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Nitrogen and Potassium Fertilization Affect Apple Fruit Quality in Southern Brazil

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Abstract: Nitrogen (N) and potassium (K) are usually found in higher concentrations than other macronutrients in apple (*Malus x domestica Borkh*) fruits and are most frequently associated with changes in fruit quality. The aim of this article was to evaluate the effects of N and K fertilization on some fruit quality attributes of Fuji apple. The experiment was conducted at São Joaquim, State of Santa Catarina, Brazil, during 2004 and 2005. A factorial design was used with N and K annual fertilizer rates (0, 50, 100, and 200 kg ha^{-1} of N and K_2O) replicated in three orchards. Fifteen days prior to harvest, three fruit samples were collected from each treatment and site. One sample was used for total soluble solid content (TSS), titratable acidity, pulp firmness, and fruit color parameter analyses, and the other samples were refrigerated in a conventional atmosphere for 3 and 6 months for subsequent determination of fruit quality. Nitrogen fertilization negatively affected fruit color, flesh firmness, and TSS content. These same variables were positively affected by K fertilization, except for flesh firmness.

Keywords: Color, firmness, *Malus x domestica Borckh*, nitrogen, potassium, soluble solids, titratable acidity

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INTRODUCTION

Apple fruit quality and postharvest storage potential are affected by several physicochemical parameters such as flesh firmness, juice titratable acidity, total soluble solids (TSS), peel coloration, and others. These quality characteristics are markedly influenced by nutritional practices used in apple orchard production. Titratable acidity is one of the most important quality parameters of stored apples (Argenta 2002). Low acidity at harvest will result in poor organoleptic quality of apple fruits after storage, and thus, it will result in low consumer acceptance. A minimum level of acidity and flesh firmness are required at harvest, below which apple fruits are not recommended for storage.

Nitrogen (N) and potassium (K) contents in apple fruit are found in higher concentrations than other macronutrients. They are usually the nutrients that are most often associated with changes of physicochemical properties of fruits. Excess N induces fast vegetative growth, which can result in excessive fruit shading and reduction in red peel coloration (Daugaard and Grauslund 2000; Stiles 1994) and TSS content (Dris, Niskanen, and Fallahi 1999). Flesh firmness also tends to be negatively correlated with apple fruit N concentration (Kingston 1992; Little 1992). Drake, Raese, and Smith (2002) evaluated apple tree response to N fertilization and observed highest fruit flesh firmness, peel coloration, and TSS content in treatments with the lowest N rates.

In general, K deficiency inhibits biosynthesis of sugars, organic acids, and vitamin C, resulting in lower fruit soluble solids content (Sobulo and Olorunda 1977; Matev and Stanchev 1979). In contrast to N, K has been positively correlated with peel coloration (Neilsen et al. 1998; Daugaard and Grauslund 2000; Neilsen et al. 2000; Hunsche, Brackmann, and Ernani 2003) and fruit acidity (Neilsen et al. 1998; Hunsche, Brackmann, and Ernani 2003). However, similar to N, K fertilizer rate can decrease fruit firmness (Hunsche, Brackmann, and Ernani 2003).

The aim of this article was to evaluate the effects of N and K fertilization rates on some physicochemical attributes of Fuji apple fruits trees from commercial orchards in southern Brazil.

MATERIAL AND METHODS

The experiment was conducted during the 2004–2005 growing seasons in the municipal district of São Joaquim, State of Santa Catarina, Brazil (28° 17′ 25″ S, 49° 56′ 56″ W, altitude 1400 m) in 6-, 9-, and 13-year-old commercial apple orchards. The three apple orchards were planted with the Fuji cultivar grafted on Marubakaido rootstock and grown under a low-plant-density system ($<$600 trees ha^{-1}), which is typical of this rootstock/cultivar combination grown in this region. The soils of all orchards were Inceptisol, previously limed and fertilized. Initial analyses indicated 4.0–6.5% of organic matter, 30–38% of clay content, pH_{H2O} of 6.4–6.8, 33–63 mg of P kg^{-1} (Mehlich extractable), and 127–240 mg of K kg^{-1} (Mehlich extractable).

A randomized complete block design arranged in a 4 × 4 factorial with three replications was used (each apple orchard was considered one replication). Treatments consisted of all combinations of N and K_2O fertilization rates of 0, 50, 100, and 200 kg ha^{-1}, annually applied. Potassium was applied as potassium chloride postharvest (month of April), together with 50 kg ha^{-1} of P_2O_5 as triple superphosphate (same rate applied for all treatments). Nitrogen applications, as urea, were split with 50% applied postharvest and 50% the beginning of the new growth season (September). Nitrogen fertilizer was applied on rainy days to minimize volatilization losses. No irrigation system was used, because the annual average precipitation (1,800 mm) is well distributed throughout the year. All fertilizers were applied to the soil surface, without incorporation, in a 2.2-m-wide strip centered on the tree row.

The experimental unit consisted of five plants, spaced 4.5 m between plants and 6.0 m between rows (in one of the orchards) and 3.0 × 6.0 m (in the other two). Plots were all managed similarly according to current recommendation procedures (Epagri 2002), except for the fertilization treatments.

Three fruit samples (15 fruits per sample) from each treatment and each orchard were collected 15 days before commercial harvest. One of these samples from each treatment was promptly analyzed for the TSS content, flesh firmness, and peel color. The two other samples were stored in a conventional atmosphere chamber at 2°C for 3 and 6 months. TSS, fruit firmness, and peel color were also determined after storage. Titratable acidity and vitamin C content were only determined in 2005, 15 days after fruit harvesting, using 20 fruits per sample.

Total soluble solids content was determined using a refractometer and expressed as Brix. Flesh firmness was determined using a penetrometer, which measured the pulp resistance to a piston (diameter = 11.3 mm) penetration and expressed as Newtons (N). Fruit peel red color was visually estimated as the proportion of red color covering the surface of fruit and expressed as a percentage of the total surface area. Fruit color was also determined using a colorimeter to determine the hue angle, which expresses the intensity of red color. The higher the hue angle, the lower the predominance of red color. In 2005, a and b values were also measured with the colorimeter. Increasing a and b values indicate an increase in the red (a) and yellow (b) pigmentation, respectively.

Fruit titratable acidity was determined in juice extracted from two longitudinal 1-cm-thick apple slices (with peel) taken from opposite sides (20 fruits per sample). After crushing the sample, a 5-mL aliquot of juice was diluted in 50 mL of distilled water, and the titratable acidity was measured using 0.1 mol L^{-1} sodium hydroxide. Vitamin C content was determined by the titration method (AOAC 1980). In this technique, vitamin C was extracted from samples with metaphosphoric acid. The filtered extracts were then titrated with 2,6-dichlorophenol indophenol.

All fruit quality data were subjected to variance and regression analysis to determine the effects of N and K rate and their interaction at the 5% level of significance. When significant, interactions were plotted as three-dimensional surface responses to visually represent the nature of the interactions.

RESULTS AND DISCUSSION

Potassium fertilization (in 2004) and N fertilization (in 2004 and 2005) reduced flesh firmness (Figures 1a and 1b). The interaction between N

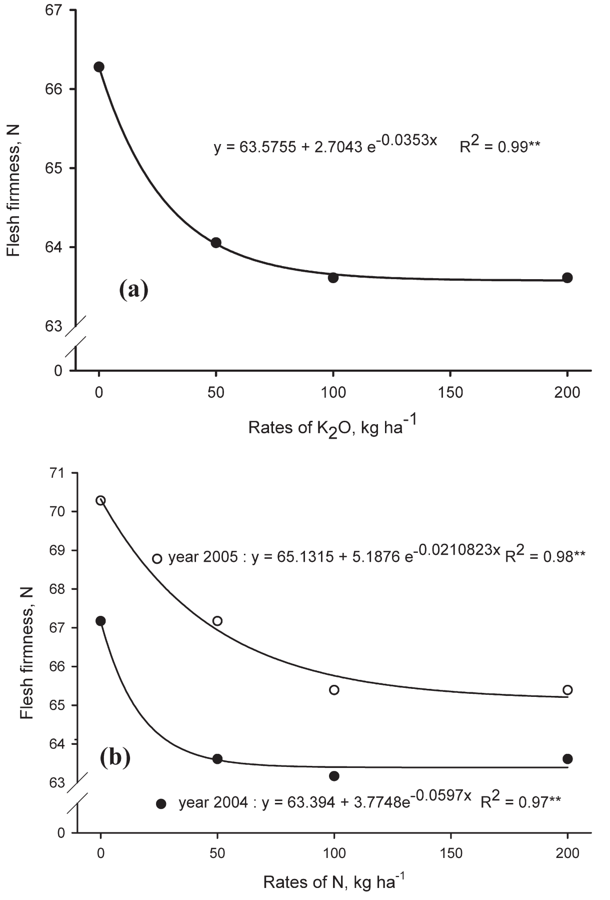


Figure 1. Apple fruit flesh firmness (a) in response to K fertilization (2004) and (b) in response to N fertilization in 2004 and 2005.

and K fertilization rates was not significant for flesh firmness. Flesh firmness decreased exponentially with K and N fertilization. Hunsche, Brackmann, and Ernani (2003) reported similar flesh firmness reduction in Gala apple fruits grown under Brazilian conditions. The effect was attributed to increased contents of K in the soil, plant, and fruit. Neilsen et al. (2004) also observed flesh firmness reduction in several cultivars of apple trees in high-plant-density orchards, after K fertilization or fertigation. Similar to K, N fertilization exponentially decreased the flesh firmness. The negative effect of N on fruit flesh firmness (2004 and 2005) has also been observed in previous research reports (Raese and Drake 1997; Neilsen et al. 1999).

Reduced fruit flesh firmness might be related to a simultaneous increase in fruit size, both effects caused by K fertilization (Hunsche, Brackmann, and Ernani 2003). Fruit weight was also significantly affected by K fertilization rates (data not presented). Larger fruits usually result in lower flesh firmness as a result of their expanded cell walls and smaller proportion of cell wall materials in relation to their total volume. Lower fruit density reduces resistance to penetration (Sams 1999). Increased fruit N–calcium (Ca) and K–Ca ratios of fruits (data not presented) with higher N and K fertilization rates may have also contributed to lower fruit flesh firmness. Calcium has been associated with cell membrane integrity and cell wall resistance. Thus, Casero et al. (2004) observed that fruit Ca concentration was positively correlated with fruit flesh firmness. However, excessive N and K fertilization rates have been reported to reduce the fruit Ca concentration (Iuchi, Nava, and Iuchi 2001). Therefore, excessive N and K fertilization of apple orchards must be avoided to obtain nutritionally balanced fruits with high fruit firmness for postharvest storage. Even more, adequate fertilization will reduce the contamination of the environment with chemicals.

Fruit acidity was not significantly influenced by N fertilization (data not presented) and was positively and linearly correlated with K fertilization in 2005 (Figure 2). A linear increase in juice titratable acidity was observed (2005 harvest) with increasing K fertilization rates. Casero et al. (2004) also observed that fruit acidity of Golden Smoothee apples was positively correlated with both leaf and fruit K concentrations. Similar results were obtained by Hunsche, Brackmann, and Ernani (2003) when evaluating the effect of K fertilization on postharvest quality of Gala apples grown under Brazilian conditions. Neilsen et al. (2004) observed that K fertilization/fertigation increased leaf and fruit K concentrations and, consequently, the fruit acidity of four apple cultivars: Gala, Fuji, Fiesta, and Spartan. Fruit acidity is one of the most important parameters for postharvest quality of stored apples. If low acidity occurs at harvest, the organoleptic quality of fruit after storage will be rejected by consumers (Argenta 2002). Hence, K fertilization is important to maintain the acidity balance of apple fruits and to allow for greater storage potential of fruit.

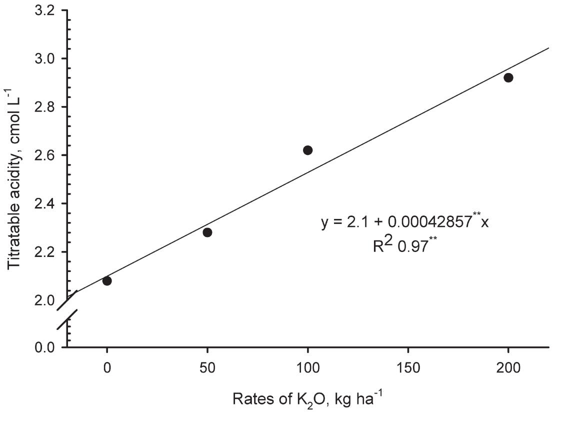


Figure 2. Apple juice titratable acidity in response to K fertilization (2005).

Average vitamin C concentration found in apple fruits was relatively low (1.4 mg/100 mL of juice) and was not significantly influenced by the N and K fertilization (data not presented).

The epidermal red surface area and the hue angle were significantly affected by N fertilization (Figure 3) but not by K fertilization, and there was no interaction between N and K in 2004. However, in 2005, the epidermal red surface area and the hue angle were positively affected by K fertilization and negatively affected by the N fertilization, with significant interactions among these treatments (Figures 4a and 4b). The hue angle, with a prevalence of red color (around 30 to 35), was obtained for low N rates (lower than 50 kg ha^{-1}). Increased N rates resulted in higher hue angle, which was attenuated by higher K rates. This effect can be confirmed by a and b values, which also were influenced by an interaction between N and K fertilization in 2005 (Figures 5a and 5b). Nitrogen fertilization reduced the a value and increased the b value (Figure 5a), indicating that N is involved in an increase in yellow fruit color and decrease in red color. In contrast to N, most K fertilization rates increased the a value and reduced the b value (Figure 5b), indicating that K increased the fruit peel red color intensity and decreased yellow color intensity. Thus to obtain high-intensity reddish apples, it is imperative to avoid K deficiency and N excess.

Hunsche, Brackman, and Ernani (2003) observed that fruit red color was positively correlated with the amount of K applied to the soil and also to the fruit anthocyanin content, inferring that K might be important in the anthocyanin pathway and could be a cofactor in the activation of some specific enzymes, similar to the case of UDPGalactose: flavanoide-3-o-glicosiltransferase (Ju, Duan, and Ju 1999).

Conversely, N deficiency usually induces carbohydrate accumulation, because they cannot be used in the synthesis of amino acids or other N

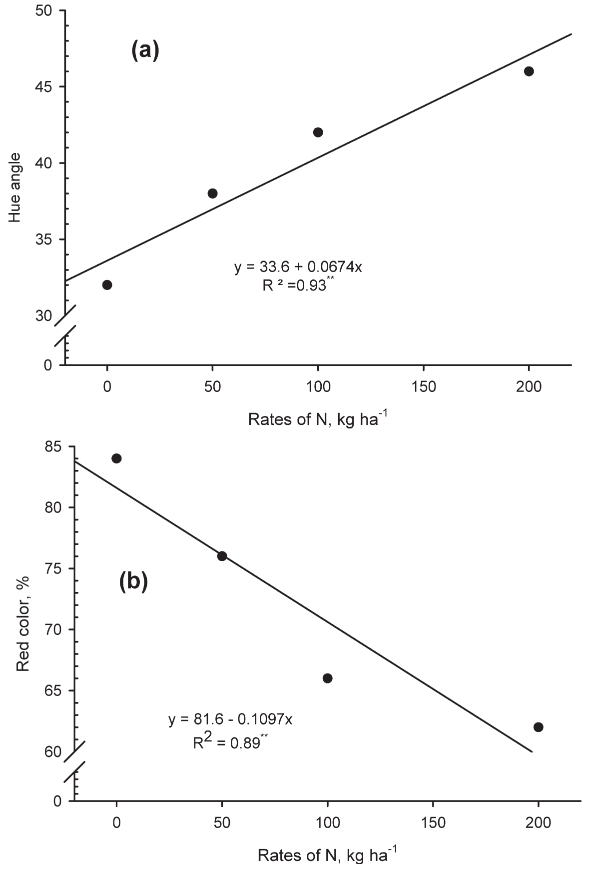


Figure 3. Apple fruit peel coloration in response to the N fertilization: (a) hue value and (b) percentage of red epidermis (2004).

compounds (Taiz and Zeiger 2004). However, the accumulated carbohydrates can be used for anthocyanin synthesis, which can partly explain the increase of red color of fruits under low N (Figures 4 and 5). Furthermore, the low fruit color observed under high N fertilization rates may have resulted from the fast vegetative growth induced by N as observed in this research (data not presented). Nitrogen fertilization promotes vegetative growth with consequent higher self-shading and fruit yellowing (Raese and Drake 1997; Neilsen, Hogue, and Meheriuk 1999; Daugaard and Grauslund 2000).

The TSS content was positively affected by K fertilization, reaching a maximum at rates as high as 125 and 143 kg ha^{-1} of K_2O for the 2004 and 2005 harvests, respectively (Figure 6a), and there was no interaction with N fertilization. The importance of K nutrition for increasing fruit TSS content has previously been observed in other reports. Evidence found in Arabidopsis

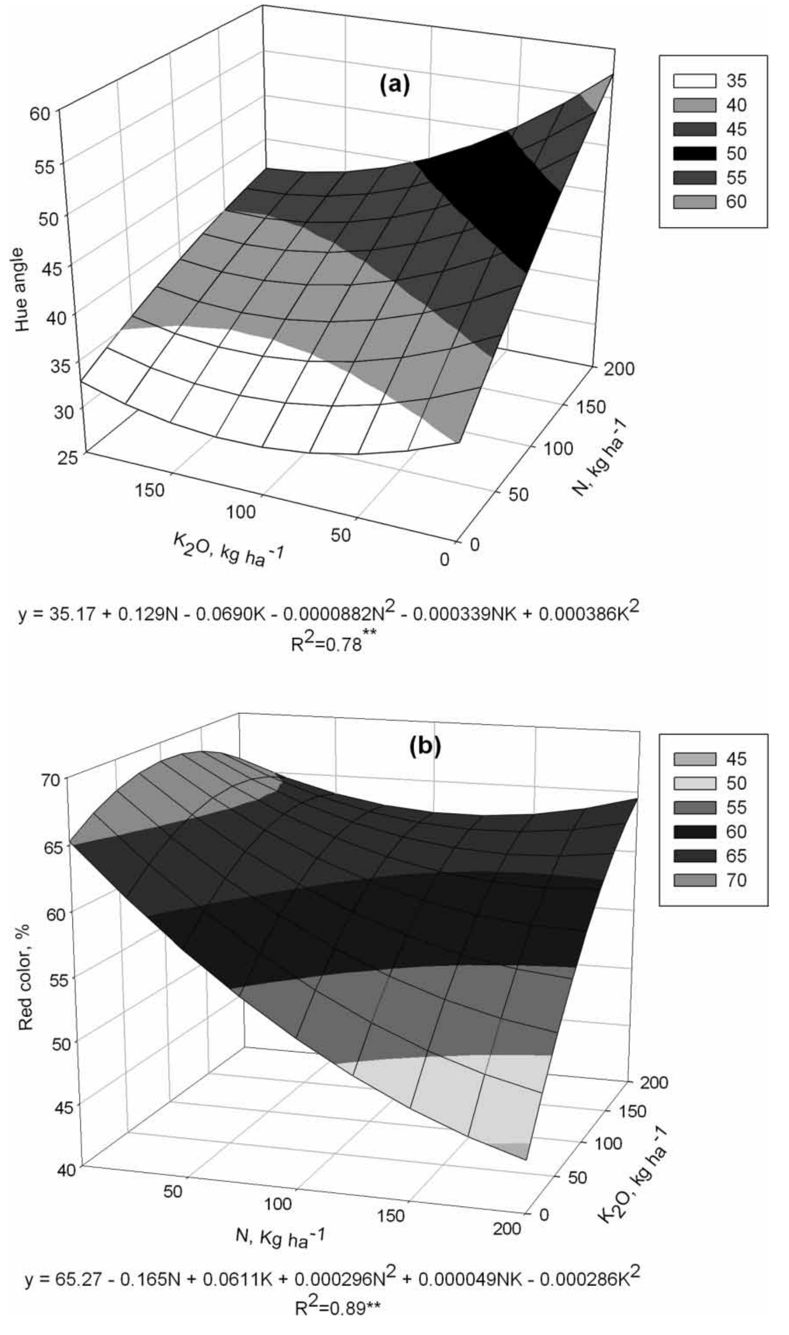
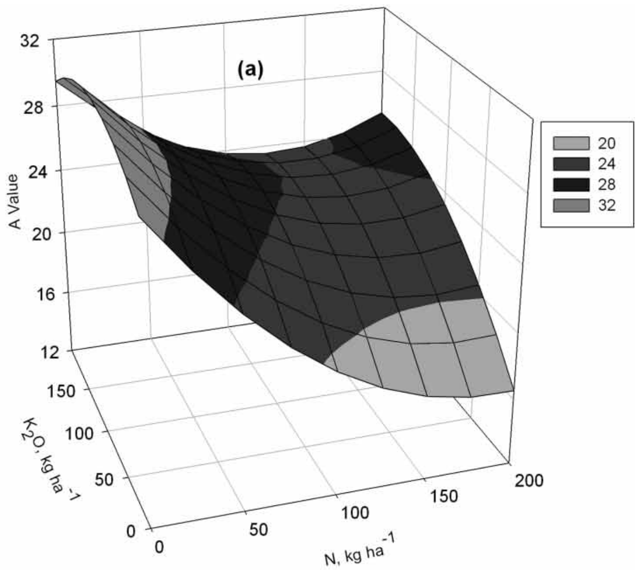
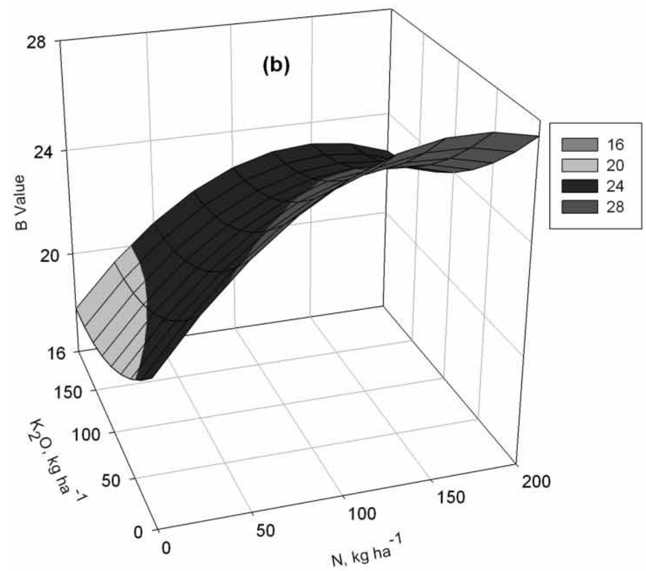


Figure 4. Peel color of apple fruit in response to the N and K fertilization: (a) hue angle (colorimetric measurement) and (b) percentage of red epidermis (visual measurement) (2005).



$y = 29.47 - 0.136 + 0.0473K + 0.000358N^2 + 0.000218NK - 0.000236K^2$
$R^2=0.80^{**}$



$y = 21.34 + 0.0798N - 0.0382K - 0.000245N^2 - 0.0000361NK + 0.000102K^2$
$R^2=0.69^{**}$

Figure 5. Peel color of apple fruit in response to the N and K fertililzation (a) a value and (b) b (2005).

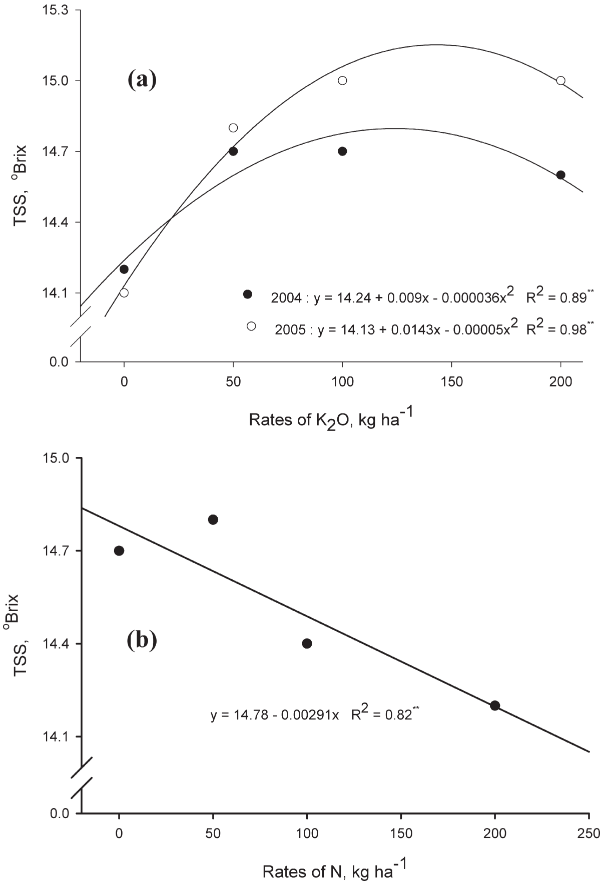


Figure 6. Total soluble solid (TSS) contents of apple fruits as affected by (a) K fertilization (2004 and 2005) and (b) N fertilization (2004).

suggests that a specific K^+ channel may be linked to sugar unloading (Lacombe et al. 2000). More studies to investigate the relationship between TSS accumulation and K accumulation in apple fruits are required.

The TSS content decreased linearly in response to N fertilization in 2004 (Figure 6b) and was not affected in 2005. This might be explained by the high self-shading, as a result of excessive vegetative growth stimulated by N and associated with reduction of sunlight incident on the fruit surface. Previous reports have also shown the depressive effect of N fertilization on TSS content of apple fruits (Dris, Niskanan, and Fallahi 1999; Drake, Raese, and Smith 2002). However, even for the highest N rate, the TSS values were within the normal range of 13.0 to 14.4 Brix for the cultivar Fuji (Argenta 2002).

CONCLUSIONS

Fruit quality was affected by both N and K fertilization with apples showing variation in physicochemical characteristics in relation to rate of N and K fertilizer application. Nitrogen was the nutrient that showed the most detrimental effect on the quality of Fuji apple. Although N applications can increase fruit yield, negative effects on color, sugar content, and firmness of the fruits were observed in the present research. Hence, when evaluating N application rates, the detrimental effects on fruit quality that this nutrient can cause must be considered, in addition to fruit yield.

Despite the high soil exchangeable K observed in the beginning of the experiment, K fertilization generally increased fruit quality, with the exception of flesh firmness. Because K is the nutrient contained in the highest concentration in harvested fruit, it is important to apply K annually to maintain the soil K levels in order to produce apple with good coloration, high sugar content and high acidity.

Future research is required to evaluate the possible interrelations among N and K fertilization, fruit yield, quality, and occurrence of physiologic disorders possibly due to the role of K and N in calcium nutrition.

REFERENCES

AOAC. 1980. *Official Methods of Analysis*; Association of Official Analytical Chemists: Washington, DC.

Argenta, L.C. (2002) Post-harvest physiology: maturation, harvest and storage of apples. In *Handbook of Apple Culture*; EPAGRI: Florianopolis, Brazil, 691–732.

Casero, T., Benavides, A., Puy, J., and Recasens, I. (2004) Relationships between leaf and fruit nutrients and fruit quality attributes in Golden Smoothee apples using multivariate regression techniques. *Journal of Plant Nutrition*, 27: 313–324.

Daugaard, H. and Grauslund, J. (2000) Fruit color and correlations with orchard factors and post-harvest characteristics in apple cv. 'Mutsu'. *Journal of Horticultural Science and Biotechnology*, 74: 283–287.

Drake, S.R., Raese, J.T., and Smith, T.J. (2002) Time of nitrogen application and its influence on 'Golden delicious' apple yield and fruit quality. *Journal of Plant Nutrition*, 25: 143–157.

Dris, R., Niskanen, R., and Fallahi, E. (1999) Relationships between leaf and fruit minerals and fruit quality attributes of apples grown under northern conditions. *Journal of Plant Nutrition*, 22: 1839–1851.

EPAGRI. 2002. *Handbook of Apple Culture*; GMC/EPAGRI: Florianopolis, Brazil.

Hunsche, M., Brackmann, A., and Ernani, P.R. (2003) Effects of K fertilization on the post-havest quality of 'Fuji' apples. *Brazilian Journal of Agricultural Research*, 38: 489–496.

Iuchi, V.L., Nava, G., and Iuchi, T. (2001) *Physiological and Nutritional Disorders of Apple Culture*; EPAGRI-/JICA: Florianopolis, Brazil.

Ju, Z., Duan, Y., and Ju, Z. (1999) Effects of covering the orchard floor with reflecting films on pigment accumulation and fruit coloration in 'Fuji' apples. *Scientia Horticulturae*, 82: 47–56.

Kingston, C.M. (1992) Maturity indices for apple and pear. *Horticultural Reviews*, 13: 407–432.

Lacombe, B., Pilot, G., Michard, E., Gaymard, F., Sentenac, H., and Thibaud, J.B. (2000) A shaker-like K channel with weak rectification is expressed in both source and sink phloem tissues of Arabidopsis. *Plant Cell*, 12: 837–351.

Little, C.R. (1992) *A Manual of Procedures for Assessing Apple Maturity for Storage Schedules*; Horticulture Research Institute: Victoria, Australia.

Matev, Y. and Stanchev, L. (1979) Effect of Na^+, K^+, Ca^{2+} and Mg^{2+} disproportion on glasshouse tomato development and fruit biological value. *Horticultural and Viticultural Science*, 16: 76–82.

Neilsen, G.H., Neilsen, D., Herbert, L.C., and Hogue, E.J. (2004) Response of apple to fertigation of N and K under conditions susceptible to the development of K deficiency. *Journal of the American Society for Horticultural Science*, 129: 26–31.

Neilsen, G.H., Hogue, E.J., and Meheriuk, M. (1999) Nitrogen fertilization and orchard-floor vegetation management affect growth, nutrition and fruit quality of Gala apple. *Canadian Journal of Plant Science*, 79: 379–385.

Neilsen, G.H., Parchomchuk, P., Meheriuk, M., and Neilsen, D. (1998) Development and correction of K-deficiency in drip irrigated apple. *Hortscience*, 33: 258–261.

Neilsen, G.H., Parchomchuk, P., Neilsen, D., and Zebarth, B.J. (2000) Drip-fertigation of apples trees affects root distribution and the development of K deficiency. *Canadian Journal of Soil Science*, 80: 353–361.

Raese, J.T. and Drake, S.R. (1997) Nitrogen fertilization and elemental composition affects fruit quality of 'Fuji' apples. *Journal of Plant Nutrition*, 20: 1797–1809.

Sams, C.E. (1999) Preharvest factors affecting postharvest texture. *Postharvest Biology and Technology*, 15: 249–254.

Sobulo, M.J. and Olorunda, A.O. (1977) The effects of nitrogen, phosphorus and potassium on the canning quality of tomatoes (*Lycopersicon esculentum*) in southwestern Nigeria. *Acta Horticulturae*, 53: 171–180.

Stiles, W.C. (1994) Nitrogen management in the orchard. In *Tree Fruit Nutrition*; Peterson, A.B. and Stevens, R.G. (eds.); Good Fruit Grower: Yakima, Wash., 41–50.

Taiz, Z. and Zeiger, E. (2004) *Plant Physiology*; Artmed: Porto Alegre, Brazil.