

Nitrogen and Phosphorus Fertilizer Management for Young, Bearing Microsprinkler-Irrigated Citrus, Final Report

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Abstract

Higher nutrient and water use efficiency are possible with microsprinkler-irrigated citrus compared to flood-irrigated citrus. Therefore, new N and P fertilizer recommendations are needed for microsprinkler-irrigated citrus. The objectives of this project were to i) determine the effects of N applications of 0 - 0.8 lb/tree/yr on fruit yield, fruit and juice quality, and N and P removal in fruit for microsprinkler-irrigated navel oranges; ii) determine the effects of P applications of 0 - 0.2 lb/tree/yr on fruit yield, fruit and juice quality, and N and P removal in fruit, and iii) develop Best Management Practices for N and P fertigation of microsprinkler-irrigated citrus. Field experiments were conducted at the University of Arizona Citrus Agricultural Center in separate blocks of 'Newhall' and 'Fukumoto' navel oranges, both on 'Carrizo' rootstock. In each block, ten treatments, consisting of all possible combinations of 5 N rates (0, 0.2, 0.4, 0.6, and 0.8 lb N/tree/yr) and 2 P rates (0, 0.2 lb P/tree/year) were applied to five replicate trees per treatment. The maximum predicted yields for both varieties during all three seasons occurred at N rates of 0.4 to 0.55 lb N tree⁻¹ yr⁻¹. There were no significant effects of P application on fruit yield or quality. There were few significant effects of N or P fertilization on packout or fruit quality. The amounts of N removed in harvested fruit at the yield-maximizing N rates were equivalent to 50-84% of the N applied. New N fertilizer recommendations for microsprinkler-irrigated navel oranges are proposed.

Introduction

Nitrogen is the nutrient most likely to limit yield and quality of citrus, and is the nutrient used in the highest amounts for citrus production. Adequate supplies of N are necessary to optimize yield of young citrus trees. Optimal growth and yield requires optimal levels of N and irrigation, but an excess of either is nonproductive, costly, and may result in loss of N by leaching and/or runoff.

Increasing water costs and declining water availability are causing growers to adopt production practices which allow them to significantly improve water use efficiency and decrease labor costs. One such practice is the installation of under-tree microsprinklers in place of conventional surface flood irrigation. In addition to allowing precise control of irrigation water applications, microsprinkler systems offer the ability to use fertigation with fluid fertilizer materials throughout the growing season.

Existing guidelines for fertilization of Arizona citrus crops were developed with flood irrigation. Previous research that we have conducted has demonstrated that the N rates recommended for young, non-bearing flood-irrigated citrus can be substantially reduced for microsprinkler-irrigated citrus. The lower N requirement is directly related to the higher water- and nutrient-use efficiency of microsprinkler irrigation compared to flood irrigation. We hypothesize that optimum N rates for fruit-bearing microsprinkler-irrigated citrus will also be lower than for

flood-irrigated citrus. Field experiments are needed to test this hypothesis.

Observed responses to P fertilization by citrus include increased juice content, increased soluble solids/acids in juice, increased yields, and decreased rind thickness (Hilgeman et al., 1938; Embleton et al., 1956; Smith, 1963; C.A. Sanchez, Yuma, AZ, unpublished data). Citrus crops in central Arizona are customarily not fertilized with P, and previous research in this area has generally shown a lack of response to P fertilization (Hilgeman and Dunlap, 1972). However, recent research in western Arizona on sandy soils showed that mature citrus converted from border flood to microsprinkler irrigation responded to granular P fertilization (C.A. Sanchez, Yuma AZ, unpublished data). Because of the altered pattern of root distribution and water and nutrient extraction by microsprinkler-irrigated citrus, compared to conventional irrigation methods, and the capability for P fertigation, current P fertilizer practices should be re-examined. Therefore, research is needed to define appropriate rates of fluid P inputs for microsprinkler irrigated citrus in the desert Southwest.

Recommended N rates for young, fruit-bearing citrus are generally based upon leaf N analysis or N removal in harvested fruit. The generally recommended critical leaf N concentration is 2.5-2.7%; within this concentration range tree N status is considered "optimum". Current Arizona recommendations are to apply 1-2 lb N/tree/yr to young bearing citrus with optimum leaf N (Doerge et al., 1991). The International Fertilizer Association (2002) summarized N recommendations worldwide for 6-year-old (bearing) citrus. Recommended rates were generally from 0.6 - 1.0 lb N/tree/yr. In Texas, recommended N rates for 6-8 year-old citrus are 1 - 1.25 lb/tree/yr (Sauls, 2002). Florida recommendations call for similar rates of N application and are based upon leaf N concentration.

None of the recommendations cited in the previous paragraphs were developed for microsprinkler-irrigated citrus. Only the Texas recommendations explicitly recognize the higher efficiency of microsprinklers by recommending a 20% reduction in N rate with microsprinklers (Sauls, 2002). Previous research at the University of Arizona has demonstrated that optimum N rates for newly-planted microsprinkler-irrigated citrus are significantly lower than rates previously considered optimum for flood-irrigated citrus (Weinert et al., 2002; Kusakabe et al., 2006). This is probably because of the higher water- and nutrient-use efficiency possible with microsprinkler irrigation. It is reasonable, therefore, to hypothesize that optimum N rates for young, bearing microsprinkler-irrigated citrus will also be lower than for flood-irrigated citrus. Because of the growing importance of microsprinklers in Arizona citrus production, there is an urgent need to determine optimum N rates.

The objectives of this project were to i) determine the effects of N applications of 0 - 0.8 lb/tree/yr on fruit yield, fruit and juice quality, and N and P removal in fruit for microsprinkler-irrigated navel oranges; ii) determine the effects of P applications of 0 - 0.2 lb/tree/yr on fruit yield, fruit and juice quality, and N and P removal in fruit, and iii) develop Best Management Practices for N and P fertigation of microsprinkler-irrigated citrus.

Materials and Methods

1. Site Characteristics and Treatments

Both 'Newhall' navel oranges (*Citrus sinensis*) and 'Fukumoto' navel oranges budded onto 'Carrizo' citrange rootstock were grown on 20 x 20-ft centers at the University of Arizona Citrus Agricultural Center, Waddell, AZ. The field is mapped as a Gilman fine sandy loam [course-loamy, mixed (calcareous), hyperthermic Typic Torrifluent], which has a pH of 7.8, ECe 0.7 dS/m, extractable K 702 ppm, extractable sodium <1%, soil organic mater 7 g/kg, and CaCO₃ <1% (Soil Conservation Service, 1975).

A field study was initiated in Mar. 1997. During Mar. 1997-Dec. 2003, the 'Newhall' navel oranges received combination of various fertigation frequencies and N rates, and the 'Fukumoto' navel oranges received various slow-release fertilizer treatments during 1997 to 2001 and uniform N fertilization from 2001 to 2003. The 'Newhall' and 'Fukumoto' trees were planted in separate blocks, therefore, separated experiments were conducted.

Each experiment was a factorial randomized complete block designs with five N rates (0, 0.2, 0.4, 0.6, 0.8 lb N/tree), two P rates (0, 0.2 lb P/tree), and five replications. Each experimental block contained 50 trees of each scion-rootstock combination and each plot contained one tree. Nitrogen was applied as urea ammonium nitrate (32-0-0) solution, and P was applied as phosphoric acid (0-52-0). The N and P fertilizers were applied to each treatment by using Dosatron fertilizer injectors (Dosatron products, Sunnyvale, Fla). The irrigation lines were flushed for at least 10 minutes before and after fertigation. Fertigation was applied monthly from 7 Apr. to 10 Sep. 2003, 18 Feb. to 22 Aug. 2004, and 29 Jan. to 15 Aug., 2005.

2. Irrigation Management

All trees received identical irrigation management. Under each tree were two 300-degree microsprinklers, located 2" from both the north and south sides of the trunk. The flow rate was 10 gal/h at a pressure of 240 kPa, which wetted 8% of the orchard floor. Main and branch irrigation lines were constructed from 0.5" (ID) black polyethylene pipe, and the lines were arranged in order to apply the appropriate treatment to each tree. Two tensiometers were installed at 12- and 24- in depths along the dripline of trees at eight locations. Soil-water tension was measured every three days at 7:30 am. Irrigation was applied when soil water tension at the 24" depth reached 30 cbar (Fig. 1). Irrigation amounts were intended to replace evapotranspiration, plus a 5 % to 10 % leaching fraction. An AZMET (The Arizona Meteorological Network) station was located within 300' of the study site. There were 10.8, 9.32, and 10.7" of precipitation during 2003, 2004, and 2005, respectively. The total cumulative reference crop evapotranspiration was 71.0", 77.1", and 73.8" during 2003, 2004, and 2005, respectively. Irrigation was applied every 5 to 12 days during the three years of this study (data not shown).

3. Leaf Sampling and Analysis

Tree nutrient status was evaluated by measuring leaf N and P concentrations. Thirty spring-flush leaves were collected from each plot in August of each year. Leaf tissue was rinsed with distilled water, dried at 65°C, and ground to pass through a 0.3 mm sieve. The ground leaf tissue was analyzed for: 1) total N by a modified Kjeldahl digestion method modified to recover nitrate, and steam distillation and titration (Bremner and Mulvaney, 1982), and 2) total P by a modified molybdate-ascorbic acid method and UV/VIS spectrophotometry after acid digestion of ground leaf tissue with concentrated H₂SO₄ (Jones and Case, 1990).

4. Fruit yield, Fruit Sampling and Analysis

Fruit was harvested in December of each year. Trees were manually strip-picked for the harvest. Harvested fruit for each plot was collected in boxes and weighed, and all fruit was passed through an automated electronic fruit sizer (Aweta-Autoline, Reedley, CA). The fruit sizer measured weight, color, exterior quality, diameter, fruit grade (USDA, 1999), and fruit packout (size categories, Anonymous, 2004). Interior fruit quality was determined on eight fruit randomly selected from each plot. Fruit quality attributes measured were fruit weight, juice weight and volume, rind thickness, and fruit diameter. Juice quality attributes measured were pH, total soluble solids (TSS), and titratable acidity (TA). Each fruit to be analyzed for quality was sliced in half and juiced with a commercial electric juicer (Sunkist, Sherman Oaks, CA). The juice was strained to remove pulp and weighed. The TA was measured by titrating 25 mL of juice with 0.3125 M NaOH to a pH of 8, and TSS was measured with a handheld refractometer (Wardowski, 1990).

Two fruit from each plot were weighed, oven-dried at 65°C, ground to pass through a 0.1 mm sieve, and analyzed. Total N and total P contents in the fruit tissue were measured to evaluate fertilizer N and P uptake efficiencies by following the procedure described above.

6. Data Analysis

Analysis of variance (ANOVA) was performed on fruit yield, fruit quality, juice quality, and leaf N during the

experiment by using the GLM procedure in SAS (SAS Institute, 1999), and mean separations were accomplished by using Duncan's Multiple Range Test. When there were no significant ($p < 0.05$) P rate or N rate x P rate interactions on yield, quadratic response equations were developed for yield as a function of N rates. Regression analysis was accomplished by using the REG procedure in SAS.

Results and Discussion

1. Fruit Yield, Packout, and Quality

Trees fertilized with N alone generally showed a positive response to increasing N rate. During 2003 and 2004, maximum predicted yield from quadratic response equations was 110-130 lb/tree for both 'Newhall' and 'Fukumoto'. During the 2005 harvest, maximum predicted yield was 180 lb/tree for 'Newhall' and 130 lb/tree for 'Fukumoto' (Figs. 2 and 3). For reasons that are not clear, the trees fertilized with N + P did not respond consistently to N fertilizer. In most cases there was no response to N, and trees fertilized with N + P yielded less than those fertilized with N alone. The maximum predicted yields for both varieties during all three seasons occurred at N rates of 0.4 to 0.55 lb N/tree/yr (Figs. 2 and 3). These yield-optimizing N rates are lower than current AZ recommendations, which were developed with flood irrigation. Current AZ recommendations call for 1.0 to 2.0 lb N/tree/yr for trees more than five years after planting (Doerge et al., 1991). Thus, the yield-maximizing N rates in this experiment were equivalent to 25 to 55% of currently recommended N rates. Our finding that yield-optimizing N rates with microsprinkler irrigation were lower than currently recommended rates agrees with previous research from Florida (Alva and Paramasivam, 1998; Syvertsen and Smith, 1995) and Arizona (Weinert et al., 2002; Kusakabe et al., 2006) that showed that N rates currently recommended for flood-irrigated citrus can be reduced for microsprinkler-irrigated citrus.

There were few significant effects of N or P fertilization on packout, across both varieties and all three years of this experiment (data not shown). Selected fruit quality parameters are summarized in Tables 1 through 6. Similar to packout, there were very few statistically significant effects of the treatments on fruit quality. Across both varieties, the ratio of solids to acid (TSS/TA) were higher during the first two years of the experiment than during 2005.

2. Leaf N and P Concentrations

Leaf N of 'Newhall' increased in a linear fashion with increasing N rates during 2003 and 2004 (Fig. 4). During these two seasons, leaf N concentrations were 25-27 mg/g (2.5 to 2.7%) at the yield-optimizing N rate (indicated by arrows on Fig. 4). This range of leaf N concentrations corresponds to the generally accepted critical leaf tissue N concentration (Tucker et al., 1995; Sauls, 2002; Kallsen, 2003). No trends were evident during 2005, and there were no significant linear relationships between N rate and leaf N for 'Newhall'. Leaf N of 'Fukumoto' was generally linearly related to N rate (Fig. 5), and leaf N concentrations at the yield-maximizing N rates were 2.4 to 2.7 %, very close to the critical concentration range. In most cases, leaf N of trees fertilized with P increased with N rate, although fruit yield did not.

Leaf P concentrations averaged 0.16 to 0.20 % during the three seasons. There was no significant effect of P fertilization on leaf P in any season or variety. The critical leaf P concentration is normally assumed to be 0.12%; thus we concluded that these trees did not need P fertilizer.

3. Nitrogen Removal in Fruit

Nitrogen removed in harvested fruit was a function of fruit N content and fruit yield. In most cases, the relationships between N harvested in fruit and N rate resembled those between yield and N rate (Figs. 6 and 7). During 2003 and 2004, 0.23 to 0.27 lb N/tree were removed in harvested 'Newhall' fruit (Fig. 6) at yield-maximizing N rates (indicated by arrows on Fig. 6). During 2005, 0.42 lb N/tree were removed. The amounts of N removed in harvested fruit at the yield-maximizing N rates were equivalent to about 56% of the N applied for

'Newhall' during 2003 and 2004. During 2005, N removal at the yield-maximizing N rate was equivalent to 84% of the N applied. (Fig. 6). For 'Fukumoto', fruit harvest removed 0.27 lb N/tree at the yield-maximizing N rate during 2003 and 2004. This was equivalent to 50-60% of N applied. During 2005, there was no significant relationship between N rate and fruit N removal for 'Fukumoto'. The N removal by trees receiving N + P fertilizer was not significantly related to N rate.

Average total P removal in fruit accounted for 16% of P applied at the yield-maximizing N fertilizer rates in both varieties (data not shown). Lower P removal in fruit may be due to the low sink demand for absorbed P in the new organs (Mattos Jr. et. al., 2003). The lack of fruit response to fertilizer P confirmed that P application was not needed.

The results suggest that these trees were not under-fertilized with N, because the N recovery in the fruit was less than that applied in fertilizer. Revised N fertilization guidelines for microsprinkler-irrigated navel oranges are presented in Table 7. These results were derived from experiments conducted at the UA Citrus Agricultural Center since 1997 for these two varieties of navel oranges. The rates presented in this table are approximately 50% of the current recommendations (Doerge et al., 1991), and explicitly account for the higher N use efficiency possible with microsprinkler irrigation compared to flood irrigation. Tissue testing should be conducted annually to ensure adequate tree N status. These guidelines were developed for navel oranges, and should be applicable for other orange varieties. The indicated N rates should be increased by about 25% for microsprinkler-irrigated lemons. These guidelines should be applicable in situations where irrigation management is optimal and other factors (e.g. other nutrients, pests, salinity) are not limiting to tree growth.

Conclusions

The maximum predicted yields for both varieties during all three seasons occurred at N rates of 0.4 to 0.55 lb N/tree/yr. There were no significant effects of P application on yield. There were few significant effects of N or P fertilization on packout or fruit quality. The amounts of N removed in harvested fruit at the yield-maximizing N rates were equivalent to 50-84% of the N applied.

Microsprinkler-irrigated navel oranges 7 to 9 years after planting should be fertilized with 0.4 to 0.6 lb N/tree/ yr, if leaf N is >2.5%, and if yield is up to 8-10 tons/ac. Higher yields or lower leaf N indicates that higher rates of N fertilization may be needed. New N fertilizer recommendations for microsprinkler-irrigated navel oranges are proposed. We concluded from these experiments that P fertilization is not needed, if tree leaf P concentrations are >0.12%.

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Table 1. 'Newhall' fruit quality data for the December 2003 harvest.

N rate	P rate	Rind Thickness	Juice	Brix	TSS/TA
lb/tree/yr	lb/tree/yr	mm	%	%	
0	0	7.0	32.4	11.1	26.6
0	0.2	6.8	35.8	12.3	25.5
0.2	0	7.1	35.1	12.1	25.1
0.2	0.2	7.4	30.8	10.8	27.6
0.4	0	7.1	37.4	10.9	27.3
0.4	0.2	6.6	38.6	11.4	23.1
0.6	0	7.7	37.1	11.8	27.8
0.6	0.2	7.2	36.6	11.4	24.5
0.8	0	6.7	35.9	11.9	29.7
0.8	0.2	7.0	38.4	12.0	25.6

Table 2. 'Fukumoto' fruit quality data for the December 2003 harvest.

N rate	P rate	Rind Thickness	Juice	Brix	TSS/TA
lb/tree/yr	lb/tree/yr	mm	%	%	
0	0	5.9	40.0	12.7	25.1
0	0.2	6.3	39.6	11.8	25.3
0.2	0	6.1	41.4	11.6	25.5
0.2	0.2	6.3	38.1	11.3	23.3
0.4	0	5.9	40.0	12.0	26.6
0.4	0.2	5.9	40.6	12.2	25.4
0.6	0	6.4	40.3	12.3	26.4
0.6	0.2	5.8	41.9	11.5	23.7
0.8	0	6.0	36.8	11.6	22.1
0.8	0.2	6.2	41.0	11.9	24.9

Table 3. ‘Newhall’ fruit quality data for the December 2004 harvest.

N rate	P rate	Rind Thickness	Juice	Brix	TSS/TA
lb/tree/yr	lb/tree/yr	mm	%	%	
0	0	7.0	35.1	11.2	28.6
0	0.2	6.8	36.0	11.4	27.7
0.2	0	6.8	29.7	12.1	28.4
0.2	0.2	7.2	32.3	10.9	29.5
0.4	0	6.7	36.8	11.4	29.3
0.4	0.2	6.7	36.5	10.8	27.3
0.6	0	6.4	41.3	12.2	26.3
0.6	0.2	6.5	37.5	11.6	28.7
0.8	0	6.9	35.3	11.4	28.7
0.8	0.2	7.0	38.6	11.5	27.3

Table 4. ‘Fukumoto’ fruit quality data for the December 2004 harvest.

N rate	P rate	Rind Thickness	Juice	Brix	TSS/TA
lb/tree/yr	lb/tree/yr	mm	%	%	
0	0	6.7	35.3	11.5	27.3
0	0.2	6.5	37.9	11.1	27.2
0.2	0	7.1	34.5	11.3	27.3
0.2	0.2	5.2	37.7	11.1	25.7
0.4	0	6.5	39.0	11.5	24.3
0.4	0.2	6.0	42.9	11.8	26.7
0.6	0	6.7	32.1	11.6	26.9
0.6	0.2	6.5	37.7	11.2	26.4
0.8	0	6.1	39.1	10.7	25.3
0.8	0.2	6.6	37.5	11.2	24.8

Table 5. ‘Newhall’ fruit quality data for the December 2005 harvest.

N rate	P rate	Rind Thickness	Juice	Brix	TSS/TA
lb/tree/yr	lb/tree/yr	mm	%	%	
0	0	6.8	40.6	11.0	22.8
0	0.2	6.6	41.0	11.7	23.6
0.2	0	6.3	41.6	12.4	22.6
0.2	0.2	6.6	36.4	11.4	23.8
0.4	0	6.5	44.5	11.5	23.8
0.4	0.2	6.4	44.0	11.5	21.6
0.6	0	6.7	44.2	11.9	20.5
0.6	0.2	6.3	41.8	12.6	23.3
0.8	0	6.8	40.3	11.1	24.4
0.8	0.2	6.4	43.0	12.0	21.5

Table 6. ‘Fukumoto’ fruit quality data for the December 2005 harvest.

N rate	P rate	Rind Thickness	Juice	Brix	TSS/TA
lb/tree/yr	lb/tree/yr	mm	%	%	
0	0	6.1	43.8	11.4	22.5
0	0.2	6.2	45.4	11.4	22.5
0.2	0	5.9	44.8	11.6	22.9
0.2	0.2	6.1	43.6	11.2	21.0
0.4	0	6.0	45.6	11.2	21.7
0.4	0.2	6.2	43.6	11.2	21.3
0.6	0	6.1	43.8	11.5	21.5
0.6	0.2	5.9	45.0	11.5	21.6
0.8	0	6.1	43.8	11.3	21.1
0.8	0.2	5.8	43.8	11.2	23.3

Table 7. Proposed N fertilizer guidelines for microsprinkler-irrigated navel oranges.

Years After Planting	N rate to apply (lb N/tree/year)	
	Leaf N <2.8%	Leaf N >2.8%
0	0	0
1	0.2	0
2	0.2-0.3	0.2
3	0.2-0.3	0.2
4	0.3-0.4	0.2-0.3
5	0.3-0.4	0.2-0.3
	Leaf N <2.5%	Leaf N <2.5%
>6	0.6 - 0.8	0.4 - 0.6

Figure 1. Tensiometer readings during 2003 and 2004.

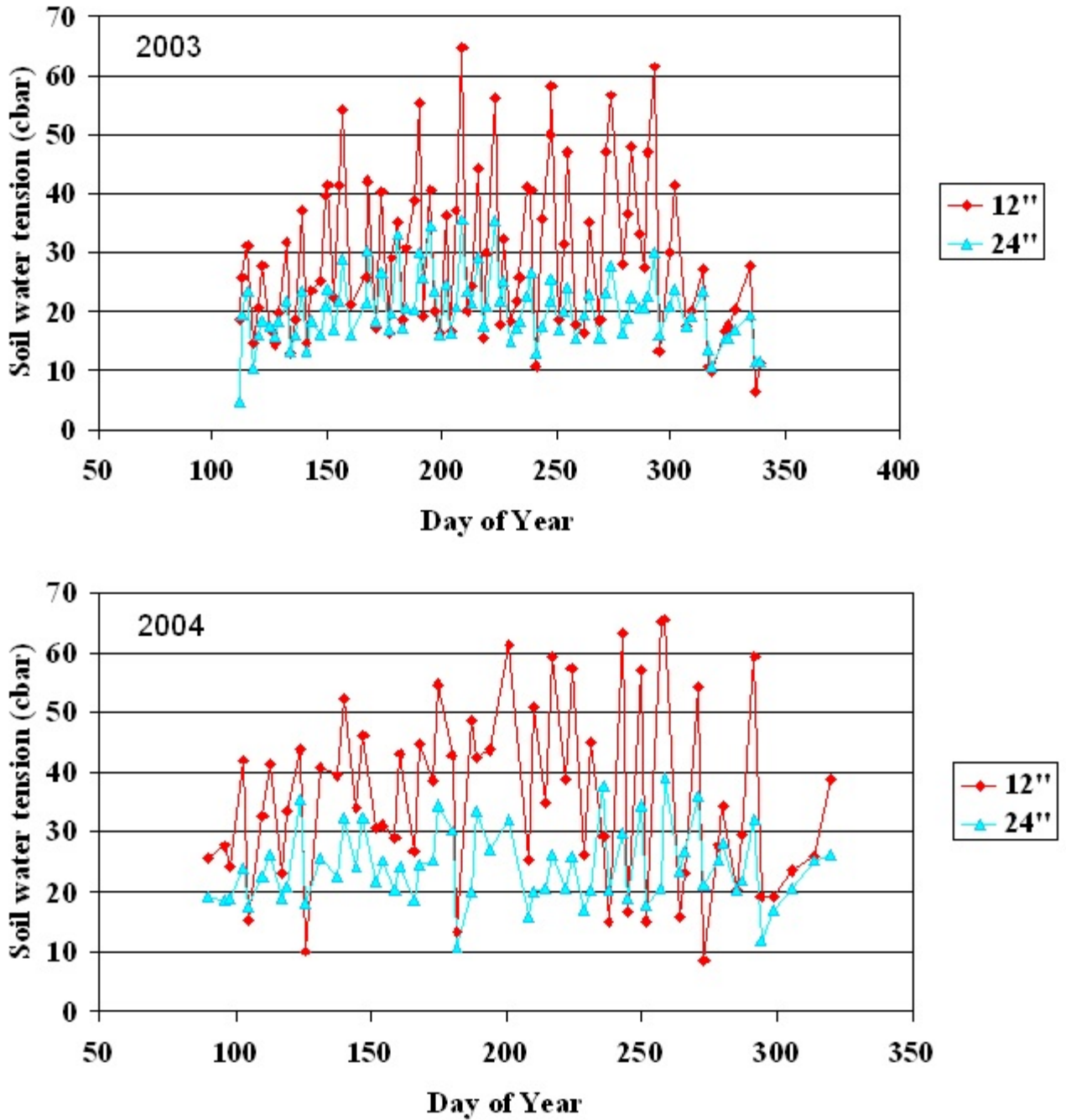


Figure 2. Yield response of 'Newhall' oranges to N fertilizer. Vertical arrows indicate N rate at the maximum predicted yield.

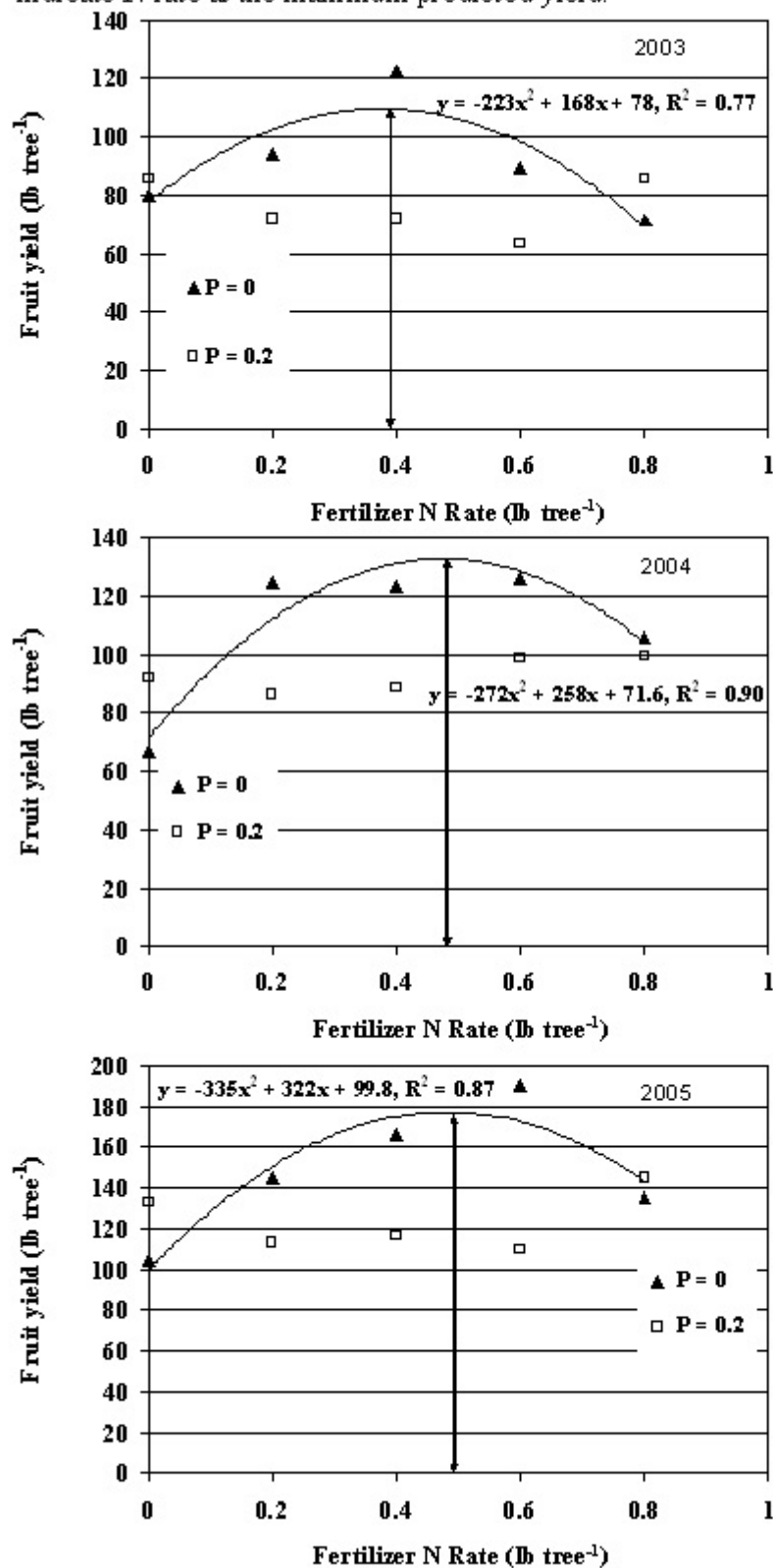


Figure 3. Yield response of 'Fukumoto' oranges to N fertilizer. Vertical arrows indicate N rate at the maximum predicted yield.

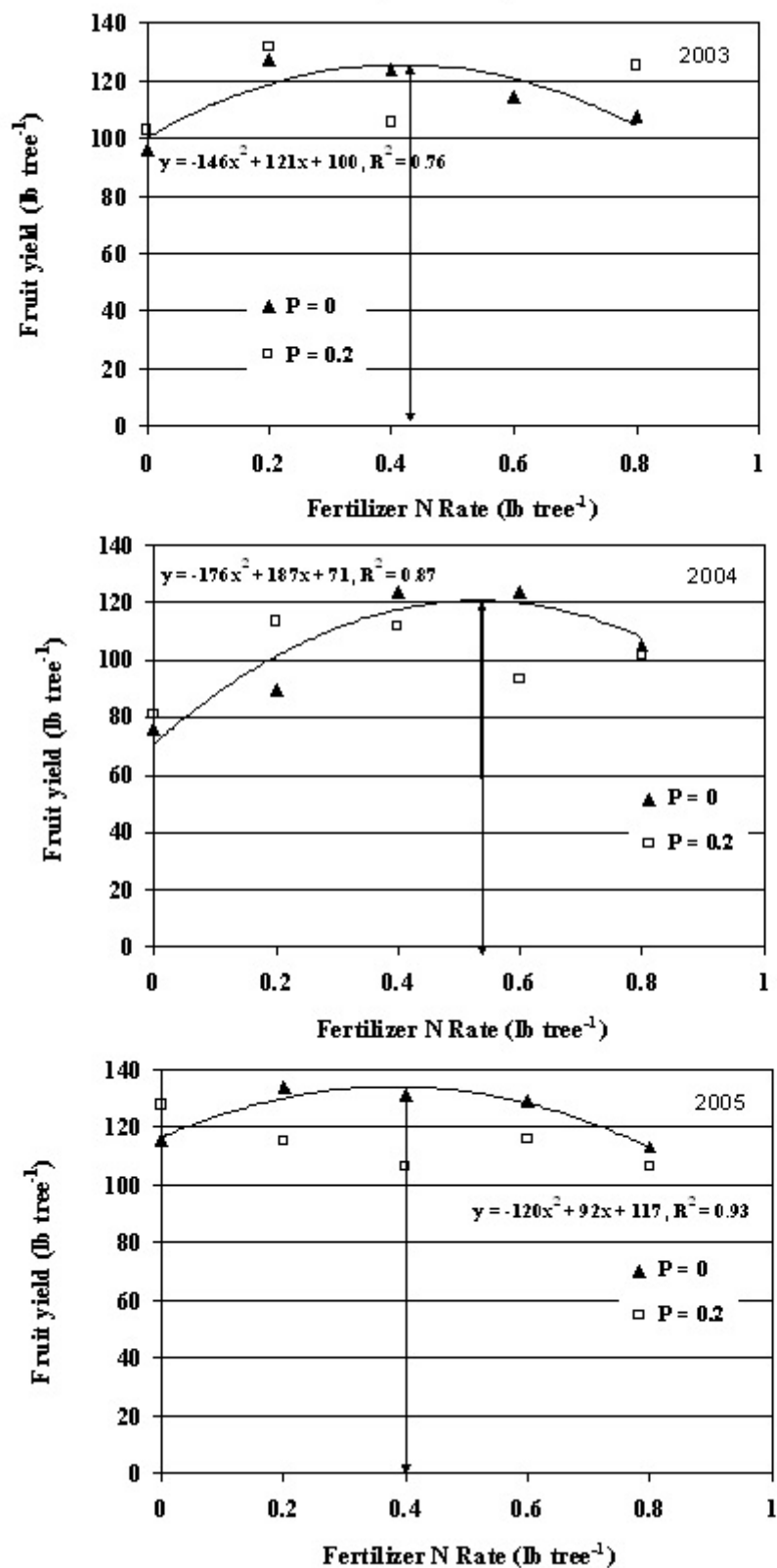


Figure 4. Leaf N concentrations of 'Newhall' oranges.

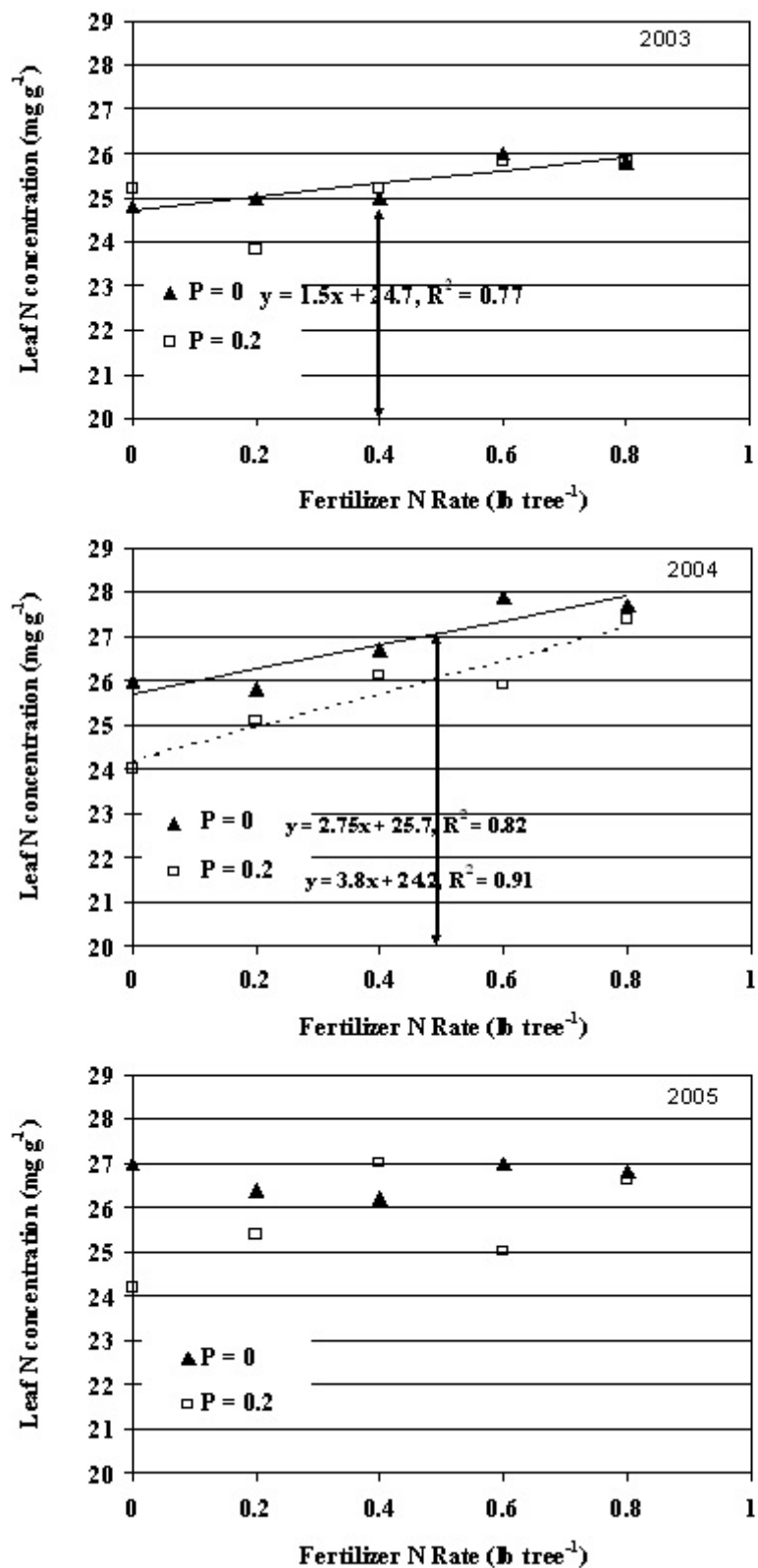


Figure 5. Leaf N concentrations of 'Fukumoto' oranges.

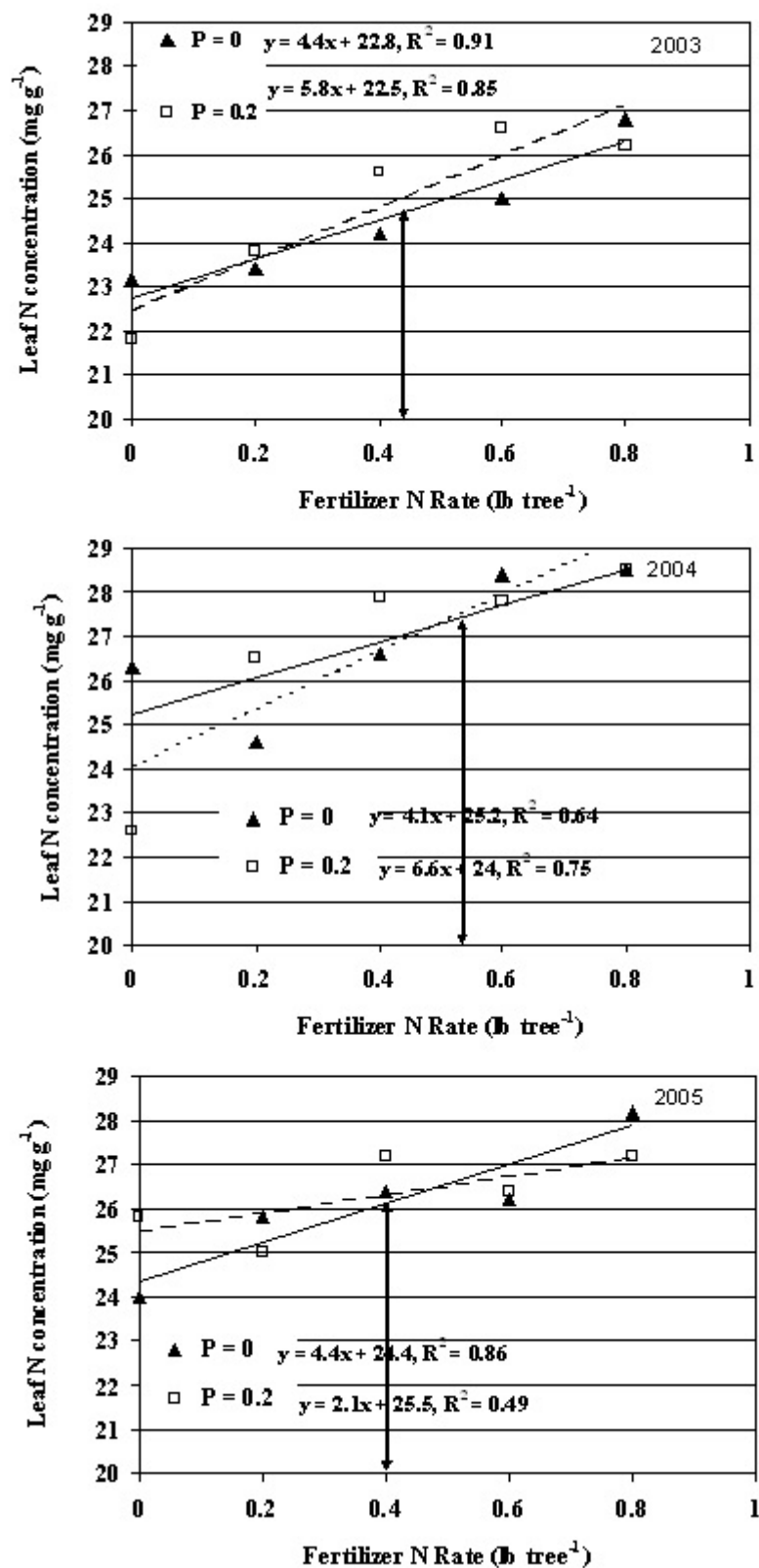


Figure 6. Nitrogen removal in fruit of 'Newhall' oranges. The vertical lines indicate N rate at the maximum predicted fruit yield.

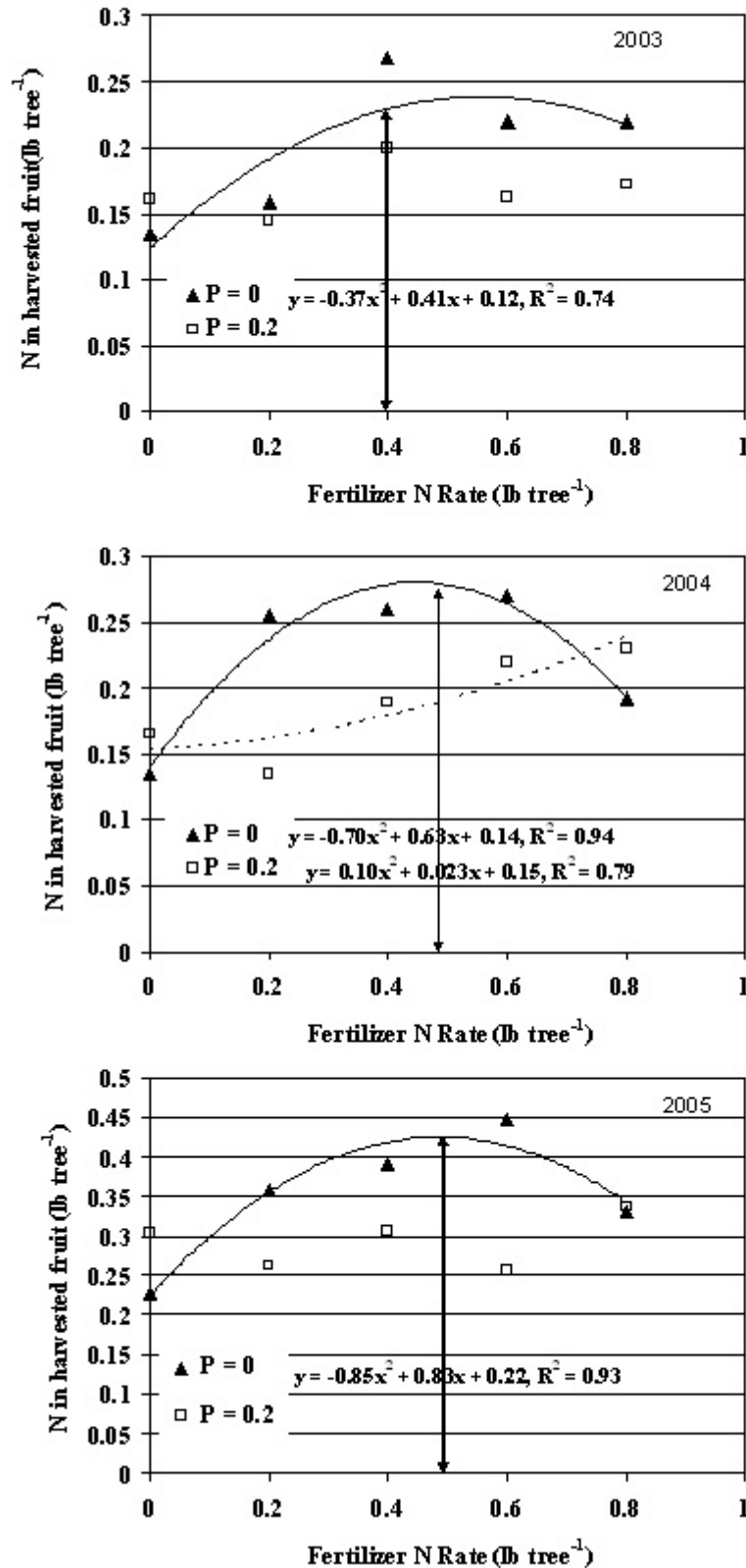


Figure 7. Nitrogen removal in fruit of 'Fukumoto' oranges. The vertical lines indicate N rate at the maximum predicted fruit yield.

