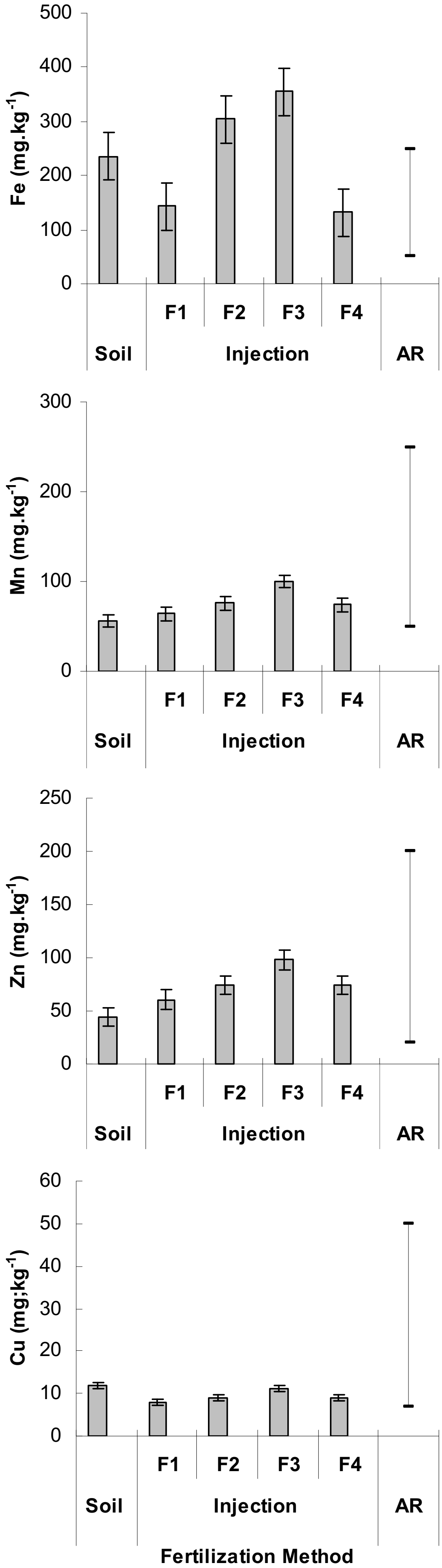


**Fig. 7 Micronutrient concentrations in mango leaves (mg.kg$^{-1}$ DW basis) as affected by soil and injection fertilization methods.** F = formula, AR = adequate range, values represent means ± Standard Error.

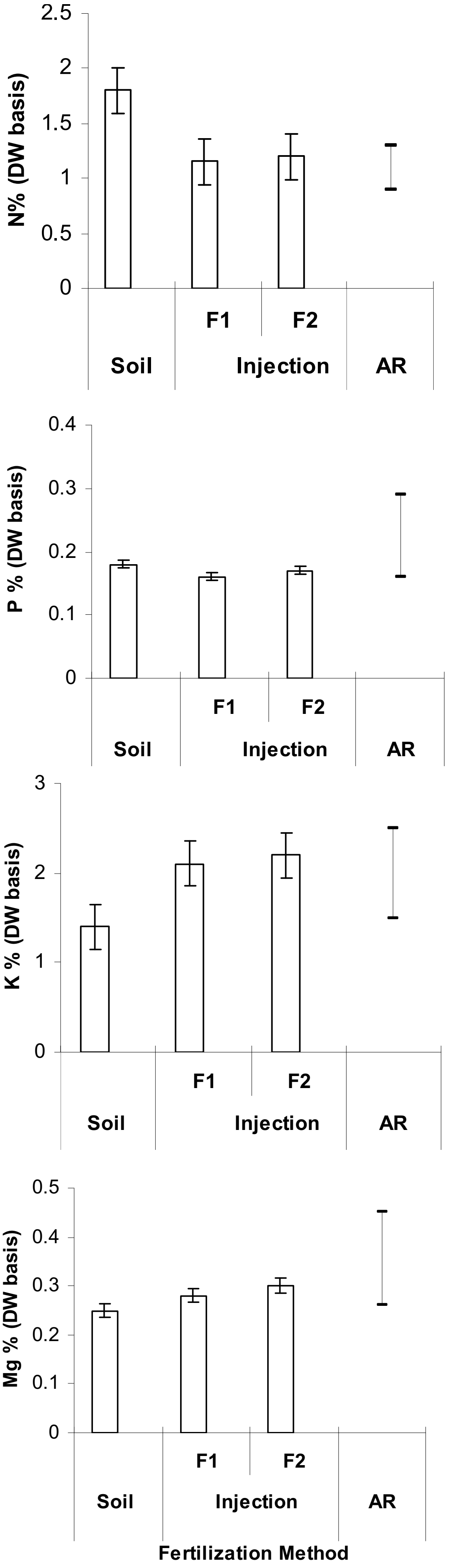


**Fig. 8 Macronutrient concentrations in grapevine leaves (% DW basis) as affected by soil and injection fertilization methods.** F = formula, AR = adequate range, values represent means ± Standard Error.

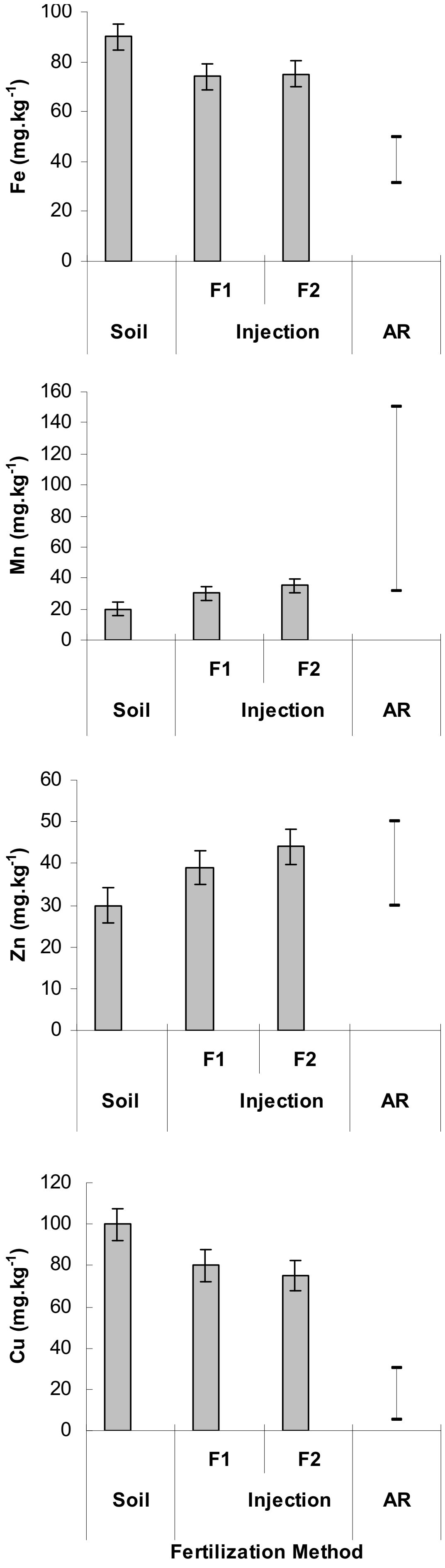


**Fig. 9 Micronutrient concentrations in grapevine leaves ($mg.kg^{-1}$ DW basis) as affected by soil and injection fertilization methods.** F = formula, AR = adequate range, values represent means ± Standard Error.

**Table 3** Quality parameters of the grapevine fresh juice (*n* = 22).

| Cultivar | Fertilization method | pH | °Brix | Reduced sugars | | Total acidity ($g.l^{-1}$) | Grape vinegar ($g.l^{-1}$) | Apple vinegar ($g.l^{-1}$) | Ethanol ($g.l^{-1}$) | Glycerine ($g.l^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Glucose ($g.l^{-1}$) | Fructose ($g.l^{-1}$) | | | | | |
| White | Soil (control) | 3.01 | 21.57 | 105.1 | 119.1 | 9.51 | 6.28 | 3.07 | 0.70 | 2.32 |
| Riesling | Injection | 3.12 | 23.19 | 111.6 | 129.4 | 8.96 | 5.59 | 2.75 | 0.99 | 3.59 |
| | $LSD_{0.05}$ | 0.226 | 3.15 | 17.99 | 21.65 | 3.27 | 1.70 | 1.37 | 0.40 | 3.30 |
| | % increase/ decrease over /above control | + 3.3 | + 7.4 | + 6.3 | + 8.6 | - 6.2 | - 13.3 | - 11.6 | + 41.4 | + 54.7 |
| Spaet | Soil (control) | 3.0 | 21.96 | 113.3 | 119.8 | 9.1 | 6.7 | 3.7 | 0.4 | 1.3 |
| burgunder | Injection | 3.2 | 24.14 | 127.9 | 133.0 | 7.6 | 5.5 | 3.8 | 0.6 | 0.4 |
| | $LSD_{0.05}$ | 0.23 | 6.41 | 8.01 | 6.8 | 1.86 | 1.79 | 1.70 | 0.22 | 0.51 |
| | % increase/ decrease over /above control | + 6.7 | + 9.0 | + 12.9 | + 11.0 | - 19.7 | - 17.9 | - 2.6 | + 50 | - 69.2 |

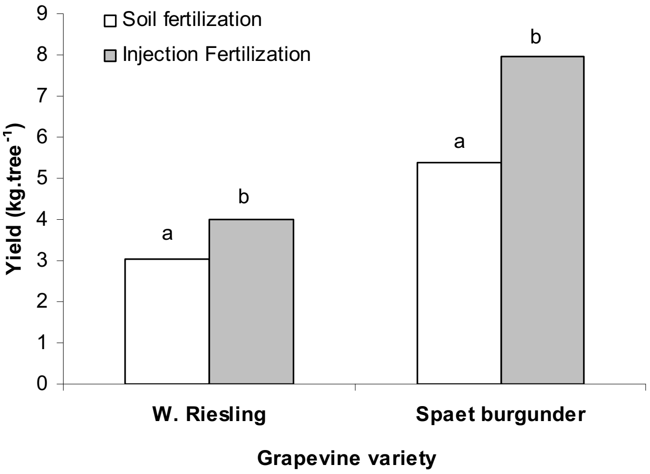


**Fig. 10 Average yield of grapevine trees ($kg.tree^{-1}$) as affected by fertilization method.** Values represent means ± Standard Error. Columns with different letters are significantly different at $P \leq 0.05$.


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