# ADDITION OF NITROGEN HAD NO EFFECT ON YIELD AND QUALITY OF APPLES IN AN HIGH DENSITY ORCHARD CARRYING A DWARF ROOTSTOCK[1]

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**ABSTRACT -** The effect of N addition on apple yield and quality may vary according to the tree vigor. Apple trees developed over vigorous rootstocks had shown no response to N application in Brazil. In this study it was evaluated the effect of N addition to the soil on yield and quality of ´Royal Gala´ apples grafted on a dwarf rootstock (M.9). The orchard was planted in 1995 (2,857 trees $ha^{-1}$) on an Oxisol containing 40 g $kg^{-1}$ of organic matter and pH 6.0. The experiment was carried out from 1998 up to 2005. Treatments consisted of rates of N (0, 50, 100 and 150 kg $ha^{-1}$ $year^{-1}$ from 1998 to 2001, and respectively 0, 100, 200 and 300 kg $ha^{-1}$ afterwards), all broadcasted within the tree row in two equal splits, at bud break and after harvest, as ammonium sulfate. Addition of N to the soil had no effect on fruit yield over the six years regardless of the applied rate. Averaged across treatments and years, fruit yield was 52.3 t $ha^{-1}$. Nitrogen in the leaves (average of 24 g $kg^{-1}$) or in the fruits (average of 346 mg $kg^{-1}$) as well as some attributes related to fruit quality (color, firmness, acidity, soluble solids, physiological disorders) were unaffected by N addition. Some plant parameters related to tree vigor, however, grew higher with the increase on N rate. Thus, it is not necessary to apply N to deep Brazilian soils containing high organic matter in order to assure good fruit quality and yield on high-density orchards carrying dwarf rootstocks probably because the N required for tree growth and fruit production is supplied from soil organic matter decay.
**Index terms**: apple yield, M.9 rootstock, fruit quality, nitrogen.

## A ADIÇÃO DE NITROGÊNIO NÃO AFETOU O RENDIMENTO E A QUALIDADE DE MAÇÃS EM POMAR COM ALTA DENSIDADE E PORTA-ENXERTO ANÃO

**RESUMO –** O efeito da adição de N ao solo no rendimento e na qualidade de maçãs pode variar em função do vigor das plantas. Experimentos conduzidos no Brasil com macieiras cultivadas sobre porta-enxertos vigorosos não têm apresentado aumento no rendimento de frutos pela aplicação de N. Este trabalho objetivou avaliar o efeito da aplicação de N no rendimento e na qualidade de frutos de macieira cultivada em alta densidade sobre porta-enxerto anão (M.9). O pomar com a cultivar Royal Gala foi plantado em 1995, na densidade de 2.857 plantas $ha^{-1}$, em um Latossolo Bruno com 40 g $kg^{-1}$ de matéria orgânica e pH 6,0. O experimento foi implantado em 1998 e foi encerrado em 2005. Os tratamentos consistiram da aplicação anual de 0; 50; 100 e 150 kg $ha^{-1}$ de N de 1998 até 2001 e de, respectivamente, 0; 100; 200 e 300 kg $ha^{-1}$ de N a partir da safra 2002-2003. Metade de cada dose foi aplicada no início da brotação, e o restante após a colheita, sempre na forma de sulfato de amônio. A aplicação de N ao solo não influenciou no rendimento de frutos em nenhuma das seis safras, independentemente da dose. Na média das doses e dos anos, o rendimento foi de 52,3 t $ha^{-1}$. A adição de N também não afetou a concentração de N nas folhas (média de 24 g $kg^{-1}$) e nos frutos (media de 346 mg $kg^{-1}$), nem tampouco os atributos relacionados com a qualidade dos frutos (cor da epiderme, firmeza da polpa, acidez, sólidos solúveis, desordens fisiológicas). Alguns atributos relacionados com o vigor das plantas, entretanto, aumentaram com o aumento da dose de N. Portanto, em solos profundos do Sul do Brasil, com alto teor de matéria orgânica, não é necessário aplicar N para obter altas produtividades e frutos de boa qualidade em pomares de ‘Royal Gala’ contendo porta-enxerto anão (M.9) e alta densidade de plantas, provavelmente porque a necessidade das árvores é suprida pelo N oriundo da decomposição orgânica.
**Termos para indexação:** produtividade de macieira, porta-enxerto anão, qualidade de frutos, nitrogênio.

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## INTRODUCTION

Nitrogen promotes a great visual impact on leaf green color intensity and on shoot growth of many plant species. For this reason, growers normally apply it in excess, especially on orchards (Weinbaum et al., 1992; Tagliavini et al., 1996) because the price of the fertilizers represents a small part of the total orchard production cost.

Nitrogen affects fruit set (Cmelik et al., 2006), fruit quality (Drake et al., 2002), yield and plant growth (Malaguti et al., 2006). Nitrogen deficiency restricts tree growth and fruit yield besides favoring early leaf drop and alternating bearing. The excess of N, on the other hand, has a negative effect on development of the skin red color (Fallahi et al., 2006), on quality of the buds due to the excessive shading, as well as on fruit storage, fruit shelf life and marketability. When the uptake of N is excessive it may favor the incidence of many physiological disorders (Raese & Drake, 1997) like bitter pit, lenticel blotch pit and fruit internal breakdown, because fruits become bigger, with less firmness, and also because N may depress Ca uptake. Calcium has influence on ripening attributes such as respiration, ethylene production, and flesh firmness (Beavers et al., 1994; Siddiqui & Bangerth, 1995), and helps to maintain membrane stability. In addition, excess of N may favor the incidence of plant diseases because it enlarges fruit cells.

In Brazil, field experiments have shown no yield responses to N addition on apple orchards carrying vigorous rootstocks due to a combination of deep soils containing high organic matter and climatic conditions that favors release of high amounts of N from organic matter decay (Basso & Suzuki, 1992; Ernani et al., 1997; Ernani & Dias, 1999; Ernani et al., 2000). On shallow soils, however, N addition has increased tree growth and yield (Nava et al., 2000; Nava et al., 2007). The use of apple trees grafted over dwarf rootstocks, like M.9, had a great increase in Brazil in the last decade. Besides the very high density, near or above 3,000 plants per hectare, these trees exploit a small soil volume due to a smaller root system relatively to plants produced over vigorous rootstocks. These trees may not get from the soil the amount of N needed for growth and fruit production.

This study was carried out in Southern Brazil to evaluate the long-term effect of N addition to the soil on fruit yield, on tree growth an on some attributes related to fruit quality of 'Royal Gala' apples grafted on a dwarf rootstock.

## MATERIALS AND METHODS

This study was carried out from 1998 to 2005, in Vacaria, Rio Grande do Sul State, Southern Brazil. The experiment was set up in a three-year-old commercial orchard of 'Royal Gala' apples, grafted on a dwarf rootstock (M.9), at a density of 2,857 trees ha$^{-1}$ (3.5 x 1.0 m). Before planting, the soil (Humic Hapludox) was adequately limed and fertilized. Soil samples collected in 1998, from the layer of 0 to 20 cm deep, showed 40 g kg$^{-1}$ organic matter, 560 g kg$^{-1}$ of clay, 10 mg P kg$^{-1}$, 0.5, 8.0 and 12 cmol$_c$ kg$^{-1}$ of K, Mg and Ca respectively, and pH 6.8 (Tedesco et al., 1995).

Treatments consisted of annual additions of ammonium sulfate to the soil at rates of 0, 50, 100 and 150 kg N ha$^{-1}$ from 1998 to 2001, and respectively 0, 100, 200 and 300 kg N ha$^{-1}$ afterwards. Each N rate was equally divided being half applied at bud break and the remaining half applied immediately after fruit harvest. Potassium was added annually at a rate of 150 kg ha$^{-1}$ $K_2O$, as KCl; P was added only at planting. Each experimental unit consisted of twelve trees distributed within the row, but only the central ten trees were used for determinations. The four replicates were arranged in a randomized complete block design. The experimental area received all management practices used in the commercial orchard, including bud break (mineral oil + hydrogen cyanamide), application of herbicide (glyphosate), insecticides, and fungicides, winter and summer pruning, and hand thinning. Since the ground cover management system may affect nutrient availability, a 2.0-meter-wide killed sod strip was maintained in the tree row.

Samples of 40 leaves were collected in each plot approximately 115 days after full bloom and analyzed for N, K, Ca and Mg. Samples of 40 fruits per plot of uniform size and maturity state were used for determinations at the harvest time. Additional samples of 200 fruits per plot were stored in conventional cold storage at –1ºC and 90-95% of relative humidity (RH), for five months. In order to assess the mineral composition, fruit sub-samples were obtained by removing two vertical sections of each sample fruit, including the peel. These parts were blended, and approximately 5.0 g of the slurry were wet digested. Leaf and fruit samples were digested with $H_2O_2$ + $H_2SO_4$, at 350 ºC. Potassium was determined by flame emission spectroscopy, N by steam distillation, using a semi-micro Kjeldahl equipment, and Ca and Mg by inductively coupled plasma (ICP) spectroscopy. Fruits were analyzed for soluble solids content, titratable acidity, starch pattern index, flesh firmness, skin background color, and incidence of russeting, bitter pit and lenticels blotch pit, and for N, K, Ca and Mg, at harvest and after cold storage. Attributes related to fruit quality were determined according to methodology described by Amarante et al. (2002).

In the seasons 2003/2004 and 2004/2005, the number of fruits per plant was counted and some attributes related to plant vigor (number of one and two-years-old shoots/branch, number of spurs/branch, length of annual shoots and trunk circumference) were measured. The fruits of the entire trees were recorded while the other attributes were evaluated only in 4 branches per plant.

The interaction of N treatments and growing seasons for each attribute was evaluated by ANOVA. The statistical significance of the effect of the N rate was evaluated by regression analysis.

## RESULTS AND DISCUSSION

Annual addition of nitrogen to the soil had no effect on fruit yield over the six years regardless of the rate applied. Averaged across treatments, yield increased as plant aged from 23.0 t ha$^{-1}$ in the first season (1998/1999) up to 74.5 t ha$^{-1}$ five years later, in the growing season of 2003/2004. Averaged across treatments and years, fruit yield was 52.3 t ha$^{-1}$. The lack of yield response to applied N may be the result of the association of many factors, but especially due to the release of N, from the decomposition of native soil organic matter and senescent leaves. According to Ernani et al. (1997), approximately 110 kg $ha^{-1}$ of N is annually released from the top 30cm of this soil due to organic matter decay. This amount of N is much larger than the requirement of these dwarf trees, which, according to Neilsen & Neilsen (2002), varies with tree age from 8.8 to 44 kg $ha^{-1}$ $year^{-1}$. According to Weinbaum et al. (1992), apple trees exports from the soil approximately 0.5 kg of N per ton of fruit harvested since the concentration of N in the fruit flesh is normally below 0.5 mg $kg^{-1}$ (Ernani & Dias, 1999). So, the amount of N exported in the season of highest yield in the present study would be around 40 kg $ha^{-1}$, showing that the N requirement by apples is not large.

In addition, temperatures during fall and winter in Brazil do not drop so much. Thus, root trees may take up N all over the year, store, and then the plant may subsequently remobilize it when needed, which makes the mineralized N to be more efficiently used by fruit trees than by annual plant species. Remobilization of N in apple plants is greatest at full bloom (Malaguti et al., 2001) predominantly for leaf growth (Millard and Thomson, 1989). According to Dong et al. (2001) apple roots start to uptake N from the soil approximately three weeks after full bloom and this process is largely influenced by the soil temperature. This is about the time the soil organic matter decomposition rate increases, occurring a synchronization between the time of N release and its uptake. Besides the O.M. content, the amount of N mineralized from the soil depends especially on the soil pH, soil moisture and temperature. In our study the pH (6.5) was in the best range for microorganism activity, and the mean annual rainfall in the region is good (1800 mm) and well distributed. In addition, as apple roots exploit a greater soil depth than annual crops, leaching of N in orchards is less probable to occur, and then most N released is taken up by trees.

Lack of yield response to N addition for apple orchards containing trees grafted over vigorous rootstocks had been previously observed by Brazilian researchers for Gala and Fuji (Ernani et al., 1997; Ernani & Dias, 1999; Ernani et al., 2000) as well as for Golden Delicious (Basso & Suzuki, 1992) all grown on deep soils containing more than 40 g $kg^{-1}$ of organic matter. In shallow soils, however, N addition has increased tree growth and apple yield (Nava et al., 2000; Nava et al., 2007), showing the importance of the soil organic matter for N supplying to apple orchards at Brazilian conditions. Thus, under conditions in which the supply of N from the soil is low, as occurs in shallow soils or in soils with low organic matter content or with low pH, or even when the root growth is restricted by some other factor, apple orchards may need supplement of N from fertilizers. Wrona (2006) also did not get any increment on yield, leaf N status, and trunk diameter of young 'Jonagored' apple trees/M.9 rootstock due to forms and rates of N addition to two different soils in Poland.

The concentration of N in the leaves or in the fruits was not affected by N addition. Leaves collected in middle summer presented an average of 24 g $kg^{-1}$ (Table 2) and is in the normal range (20 – 25 g $kg^{-1}$) according to Brazilian apple standards. The concentration of N in the fruits was also in the normal range, averaging 406 mg $kg^{-1}$ (Table 3). Addition of N had also no effect on the concentration of Ca, Mg and K in the leaves (Table 2) as well as in the fruits (Table 3) regardless of the rate applied or the growing season. The concentration of these three cations in the leaves was respectively 11.7, 3.2 and 12.4 g $kg^{-1}$; in the fruits, it was 54, 57 and 817 mg $kg^{-1}$, respectively. All these values are in the normal range for both plant parts (leaves and fruits).

The parameters related to fruit quality were unaffected by addition of nitrogen to the soil regardless the rate or the growing season (Table 4). In addition, there was no interaction between the rate applied and the production season. Thus, the results of these parameters are averaged across years, and also within the normal range. The mean fruit area affected with russeting was small, 7.8 $cm^2$/fruit. Mean values for flesh firmness, soluble solids content, starch pattern index, and titratable acidity, after harvest, were respectively 76.7 N, 13.5 °Brix, 3.8 (in a range of 1 to 5) and 3.7 meq of malic acid/100mL. Thus, when added in non abusive rates, N should not have any detrimental effect on fruit quality and storability. The background color as well as the intensity of the red color on the skin was not influenced by addition of N (Table 4).

The effects of N addition on most apple attributes obtained worldwide, including fruit yield, varies according to variations on the experimental conditions like soil type, pH and organic matte contents, cultivar, and climate. Drake et al. (2002) are also did not find any effect of N addition to the soil on fruit size, color, firmness, soluble solids, and titratable acidity. Meheriuk et al (1996) applied N to the soil to four green apple cultivars up to 160 kg $ha^{-1}$ and found no effect on ground color or fruit quality relative to the lower rate applied of 80 kg N $ha^{-1}$. However, Fallahi et al. (2001) found that increasing N addition decreased the red color of 'Fuji'. Raese & Drake (1997) observed that lower rates of N fertilizer promoted lower concentrations of leaf and fruit N, redder fruit skin color, greater fruit firmness and soluble solids concentration, higher fructose levels, and a lower incidence of bitter pit and scald in 'Fuji' than the higher rates of 113 or 170 kg $ha^{-1}$. Raese et al. (2007) applied up to 908 g actual N/ tree of 'Golden Delicious' and found that fruits from the higher N rates had greener peel and lower firmness, soluble solids content and titratable acidity.

Most attributes related to tree vigor were affected by N addition (Table 5). Averaged across seasons 2003/2004 and 2004/2005, when the trees were respectively 8 and 9-years-old, the number of shoots/branch, the number of spurs/branch and the length of annual shoots grew higher with increases on N rate applied in the previous 5 or 6 years. The regression equations describing the relationship between N rate (x, in kg $ha^{-1}$) and each attribute (y) were: number of one and two-year-old shoots per branch = $3.01 + 0.0066x – 0.00001x^2$, $R^2 = 0.99$; length of annual shoots (cm) = $12.8 + 0.0043x – 0.000032x^2$, $R^2 = 0.92$; number of spurs per branch = $2.93 + 0.0033x$, $R^2 = 0.99$; number of fruits per plant = $165 + 0.15x – 0.00027x^2$, $R^2 = 0.75$. The cross sectional trunk circumference, however, was not affected by N, and averaged across N rates and seasons (2003 to 2005) it was 20.7

**TABLE 1** - Fruit yield of 'Royal Gala'apple in different growing seasons as affected by annual addition of N to the soil.

| Treatment | Growing Season | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1998/99 | 1999/00 | 2000/01 | 2002/03 | 2003/04 | 2004/05 | Average |
| | t ha$^{-1}$ | | | | | | |
| $N_0$[1] | 27.6 | 40.5 | 68.9 | 62.7 | 71.98 | 43.7 | 52.6 |
| $N_1$ | 19.0 | 42.6 | 58.5 | 53.2 | 69.0 | 47.0 | 48.9 |
| $N_2$ | 25.8 | 43.7 | 66.9 | 58.6 | 82.20 | 53.9 | 55.1 |
| $N_3$ | 29.8 | 42.1 | 65.7 | 51.0 | 74.97 | 51.0 | 52.4 |
| Average | 25.5 e | 42.2 d | 65.0 b | 56.4c | 74.53a | 49.0d | 52.3 |

[1] $N_0$, $N_1$, $N_2$ and $N_3$ represent the rates of N (kg ha$^{-1}$) which were respectively 0, 50, 100 and 150 from 1998 until 2001 and 0, 100, 200 and 300 afterwards. Half of each rate was applied at bud break and the other half immediately after fruit harvest. There was no significance ($P < 0.05$) for the regression coefficients between N rates and fruit yield regardless of growing season

**TABLE 2 -** Chemical composition of 'Royal Gala'apple leaves as affected by annual addition of nitrogen to the soil. Averaged over four growing seasons and four replicates.

| N | Ca | Mg | N | K |
|---|---|---|---|---|
| | g kg-1 | | | |
| $N_0$[1] | 11.4 | 3.4 | 23.7 | 12.7 |
| $N_1$ | 12.4 | 3.5 | 25.4 | 12.0 |
| $N_2$ | 11.7 | 3.2 | 24.0 | 12.0 |
| $N_3$ | 11.3 | 2.7 | 23.1 | 13.0 |
| Average | 11.7 | 3.2 | 24.0 | 12.4 |

[1] $N_0$, $N_1$, $N_2$ and $N_3$ represent the rates of N (kg ha$^{-1}$) which were respectively 0, 50, 100 and 150 from 1998 until 2001 and 0, 100, 200 and 300 afterwards. Half of each rate was applied at bud break and the other half immediately after fruit harvest. There was no significance ($P < 0.05$) for the regression coefficients between N rates and any fruit attribute regardless of growing season.

**TABLE 3 -** Chemical composition of 'Royal Gala' apple fruits as affected by annual addition of nitrogen to the soil. Averaged over four growing seasons and four replicates.

| Treatment | Ca | Mg | N | K |
|---|---|---|---|---|
| | mg kg$^{-1}$ | | | |
| $N_0$[1] | 51.8 | 52.4 | 325 | 805 |
| $N_1$ | 52.0 | 52.7 | 356 | 808 |
| $N_2$ | 55.4 | 61.7 | 367 | 824 |
| $N_3$ | 57.0 | 61.8 | 325 | 830 |
| Average | 54.0 | 57.1 | 346 | 817 |

[1] $N_0$, $N_1$, $N_2$ and $N_3$ represent the rates of N (kg ha$^{-1}$) which were respectively 0, 50, 100 and 150 from 1998 until 2001 and 0, 100, 200 and 300 afterwards. Half of each rate was applied at bud break and the other half immediately after fruit harvest. There was no significance ($P < 0.05$) for the regression coefficients between N rates and any fruit attribute regardless of growing season.

**TABLE 4** - Attributes capital of 'Royal Gala'apple fruits as affected by annual addition of nitrogen to the soil. Averaged over four replicates and six growing seasons.

| Treatment | Color (1 a 8)[2] | Red % | Russeting cm$^2$/fruit | Starch (1 a 5) | Firmness N | Solids ºBrix | Acidity meq/100ml |
|---|---|---|---|---|---|---|---|
| $N_0$[1] | 5.6 | 65.9 | 7.7 | 3.9 | 72.0 | 13.0 | 3.8 |
| $N_1$ | 5.7 | 66.0 | 8.4 | 4.1 | 70.3 | 13.9 | 3.5 |
| $N_2$ | 5.7 | 69.1 | 7.9 | 3.9 | 82.3 | 13.3 | 3.6 |
| $N_3$ | 5.9 | 68.2 | 7.1 | 4.0 | 82.0 | 13.2 | 3.7 |
| Average | 5.7 | 67.2 | 7.8 | 3.8 | 76.7 | 13.5 | 3.7 |

[1] $N_0$, $N_1$, $N_2$ and $N_3$ represent the rates of N (kg ha$^{-1}$) which were respectively 0, 50, 100 and 150 from 1998 until 2001 and 0, 100, 200 and 300 afterwards. Half of each rate was applied at bud break and the other half immediately after fruit harvest. There was no significance ($P < 0.05$) for the regression coefficients between N rates and any fruit attribute regardless of growing season.
[2] On a scale of 1 to 5, where 1 indicates the least and 5 the most starch to sugar conversion.
[3] On a scale of 1 (dark-green) to 8 (yellow-green).

**TABLE 5 -** Attributes related to the vigor of 'Royal Gala' trees as affected by annual addition of nitrogen to the soil. Averaged over two growing seasons (2003/04 and 2004/05) and four replicates.

| Attributes | Nitrogen added (kg $ha^{-1}$) | | | |
|---|---|---|---|---|
| | 0 | 100 | 200 | 300 |
| Number of shoots/branch | 3.0 | 3.6 | 3.9 | 4.1 |
| Length of annual shoots (cm) | 13.3 | 15.3 | 21.6 | 22.3 |
| Number of spurs/branch | 2.9 | 3.3 | 3.6 | 3.9 |
| Trunk circumference (cm) *ns | 21.1 | 20.1 | 21 | 20.7 |
| Number of fruits/plant | 167 | 171 | 191 | 184 |

Half of each rate was applied at bud break and the other half immediately after fruit harvest. * ns = There was no significance ($P < 0.05$) for the regression coefficient between rates of N and trunk circumference. The equations for the other attributes are described in the text.

## CONCLUSION

It is not necessary to apply N to 'Royal Gala' trees grafted on dwarf rootstocks to obtain high yield and good fruit quality when planted on high-density orchards on deep Brazilian soils containing high organic matter. In this situation, the amount of N required for tree growth and fruit production is probably completely supplied from soil organic matter decay. Application of N to the ground, however, increased some attributes related to tree vigor, but the N rates that were added had no detrimental effect on the chemical composition of leaves or fruits as well as on fruits attributes associated with quality and storability.

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