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Fertilizer Rates, Application Timing, Growth, and Yields of Papaya Plants in North Central Florida

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Optimum nitrogen (N) fertilizer rates and application timing have not been clearly established for papaya plants in north central Florida. Annual N application rates vary from 160 to 500 kg·ha^{-1} and papaya growers in Florida often band fertilizer within the row before and after planting. 'Red Lady' papaya (*Carica papaya* L.) seedlings were transplanted to the field in Gainesville, Florida. For the N rate study, granular fertilizer was applied to the soil. Nitrogen was applied at 50, 100, 200, or 300 kg/treated ha per year to determine the N rate for optimum papaya growth and yields. A second set of experiments compared the effects of various application timings on papaya growth and yields. Treatments consisted of all fertilizer (N at 223 kg·ha^{-1}) applied prior to planting (preplant); 2/3 preplant and 1/3 applied after planting (post-plant); 1/3 preplant and 2/3 post-plant; and all fertilizer applied post-plant three times per year. Total plant vegetative fresh weights increased linearly from the 50 to the 300 kg/treated ha annual N rate in both years and stem diameter also increased linearly with time but independent of treatment. Total fruit yield per plant, fruit weight, and fruit number increased, reaching a maximum level at the 223 kg/treated ha rate. In the fertilizer application timing study, there were no significant treatment effects on growth of any plant part except root fresh weight. Root fresh weight was lowest when fertilizer was applied entirely pre-plant in 2005. Application timing generally had no effect on growth, yields, or petiole N content.

Papaya (*Carica papaya* L.) is grown commercially in over 56 countries worldwide and locally throughout the warm tropical and subtropical regions of the United States. It is a large, herbaceous, rapidly growing perennial plant. Papayas are grown in a wide range of soil types from heavy clay to volcanic and sandy loam soils, although they grow best in slightly acidic, sandy loam soils (Nakasone and Paull, 1998). In Florida, there are currently 68 papaya producers in 11 counties (USDA–NASS, 2009). Miami–Dade County has 68 ha in commercial production. Total crop value and production statistics for the other counties are unknown. Papaya plants in Florida are grown mostly in the calcareous, well-drained Krome very gravelly loam soil of southern Florida (Noble et al., 1996). Papaya plants have limited freeze tolerance (leaves are damaged at –2 °C) and there is some interest in growing this crop in marginal subtropical areas of north central Florida by using water or covers for cold protection (Ferguson and Crane, 1997).

Papaya nutrition and fertilizer requirements have been studied throughout the world for many years. Awada and Long (1971) applied three rates and two sources of N to 'Solo' papaya plants in Hawaii. They found that N rate had little effect on stem diameter, but that the 0.44 kg N/plant rate applied every 6 weeks produced optimum yields. In subsequent studies, Awada (1977) and Awada and Long (1980) using factorial combinations of N, P, and K observed that maximum marketable yield occurred at about 1084 kg·ha^{-1} of N, and at petiole N levels of 1.44%. Fertilizer was applied at 6- to 12-week intervals.

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Fertilization and irrigation studies from India suggested that N rates of 300–450 g/plant produced higher yields than 150 g/plant. The highest rate translated to an annual application of about 750 kg·ha^{-1}. The optimum petiole N level ranged from 1.08% to 1.11% (Srinivas and Hegde, 1992). Werner (1993) studied effects of various N rates, sources, and application frequencies on growth and yields of 'Tainung 2' papaya in the Dominican Republic. An annual N rate of 100–150 kg·ha^{-1}, which is considerably below that of other papaya regions, produced the highest yields, and rates above 150 kg·ha^{-1} reduced vegetative growth. Fertilizer application frequency and N source had no effect on growth, yields, or fruit quality. Allan et al. (2000) applied four different N levels to 'Solo' papaya plants grown in a greenhouse in Australia. Fertilizer was applied at weekly intervals. Maximum growth occurred at moderate N levels and optimum petiole N concentration ranged from 1.30% to 2.50%.

Shukla and Singh (2001) compared four plant densities and three N rates for papaya plants in India. The highest annual yield occurred at about 444 kg·ha^{-1} N. There was also an interaction between density and N rates. Perez-Lopez and Reyes-Jurado (1983) also conducted factorial rate studies with N and B on clay soils in Puerto Rico. Nitrogen rate alone had no effect on papaya height or stem diameter and the 170 kg·ha^{-1} N annual rate produced the highest yields. In contrast, 25–35 kg·ha^{-1} of N per annum (which seems unusually low) produced the highest yields for papaya plants in Trinidad (Colom-Covas, 1977).

Bueno-Jaquez et al. (2005) applied varying levels of N, P, and K to papaya plants in Mexico and observed that the optimum economic yield occurred at an annual N rate of 220 kg·ha^{-1}. Recently, Kumar et al. (2010) also studied the effects of varying N, P, and K rates on growth and yields of papaya plants at four locations in India. They found that a balanced annual application of 300 g/plant of N, P, and K produced the highest yields. The wide range of optimum N values worldwide is likely due to differences in soil type and climate among the growing regions.

There is little information on the effects of N rates and application timing on papaya growth and yields on the sandy soils in north central Florida. Most growers apply 160 to 500 kg·ha^{-1} N per year at various times in southern Florida (J. Crane, personal communication). Our first objective was to determine the N application rate for optimum vegetative growth and yields of papaya plants in north central Florida. Our second objective was to determine the effects of various pre- and post-planting fertilizer application timings on vegetative growth and yields of papaya plants in north central Florida. Many growers apply varying amounts of N prior to planting, which is a standard practice for vegetable growers in southern Florida. They then apply the remaining fertilizer at varying intervals for the rest of the season. This preplant and split application procedure is not used in most other papaya-growing areas and has not been thoroughly evaluated in Florida.

Materials and Methods

'Red Lady' papaya seeds were obtained from a commercial source (Farm and Nursery Supply, Homestead, FL) and soaked in water and MiracleGro (18N–15.8P–13.9K) (The Scotts Co., Geldermalsen, The Netherlands) (1 g·L^{-1}) for 2 h before planting into trays containing a 1:1 v/v mixture of peat moss and perlite. Plants were grown in the greenhouse in 15-cm-diameter containers for about 3 months and were transported to the field near Gainesville, FL, when they were 8 to 12 mm in stem diameter and 30 to 40 cm in height. Seedlings were planted in groups of three at 30 cm apart to allow for subsequent selection of one hermaphroditic plant per treatment in each block after flowering (early August). The final plant spacing was 5 m within and between rows. Soil type was Arredondo fine sand (loamy, siliceous, hyperthermic Grossarenic Paleudult). Overhead sprinklers were run for 4 h each day at 2-d intervals for 2 weeks after planting to establish the plants and then at regular intervals of 3–5 d depending on the amount and timing of rainfall throughout the season. Currently, there are no recommendations for papaya irrigation using overhead sprinklers in this soil type. Pest and disease problems were minimal and weeds were controlled using glyphosate.

N rate studies 2007–2008. Granular fertilizer was applied in both years to each group of three plants at an annual N rate of 50, 100, 200, or 300 kg/treated ha using a 10N (6.9% ammoniacal, 3.1% nitrate nitrogen)–8.8P–6.6K fertilizer plus Fe (0.19%), Zn (0.07%), Mn (0.07%), Cu (0.01%), and B (0.01%). Application rates were determined based on the amount of N in the fertilizer as this is the most important element for papaya growth as described above. In addition, P and K levels are inherently very high in these soils. Fertilizer was applied by hand to a 1-m^2 area for the first two applications (April and June), a 1.5-m^2 area at flowering (August), and to a 2.0-m^2 area for the last application in October. The area of ground coverage was chosen based on previous observations on root distribution in this soil type. This procedure minimized fertilizer application outside of the root zone, especially early in the season.

The experiment was arranged in a randomized complete-block design with 10 blocks. Each of the four treatments within a block contained three plants for the first two fertilizer applications and one hermaphroditic plant for the last two applications. Stem diameter and height were measured about monthly for each plant from 25 Apr. to 25 Aug. 2007 and 16 Apr. to 14 Aug. 2008, after which one hermaphroditic plant from the three initial plants was selected and the measurements continued until 7 Oct. 2007 and 22 Oct. 2008. The other two plants in the group were removed. Time of first flowering and flower type (male, female, or hermaphrodite) and intensity (estimated number of flowers per m^2) were observed at regular intervals. Data were analyzed using ANOVA (SAS Institute, Cary, NC) for fruit yields, number, and weight and plant fresh weights and by repeated measures analysis for stem diameter and plant height data. Regression analysis and curve-fitting were done using SigmaPlot 10.0 and TableCurve 2D 5.01 (SYSTAT software, Richmond, CA). Flowering intensity was rated subjectively from 5-highest to 1-lowest. Fruit were harvested, counted, and weighed on 7–9 Nov. 2007 and 24–26 Nov. 2008 and total fresh weight of leaves, stems, petioles, and roots determined. Petioles were collected at harvest each year and washed in DI water, dried, ground, sieved, and N, P, and K levels analyzed using flame spectrophotometry at the University of Florida soil testing lab. Petiole rather than leaf tissues are typically used for nutrient analysis of papaya plants (Awada and Long, 1980).

Application timing studies 2005–2006. Each group of papaya plants received the equivalent of N at 222 kg·ha^{-1} per year of a 10N (6.9% ammoniacal, 3.1% nitrate nitrogen)–8.8P–6.6K fertilizer plus Fe (0.19%), Zn (0.07%), Mn (0.07%), Cu (0.01%), and B (0.01%) in both years. This N rate was based on rates used in southern Florida (J. Crane, personal communication) and not on the N rate experiments in this study. Treatments consisted of applying the entire N preplant; 2/3 preplant and 1/3 post-plant; 1/3 preplant and 2/3 post-plant; and all post-plant. Preplant fertilizer was broadcast by hand on 5 Apr. 2005 and 12 Apr. 2006 just prior to planting. Post-plant applications were made on 3 June, 3 Aug., and 6 Oct. 2005 and 6 June, 7 Aug., and 5 Oct. 2006.

The experiment was arranged in a randomized complete-block design using eight blocks in 2006 and 10 blocks in 2007 each having four treatments/block. Stem diameter and height were measured about monthly for each plant until 8 Aug. 2005 and 12 Aug. 2006 when one hermaphroditic plant from the three initial plants was selected and the remaining two plants were removed. Measurements continued until December. The stem diameter and height data were analyzed using repeated measures analyses (SAS Institute) and SigmaPlot version 10.0 (SYSTAT software).Time of first flowering and flower type and intensity were observed at regular intervals. Flowering intensity was rated subjectively from 5-highest to 1-lowest. Fruit were harvested and weighed on 15 Nov. 2005 and 31 Oct. 2006 and three entire plants per treatment were harvested on 18 Nov. 2005 and five plants per treatment were harvested in 5 Nov. 2006 and total fresh weight of leaves, stems, petioles, and roots determined.

Results and Discussion

N rate studies 2007–2008

Growth. There was a highly significant time (date) ($P < 0.01$) effect on stem diameter as expected, but treatment and time × treatment effects were nonsignificant in 2007 and 2008 based on repeated measures analysis (data not shown). Stem diameter increased linearly at the same rate for all N treatments, but growth rate leveled off in October. In contrast, there was a highly signifi-

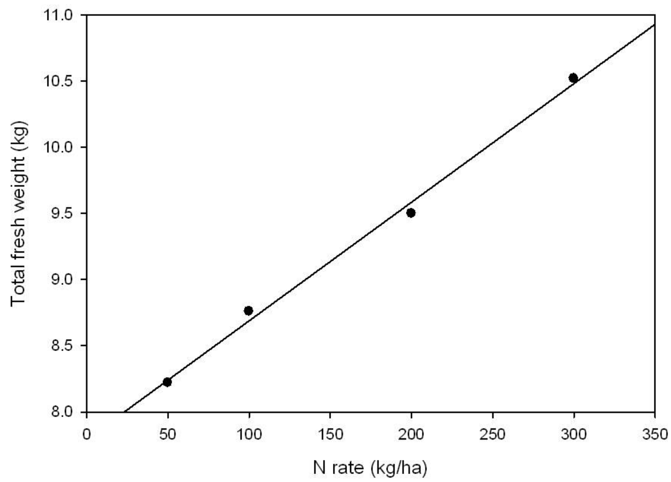

Fig. 1. Effects of N rate on total vegetative fresh weight per plant of 7-month-old 'Red Lady' papaya plants in 2007. Values represent means of 10 plants/treatment for each date. $y = 6.08 + 0.013x$, $r^2 = 0.94$.

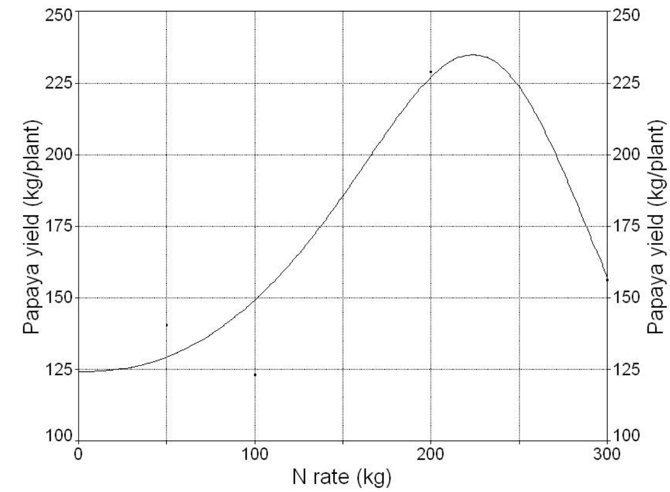

Fig. 3. Effects of N rate on mean total fruit yield per plant of 'Red Lady' papaya plants for 2007–2008 data combined. Values represent means of 20 plants/treatment for each date. $y^{-1} = 0.008 - 3.02e - 08x^{2.5} + 1.68e - 09x^3$, $r^2 = 0.88$.

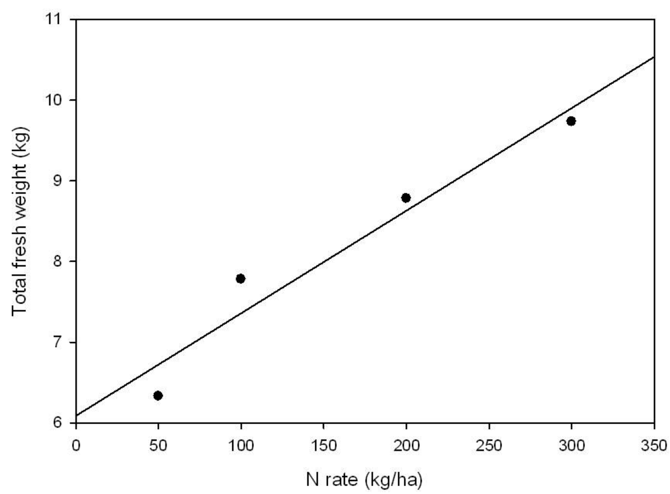

Fig. 2. Effects of N rate on total vegetative fresh weight per plant of 8-month-old 'Red Lady' papaya plants in 2008. Values represent means of 10 plants/treatment for each date. $y = 7.79 + 8.96e^{-3}x$, $r^2 = 0.99$.

cant, positive linear increase in total vegetative plant fresh weight as N rate increased from 50 to 300 kg/treated ha in both years (Figs. 1 and 2) and the shapes of the curves differed slightly between years. Overall statistical analysis indicated significant year, treatment, and block effects. Therefore, the N rate and vegetative plant fresh weight data for 2007 (Fig. 1) and 2008 (Fig. 2) are presented separately. The increase in fresh weight in both years was due to increases in petiole and root fresh weights and not due to stem or leaf fresh weight increases (data not shown). The stem fresh weight data are in agreement with the stem diameter measurements. Previous papaya studies also suggested that N rate had no effect on stem diameter in Hawaii (Awada and Long, 1971) and Puerto Rico (Perez-Lopez and Reyes-Jurado, 1983).

Fruit yield, weight, and number. There was a highly significant, complex polynomial relationship between N rate and total fruit yield in 2007 and 2008 (Fig. 3), but there were no significant year, or year × treatment interactions (data not shown) and data from both years were combined. There was a highly significant block effect, but no block × treatment interaction. The pronounced block effect appeared to be due to differences in soil characteristics (not soil series) from the north to south end of the experimental plot as observed in previous studies. This variation in soil characteristics was the original reason for blocking the treatments. However, treatment effects were consistent within each block. The maximum fruit yield occurred at a 223 kg/treated ha annual rate for the combined years. In addition, there was a highly significant complex polynomial relationship between N rate and both fruit fresh weight (Fig. 4) and number (Fig. 5) in 2007 and 2008, but there were no significant year, or year × treatment interactions (data not shown) and data from both years were combined. The shape of the curves were more similar and r^2 values were much greater for the total yield and fruit weight data than for total yield and fruit number data, although both factors contributed to total yield. Yields were considerably lower for papaya plants growing in north central Florida than in southern Florida (Migliaccio et al., 2010) or more tropical growing regions (Bueno-Jaquez et al., 2005) due to the great differences in the length of the growing season.

Optimum N rates in this study are intermediate to those found in other papaya areas worldwide. The optimum annual N rate was 1084 kg·ha^{-1} in Hawaii (Awada and Long, 1980), 444 kg·ha^{-1} in India (Shukla and Singh , 2001), 220 kg·ha^{-1} in Mexico (Bueno-Jaquez et al., 2005), 170 kg·ha^{-1} in Puerto Rico (Perez-Lopez and Reyes-Jurado, 1983), but only 110–150 kg·ha^{-1} in the Dominican Republic (Werner, 1993). The wide ranges in optimum N rates likely resulted from differences in cultivar, climate, soils, and irrigation in the various regions, but also could be related to whether N was applied on a total ha or treated ha basis as in this study. There was no significant effect of N rate on flower type or flowering intensity in either year (data not shown).

Petiole nutrient levels. Petiole nutrient concentration for N, P, and K were not significantly different for all N rates in 2007 and N values ranged from 0.95% to 1.03% in 2007 and 0.78% to 0.97% in 2008. These values are lower than those reported for papayas growing in Hawaii (1.44%) (Awada and Long, 1980) and Australia (1.3% to 2.5%) (Allan et al., 2000), but similar to

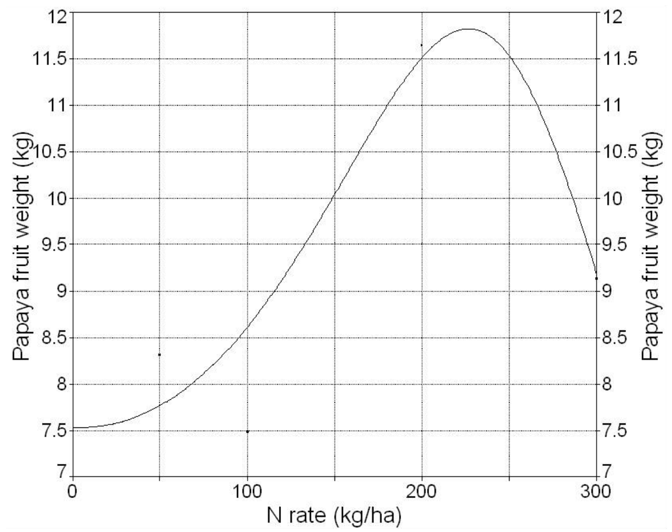

Fig. 4. Effects of N rate on mean total fruit fresh weight per plant of 'Red Lady' papaya plants for 2007–2008 data combined. Values represent means of 20 plants/treatment for each date. $y^{-1} = 0.149 - 5.11e - 07x^{2.5} + 2.85e - 08x^3$, $r^2 = 0.89$.

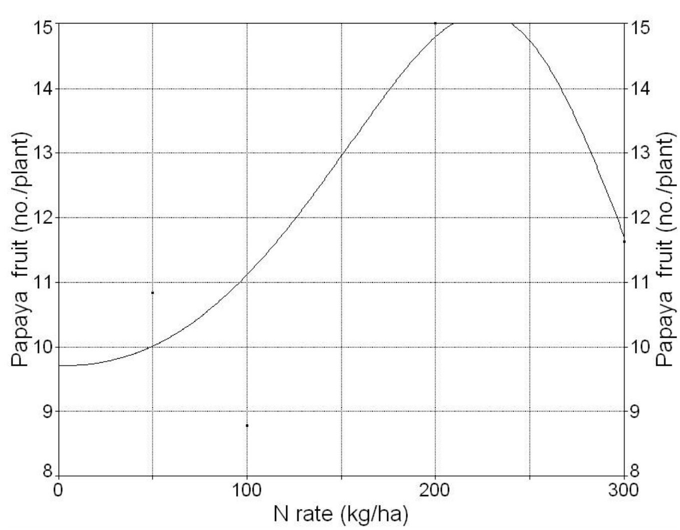

Fig. 5. Effects of N rate on mean total fruit number per plant of 'Red Lady' papaya plants for 2007–2008 data combined. Values represent means of 20 plants/treatment for each date. $y^{-1} = 0.100 - 2.90e - 07x^{2.5} + 1.61e - 08x^3$, $r^2 = 0.69$.

those reported in India (1.08% to 1.11%) (Srinivas and Hedge, 1992). It is not clear why petiole nutrient levels were apparently not related to N application rate.

Application timing studies, 2005–2006

Growth. There was a highly significant time (date) effect ($P < 0.01$) on stem diameter, but treatment and time × treatment effects were nonsignificant in 2005 and 2006 using repeated measures analysis (data not shown). Stem diameter increased linearly during each season independent of treatment, but growth rate leveled-off in November. In addition, there were no treatment effects on leaf, petiole, or stem fresh weights in 2005 or 2006; however, there was a year × treatment interaction in 2005. Root fresh weight was lowest for the plants receiving all of the fertilizer preplant (Table 1).

Fruit yield, weight, and number. There was no significant effect of fertilizer application timing on total fruit yield, weight or number in 2005 or 2006 and there were no significant year, or year × treatment interactions (data not shown). Similarly, Werner (1993) observed that time of fertilizer application had no effect on papaya growth or yields on a different soil type in the Dominican Republic. There was no significant effect of fertilizer application timing on flower type or flowering intensity in either year (data not shown).

Petiole nutrient levels. Petiole N concentration differed by year and treatment. In 2005 petiole N concentration was highest for the 2/3–1/3 treatment and lowest for the entire post-plant treatment with the other treatments giving intermediate values (Table 2). Petiole N concentrations ranged from 1.08% to 1.22%. In 2006 the same trend occurred as in 2005 with the lowest value occurring in the entire post-plant treatment for petiole N concentrations but values ranged from 0.94% to 1.03% (Table 3). As indicated in the previous section, these values are lower than those reported for papayas growing in Hawaii (1.44%) (Awada and Long, 1980) and Australia (1.3% to 2.5%) (Allan et al., 2000), but similar to those reported in India (1.08% to 1.11%) (Srinivas and Hedge, 1992).

Table 1. Effects of fertilization timing on leaf, petiole, stem, root, and total fresh weight (fwt) of 7-month-old 'Red Lady' papaya plants, Gainesville, FL, 2005.

Treatment (N at kg·ha^{-1})		Leaf^z	Petiole^z	Stem^z	Root^z	Total^z
Pre^y	Post^x	fwt (kg)	fwt (kg)	fwt (kg)	fwt (kg)	fwt (kg)
0	222	2.15 a	1.25 a	4.17 a	4.15 a	12.26 a
73	149	2.50 a	1.43 a	4.71 a	3.88 a	12.52 a
149	73	1.83 a	1.01 a	4.70 a	3.67 a	11.21 a
222	0	1.93 a	1.03 a	3.49 a	2.41 b	8.86 a

^{z}Mean separation within columns by DMRT, $P < 0.05$, n = 3.
^{y}Pre-plant fertilizer was broadcast on 5 Apr. 2005.
^{x}Post-plant fertilizer was broadcast on 3 June, 3 Aug., and 6 Oct. 2005.

Table 2. Effects of fertilization timing on petiole nutrient content of 7-month-old 'Red Lady' papaya plants in Gainesville, FL, 2005.

Treatment (#N)		N^z	P	K	Mg
Pre^y	Post^x	(%)	(%)	(%)	(%)
0	222	1.08 b	0.43 a	1.01 a	0.52 a
73	149	1.15 ab	0.28 ab	0.85 a	0.47 a
149	73	1.22 a	0.42 a	1.00 a	0.50 a
222	0	1.18 ab	0.40 ab	0.94 a	0.48 a

^{z}Mean separation within columns by DMRT, $P < 0.05$, n = 8.
^{y}Pre-plant fertilizer was broadcast on 5 Apr. 2005.
^{x}Post-plant fertilizer was broadcast on 3 June, 3 Aug., and 6 Oct. 2005.

Table 3. Effects of fertilization timing on petiole nutrient content of 7-month-old 'Red Lady' papaya plants in Gainesville, FL, 2006.

Treatment (#N)		N^z	P	K
Pre^y	Post^x	(%)	(%)	(%)
0	222	0.94 b	0.31 a	0.68 a
73	149	0.97 ab	0.31 ab	0.62 a
149	73	1.03 a	0.27 a	0.62 a
222	0	0.99 ab	0.26 ab	0.65 a

^{z}Mean separation within columns by DMRT, $P < 0.05$, n = 10.
^{y}Pre-plant fertilizer was broadcast on 12 Apr. 2006.
^{x}Post-plant fertilizer was broadcast on 6 June, 7 Aug., and 5 Oct. 2006.

There were no significant treatment effects on petiole P and K in either year. In general it appears that papaya growth, yields, and petiole nutrition are not strongly correlated with N application timing under conditions in north central Florida.

Conclusions

Total vegetative fresh weight of 'Red Lady' papaya plants continued to increase with increasing N rates and may not plateau until N rates reach above 300 kg/treated ha. The increase in total vegetative fresh weight is a function of increases in petiole and root fresh weights, while leaf and stem fresh weights and stem diameters were not affected by N rate. In contrast, fruit yield, weight and number reached maxima at 223 kg N/treated ha and declined thereafter in favor of enhanced vegetative growth. Trends for both vegetative and fruiting factors were very similar between years and r^2 values were relatively high. Time of N application, however, had little effect on 'Red Lady' papaya growth, yields, or petiole nutritional levels. Therefore, preplant fertilizer application appears to have no benefit over application at regular intervals throughout the season. For the first year in the field, growers in cool, non-traditional papaya growing areas like north central Florida should also consider applying N to targeted areas around the plant based on root distribution rather than as a broadcast application. This practice will result in fertilizer cost savings and a decrease in production costs without decreasing yields.

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