

# Residual Soil Nitrogen Evaluations In Irrigated Cotton, 2006

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## Abstract

Field experiments have been conducted for the past 19 seasons at three Arizona locations on University of Arizona Agricultural Centers (Maricopa, MAC; Marana, MAR; and Safford, SAC) aimed at investigating nitrogen (N) fertilizer management in irrigated cotton (*Gossypium* spp.) production. The MAC and SAC experiments have been conducted each season since 1989 and the Marana site was initiated in 1994. The original purposes of the experiments were to test N fertilization strategies and to validate and refine N fertilization recommendations for Upland (*G. hirsutum* L.) and American Pima (*G. barbadense* L.) cotton. The experiments have each utilized N management tools such as pre-season soil tests for  $\text{NO}_3^-$ -N, in-season plant tissue testing (petioles) for N fertility status, and crop monitoring to ascertain crop fruiting patterns and crop N needs. At each location, treatments ranged from a conservative to a more aggressive approach of N management. The integrity of the experimental sites at each location was maintained in each consecutive season. Results at each location revealed a strong relationship between the crop fruit retention levels and N needs for the crop. This pattern was further reflected in final yield analysis as a response to the N fertilization regimes used. The higher, more aggressive N application regimes did not consistently benefit yields at any location. Generally, the more conservative, feedback approach to N management provided optimum yields at all locations. In 2001, a transition project evaluating the residual N effects associated with each treatment regime was initiated and no fertilizer N was applied. From 2001 to 2005 the residual N studies were conducted at two of these locations (MAC and MAR). In 2006, the residual N study was conducted only at MAC (the University of Arizona ceased operations at MAR at the end of the 2005 season). Therefore, all N taken-up by the crop was assumed to be derived from residual soil N. However irrigation water analysis showed that  $\text{NO}_3^-$ -N concentration levels added to the crop ranged from about 5 to 15 ppm. In 2001- 2005 there were no significant differences among the original fertilizer N regimes in terms of residual soil  $\text{NO}_3^-$ -N concentrations, crop growth, development, lint yield, or fiber properties. In 2006 however, significant differences in lint yield among N fertilization regimes for the Maricopa location were found. This suggests a possible pattern associated with the residual fertilizer N effects in relation to the original treatments at the Maricopa site.

## Introduction

The nutrients that are the most susceptible to loss to the environment are those that are mobile in the soil such as nitrate-N ( $\text{NO}_3^-$ -N) and sulfate-S ( $\text{SO}_4^{2-}$ -S). Due to their mobility in the soil, these nutrients are subject to losses from the soil-plant system through leaching. Leaching of nutrients will occur under saturated soil conditions with water percolating downward through the soil profile. Therefore, nutrient and water interactions in the soil system are very important in this respect. Proper management of crop fertilization and soil-water relations are important in a rain-fed cropping system and even more critical with irrigated systems.

There are many possible fates associated with fertilizer N that is applied to a soil-plant system. Immobilization is an important process that can render the applied fertilizer N as “unavailable”, at least on a short-term basis. The N that is immobilized can also undergo mineralization transformations into compounds that are plant-available. However, the rate or degree of immobilization/mineralization is not fully understood. This is particularly true in desert, low organic matter soils that are common to the agricultural production areas of Arizona. Thus, the assessment of the residual effects of fertilizer N on crops such as cotton (*Gossypium* spp.) grown in subsequent seasons could be important to the development of optimal long-term N management.

Olson and Kurtz (1982) described plant use and efficiency of fertilizer N as a function of: 1) time of application, 2) rate of N applied, and 3) precipitation and climate-related variables. They also related maximum fertilizer N efficiency to

the latest application being compatible with the stage of crop development associated with maximum uptake. Therefore, information pertaining to crop N requirements (e.g. amount of N needed to produce a given unit of yield) and the uptake and utilization patterns for the crop in question are considered to be fundamental to developing N management strategies that optimize uptake and efficiency (Keeney, 1982). With respect to cotton fertilization, McConnell et al. (1996) and Boquet et al. (1991) found that a nutrient balance approach to N management provided the best results in terms of fertilizer N uptake and recovery in both irrigated and dry land conditions. They point out that over-fertilization of cotton with N can produce plants with excessive vegetative growth without gaining additional yield, in addition to providing a greater potential for loss of N to the environment beyond the soil-plant system.

Uptake and utilization of N by cotton has been described in a number of crop production environments and conditions (Bassett et al., 1970; Halevy, 1976; Mullins and Burmester, 1990; and Unruh and Silvertooth, 1996). Results from these and other studies have provided estimates of N utilization by cotton. Approximately 60 to 70 lbs. N (per acre) are commonly used as estimates for the production of one bale (480 lbs. lint) of both Upland (*G. hirsutum* L.) and American Pima (*G. barbadense* L.) cotton. Peak periods of uptake and utilization of N by a cotton crop commonly occur near the formation of the first pinhead square (PHS) and again near peak bloom (PB). Silvertooth et al. (1991a) found that the greatest potentials for losses of  $\text{NO}_3^-$ -N in an irrigated cotton production system in Arizona occurred with pre-plant applications of fertilizer N and with those occurring late in the season after PB (Silvertooth et al., 1991b). These results were further corroborated in subsequent studies in Arizona (Navarro et al., 1997 and Norton and Silvertooth, 1998) that also demonstrated greater levels of N use efficiency with split applications. Work in several parts of the U.S. cottonbelt with long-term N management studies have also demonstrated the value of split applications of fertilizer N in-season for optimizing cotton fertilization (Maples et al., 1990; McCarty and Funderburg, 1990; Robinson, 1990; Tracy, 1990; Silvertooth et al. 1990-1995; Silvertooth and Norton 1996 and 1997; Silvertooth and Norton, 1998a; Silvertooth and Norton, 1998b; Silvertooth and Norton, 1999; Silvertooth and Norton, 2000; and Silvertooth et al., 2001 and 2002). Therefore, N fertilizer management recommendations for cotton commonly include the utilization of split applications of fertilizer N in-season.

In an effort to evaluate the relative efficiencies of fertilizer N applications at several stages of growth, Silvertooth et al. (1997 and 1998) provided applications of fertilizer N labeled with  $^{15}\text{N}$  to cotton in irrigated cotton production systems in Arizona. Applications of labeled fertilizer N were made as side-dressing at three stages of growth, namely at PHS, early bloom (EB), and PB at a constant rate of (50 lbs. N/acre). Rates of total N uptake and percent  $^{15}\text{N}$  recovery did not differ significantly for the N fertilizations made among these three stages of growth. These results support recommendations to split applications of fertilizer N between PHS and PB to realize optimum efficiencies in cotton production systems. From these studies approximately 80% of the applied fertilizer N was accounted for in either aboveground plant parts or in the soil (measured as total N) to a depth of 180 cm. This level of fertilizer N recovery is very high in relation to common levels measured in other crops (Raun and Johnson, 1999). The relatively high rates of fertilizer N recovery experienced in these experiments is ostensibly due to the application of the fertilizer N in close relation to the period of peak uptake and demand by the crop. Of the total fertilizer N recovered, the plant took up approximately 40%, and the remaining 60% was found in the soil in the Arizona studies. Over 90% of the fertilizer N recovered in the soil was found in the top 30 cm. Even though organic matter levels are low (<1.0 %) this would indicate a considerable degree of interaction with organic N fractions and significant immobilization.

The N management experiments in Arizona have also provided a comparison of scheduled versus feedback management strategies and a wide range of rates applied in-season (Silvertooth et al., 1990-1995; Silvertooth and Norton, 1996 and 1997; Silvertooth and Norton, 1998a; Silvertooth and Norton, 1998b; Silvertooth and Norton, 1999; Silvertooth and Norton, 2000; Silvertooth et al. 2001, 2002, and 2003). A point revealed by these studies over 14 seasons is related to the apparent N mineralization in desert soils with < 1% organic matter. Thus, the dynamics associated with residual N effects and the mineralization-immobilization processes are important to understand. At present, there is very little information available in relation to residual N effects and subsequent mineralization potentials.

Current N management recommendations in many cotton-producing regions (McConnell et al., 1996; Silvertooth and Doerge, 1990; and Silvertooth and Norton, 1998c) include the use of split applications of fertilizer N. In Arizona, fertilizer N applications are recommended between PHS and PB (referred to as the "N application window") in relation to crop condition (fruit retention, vigor, and N fertility status) and previous amounts of fertilizer N applied (in-season). Utilizing stage of growth and crop condition in N fertilization is an important application of the crop monitoring systems that are being developed in many cotton producing regions (Bourland et al., 1992; Kerby et al., 1997; and Silvertooth and Norton, 1998c). The accuracy of these crop monitoring systems in relation to stage of growth and

management practices such as N fertilization, are improved markedly in many cases with the use of heat unit (HU) systems to predict crop phenology (Brown, 1989).

A better understanding of residual N and mineralization potentials would also benefit fertilization management and improved efficiencies for many crops, including cotton (Raun et al., 1998). Broadbent and Norman (1946) concluded that crop recovery of residual N by two to three crops following the initial fertilizer application was primarily derived from three pools: 1) protein from oat (*Avena sativa* L.) straw (crop residuals), 2) added  $\text{Ca}(\text{NO}_3)_2$  (fertilizer N additions), and 3) soil organic matter. They also found the rate of decomposition of the soil organic matter to be a function of the amount of energy sources (crop residues) added to the soil, and the amount of N released to be heavily dependent upon the N content of the organic material or residues added. Westerman and Kurtz (1972) found that 22 to 26% of the initial fertilizer N applied to sorghum-sudan grass (*Sorghum sudanense*) was present as residual soil N after two cropping seasons. Nitrogen fertilization history influences soil N availability (McCracken et al., 1989). However, this is very difficult to assess or predict. Azam et al. (1993) compared the mineralization of N from several  $^{15}\text{N}$  labeled crop residues and found proportions decreasing in accordance to their total N content. In a winter wheat (*Triticum aestivum* L.) system Bhogal et al. (1997) found that 60-77% of the  $^{15}\text{N}$  labeled fertilizer N had been recovered within two seasons following application. Levels of residual fertilizer N increased with increasing rates of application in the initial season, particularly with large N applications ( $> 175$  kg N/ha). A number of approaches have been taken in an effort to develop a measurement or index of residual soil N effects on crop growth. McCracken et al. (1989) conducted a study that examined the ability of selected soil indices to detect management-induced differences in soil N availability including: anaerobic incubation, total soil C, total kjeldahl N (TKN), and soil  $\text{NO}_3^-$ -N. From this single site-year study they found the best correlation between soil  $\text{NO}_3^-$ -N (KCl extractable) concentration with corn (*Zea mays* L.) yield and N uptake. Gomah and Amer (1981) conducted a study to evaluate the residual effects of N fertilizer to a cotton crop on a subsequent wheat crop. They found that the residual effect on the wheat crop was due more to the mineralizable N than to residual  $\text{NO}_3^-$ -N measured in the soil prior to planting the wheat crop. This relates to the complications with attempts to use residual soil  $\text{NO}_3^-$ -N as an indicator of fertilizer N carryover for a corn production system in the humid Midwest of the US (Vanotti and Bundy, 1994).

The objective of the present study is to examine the effects of fertilization history on residual N availability for irrigated cotton in Arizona.

## Materials and Methods

The residual N experiments were conducted from 2001-2006 on existing N management sites on University of Arizona Agricultural Centers at Maricopa (MAC), and Marana (MAR). These experiments are part of a long-term project addressing N management in irrigated cotton production systems. The integrity of each experimental site in this project was maintained (plots were maintained in the exact same locations each season). The soil at MAR is a Pima clay loam (fine-silty, mixed (calcareous), thermic Torrifuvent) and at MAC a Casa Grande sandy loam (Fine-loamy, mixed, hypothermic Typic Natrigid). Upland cotton was planted at each location each year. The experimental design at each location was a randomized complete block (RCB) with four replications with the four basic treatments. Plots were eight; 40 inches rows wide and extend the full length of the irrigation run (~600 ft.). Each plot (treatment by replicate combination) has been and will continue to be maintained in the exact same location each season. Table 1 identifies the N treatments that had been employed for each site-year prior to the residual N experiment (long term N experiments). The actual rate of fertilizer N applied was dependent upon the growing conditions of a given location and season. However, N rates generally ranged from 0 (check plots) to  $336$  kg N ha<sup>-1</sup>. Therefore, a broad range of N fertilizer rates were used each site-year. Examples of common rates and methods associated with this type of experimental approach can be found in a number of recent reports (Navarro et al., 1997 and Silvertooth and Norton, 1998a, 1999, 2000; and Silvertooth et al., 2001, 2002, and 2003). The summaries of planting and initial wet dates for both locations are outlined in Table 2. During each season, all pest control and irrigation management practices were carried out on optimum and an as-needed basis at each location.

Soil samples were collected pre-season to a depth of four feet at both locations, to which soil nitrate-N analyses were performed (Table 3, Figure 1). Basic plant measurements were carried out within each plot on approximately 14-day intervals for the entire season. These measurements included plant heights, number of mainstem nodes per plant, flower numbers per 167 ft.<sup>2</sup> area, and the number of nodes above the top white flower to the terminal (NAWF). These plant mapping measurements were performed on each distinct treatment. Results from the plant mapping provide information concerning the percent total fruit retention (sum of positions one and two on each fruiting branch) for each treatment, a record of the general vegetative/reproductive balance maintained by the various treatments over time, and maturity progress. Water samples were collected during the irrigation events to determine the amount of N being added

to the crop via irrigation water.

At the end of each season, dry matter production estimates were made. Lint yields were also obtained for each treatment by harvesting the entire center four rows of each plot with a two row mechanical picker. Seedcotton subsamples were collected for ginning, from which lint turnout estimates were made. These subsamples were then sent to the USDA Cotton Classing office in Phoenix, AZ for HVI (High Volume Instrument) analysis for a complete fiber quality evaluation. Results were analyzed statistically in accordance to procedures outlined by Steel and Torrie (1980) and the SAS Institute (SAS, 1990). An analysis of variance was performed for each location to determine differences among the N treatments for all dependent variables (lint yield, fiber micronaire, etc.).

## Results

Fruit retention (FR) and height to node ratio (HNR) results are presented for both locations and treatments in Figures 3a-4. Lint yield results are presented in Tables 4 and 5 and Figures 5 and 6.

The crop growth and development data revealed relatively strong FR levels at each location through the 2006 season (Figures 3a-4). The FR levels reflect the demand (sink) for available N. Higher FR levels indicate stronger N sink demand. The HNR is used as a vigor index. Under N deficiency conditions it would be expected to experience low crop vigor (HNR levels below the middle baseline). This was consistently the case either at Marana from 2001-2005 or Maricopa 2001-2006. Plant symptoms consistent with N deficiency were visually noted at both locations with slight discoloration of the foliage.

In 2006 at MAC, the HNR data (Figure 3b) revealed that plants were somewhat shorter and stunted than normal, particularly at the beginning of the growing season at each location. Similarly, the FR levels were below the baselines indicating a relatively poor fruit load. Plants in these residual experiments consequently produced fewer nodes, fruiting branches, and fruiting sites. This was expressed through the HNR data shown in Figure 3b.

During the 2001-2006 seasons, there were no significant differences among any of the original N fertilization regimes at any location in terms of residual  $\text{NO}_3^-$ -N (Table 3; Figures 1 and 2), crop growth and development patterns (HNR, FR, NAWF, etc. – Figures 2 and 3a, 3b and 4), lint yield, and fiber properties (Tables 4 and 5; Figures 5 and 6). In 2006 however, significant differences in lint yield among N fertilization regimes for Maricopa location were found (Table 4; Figure 5). The pre-season soil sample data revealed varied concentration levels of  $\text{NO}_3^-$ -N over the experimental period (Table 3; Figures 1 and 2). Lint yield averages and the respective estimates of N uptake by the crops (in accordance to values outlined in Unruh and Silvertooth, 1996) are presented in Table 6. In 2005 and 2006, irrigation water samples collected from each site were analyzed for  $\text{NO}_3^-$ -N (Table 7) and results revealed that contributions to the crop were significant. The  $\text{NO}_3^-$ -N contained in the irrigation water averaged 7 ppm for both years, contributing about 10 lbs.  $\text{NO}_3^-$ -N/acre/irrigation. The contributions of plant available N from the irrigation water over the 2006 season totaled 77 lbs.  $\text{NO}_3^-$ -N/acre. Considering the fact that zero fertilizer N was applied, and the irrigation water contributed approximately 77 lbs. N/acre, the remaining N taken-up by the crop was residual N. Based on the N uptake and yield relationships established by Unruh and Silvertooth (1996), most of the lint yield was supported by the N in the irrigation water. Based on the yield results and the pre-season  $\text{NO}_3^-$ -N concentrations in the soil, less than one half of the total N taken-up by the crop at MAC in 2006 was derived from soil N mineralization (approximately 52 lbs. N/acre). Therefore, based on the pattern of results during the residual study (2001-2006), the residual N has been substantially reduced after six seasons.

Over the course of the residual study, average crop yields have progressively dropped below the levels of that were common when the fertilizer N treatments were being applied to these experimental sites. Thus, the residual N that was provided each season due to apparent mineralization supported reasonable lint yields at both locations (Table 6 and 7). These experiments reveal a rather strong capacity for these desert soils to maintain significant residual N levels for several seasons following fertilization. This also reinforces the need to develop better indices for measuring and predicting residual soil N that can be made available through mineralization during the course of a growing season and the importance of developing an accurate N balance for the optimizing fertilizer N efficiency in a soil-plant system.

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Table 1. Nitrogen fertilization treatments at the Maricopa and Marana, Agricultural Centers, 1989-2000. \*

N Treatment Number	Fertilizer N Management
1	Check (No fertilizer N)
2	Standard: Preplant & Side-dress
3	Feedback approach from soil and petiole NO <sub>3</sub> <sup>-</sup> -N analysis, 1X rate
4	2X rate from soil and petiole NO <sub>3</sub> <sup>-</sup> -N feedback

\* The Marana location was initiated in 1994; No N application since 2000 for both locations.

Table 2. Summary of agronomic information for Maricopa and Marana, Agricultural Centers, 2000-2006<sup>11</sup>.

Location / Year	Planting date	Wet Date	Final Irrigation Date	Harvest Date	Variety Planted
<b>Maricopa</b>					
2000	5 April	5 April	4 August	18 October	DP33B
2001	13 April	16 April	15 August	26 September	DP458BR
2002	2 April	3 April	17 August	24 October	DP458BR
2003	2 April	7 April	15 August	23 October	DP449BR
2004	14 April	14 April	5 August	7 October	DP449BR
2005	4 April	6 April	11 August	4 October	DP449BR
2006	6 April	11 April	24 July	21 September	DP449BR
<b>*Marana</b>					
2000	5 April		9 August	4 October	DP33B
2001	2 May		29 August	16 October	DP422BR
2002	11 April		14 August	14 October	DP422BR
2003	11 April		16 August	13 October	DP422BR
2004	22 April		9 August	30 September	DP451BR
2005	15 April		1 August	3 October	DP451BR

\*Cotton was planted into moisture at this location.

<sup>11</sup> Maricopa was the only site planted in 2006.

Table 3. Preseason soil nitrate-N concentration for Maricopa and Marana, Agricultural Centers at 1 and 2 feet depths, 2000-2006.

Location / Treatment	Depth (feet)	Nitrate-N Concentration (ppm)						
		2000	2001	2002	2003	2004	2005	2006
<b>Maricopa</b>	1	4.7	8.3	8.0	3.2	10.0	18.0	2.1
		3.8	2.2	4.1	2.1	9.4	15.0	1.0
	2	7.9	18.0	4.6	1.5	11.0	19.0	16
		5.2	3.8	3.9	4.0	11.0	18.0	15
	3	5.3	11.0	5.6	4.0	11.0	17.0	13
		3.5	1.9	4.7	4.0	10.0	18.0	12
	4	7.7	14.0	2.9	2.8	11.0	19.0	33
		5.3	1.8	5.5	0.9	4.7	14.0	31
<b>Marana</b>	1	2.8	8.0	4.2	0.9	9.2	13.0	-----
		1.9	3.0	3.9	4.0	9.0	13.0	-----
	2	7.1	20.0	3.0	2.0	8.2	19.0	-----
		6.2	15.0	1.9	4.0	7.9	19.0	-----
	3	4.6	23.0	3.8	3.7	7.2	18.0	-----
		4.7	10.0	2.7	4.0	12.0	11.0	-----
	4	4.7	25.0	4.1	4.0	11.0	16.0	-----
		3.0	24.0	3.5	4.0	7.7	17.0	-----



Table 4. Lint yields (lbs. lint/acre) from Maricopa residual N evaluation studies, 2000-2006.

Treatment	2000§		2001		2002		2003		2004		2005		2006	
	Maricopa Ag. Center													
	Lint Yield	Mic *	Lint Yield	Mic	Lint Yield	Mic	Lint Yield	Mic	Lint Yield¶	Mic	Lint Yield	Mic	Lint Yield	Mic
1	1542 bc	4.6	1534	5.4	1482	5.4	1357	5.4	810	4.8	1277	5.4	938 b	5.3
2	1518 c	4.5	1541	5.5	1480	5.3	1284	5.5	815	4.8	1303	5.3	915 b	5.3
3	1608 a	4.6	1557	5.4	1487	5.6	1342	5.6	836	4.8	1341	5.2	1024 a	5.3
4	1588 ab	5.1	1570	5.3	1444	5.4	1304	5.5	850	4.8	1390	5.3	976 ab	5.2
OSL <sub>0.05</sub>	0.0091		0.863		0.7430		0.0940		0.4887		0.1643		0.0213	
CV(%)	1.96		4.25		4.10		3.00		4.7		5.1		4.3	
LSD <sub>0.05</sub>	49		NS		NS		NS		NS		NS		65.6	

§The last fertilizer applications of any kind were made during the 2000 production season.

¶Visual sign of monsoon storm damage was apparent on the crop and must have significantly reduced lint yield.

\* Mic = Micronaire.

Table 5. Lint yields (lbs. lint/acre) from Marana residual N evaluation studies, 2000-2005.

Treatment	2000§		2001		2002		2003		2004		2005	
	Marana Ag. Center											
	Lint Yield	Mic	Lint Yield	Mic	Lint Yield	Mic	Lint Yield	Mic	Lint Yield	Mic	Lint Yield	Mic
1	1213 c	-	1103	47	1037	49	1234	53	1091	50	1056	49
2	1278 b	-	1053	44	1047	47	1261	52	1078	50	1090	51
3	1299 ab	-	1085	46	1069	47	1213	51	1110	50	1005	51
4	1319 a	-	1079	47	1085	47	1241	52	1023	50	1005	51
OSL <sub>0.05</sub>	0.0007		0.2360		0.3270		0.2680		0.3471		0.6947	
CV(%)	1.82		2.95		3.57		2.52		6.2		11.4	
LSD <sub>0.05</sub>	37		NS		NS		NS		NS		NS	

§The last fertilizer applications of any kind were made during the 2000 production season.

\* Mic = Micronaire.

Table 6. Average lint yields (lbs. lint/acre) and estimated N uptake (lbs. N/acre) from Maricopa and Marana residual N evaluation studies, 2000-2006.

Year	Maricopa		Marana	
	Average Lint Yield	*Estimated N Uptake	Average Lint Yield	Estimated N Uptake
2000	1564	212	1277	173
2001	1551	210	1080	146
2002	1473	199	1060	143
2003	1322	179	1237	167
2004	828	112	1076	146
2005	1328	180	1040	141
2006	963	129	-----	-----

\*Estimated N uptake determined using values established by Unruh and Silvertooth, 1996.

Table 7. NO<sub>3</sub>-N content in irrigation water (ppm and lb/acre) from Maricopa and Marana residual N evaluation studies, 2005-2006.

Year	Maricopa			Marana	
	Sampling date	NO <sub>3</sub> -N (ppm)	NO <sub>3</sub> -N (lb/acre)	NO <sub>3</sub> -N (ppm)	NO <sub>3</sub> -N (lb/acre)
2005*	7/1/05	1.0	1.4	7.9	10.7
	7/15/05	1.0	1.4	9.8	13.3
	8/1/05	9.4	12.7	9.9	13.4
<b>Average</b>		<b>3.8</b>	<b>5.2</b>	<b>9.2</b>	<b>12.5</b>
2006	4/20/06	15.5	21.0	-----	-----
	5/26/06	8.2	11.1	-----	-----
	6/9/06	1.1	1.5	-----	-----
	6/23/06	0.6	0.8	-----	-----
	7/5/06	12.9	17.4	-----	-----
	7/15/06	13.1	17.7	-----	-----
	7/24/06	5.2	7.1	-----	-----
<b>Average</b>		<b>8.1</b>	<b>10.9</b>	-----	-----

\*Only the last three irrigation dates were sampled.

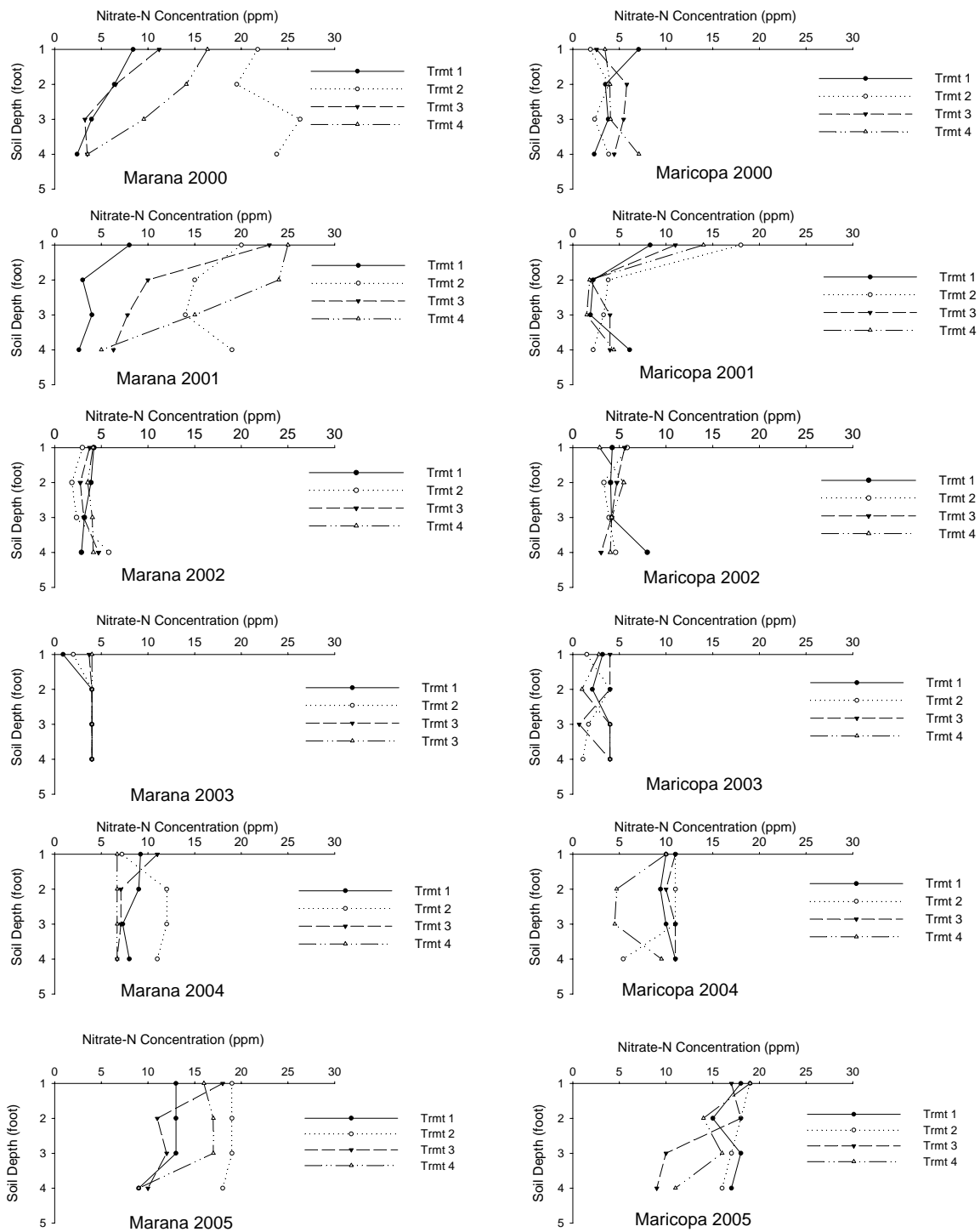


Fig. 1. Preseason nitrate-N concentration for each treatment at four depths (1-4 feet) for Marana and Maricopa Ag. Centers, 2000-2005.

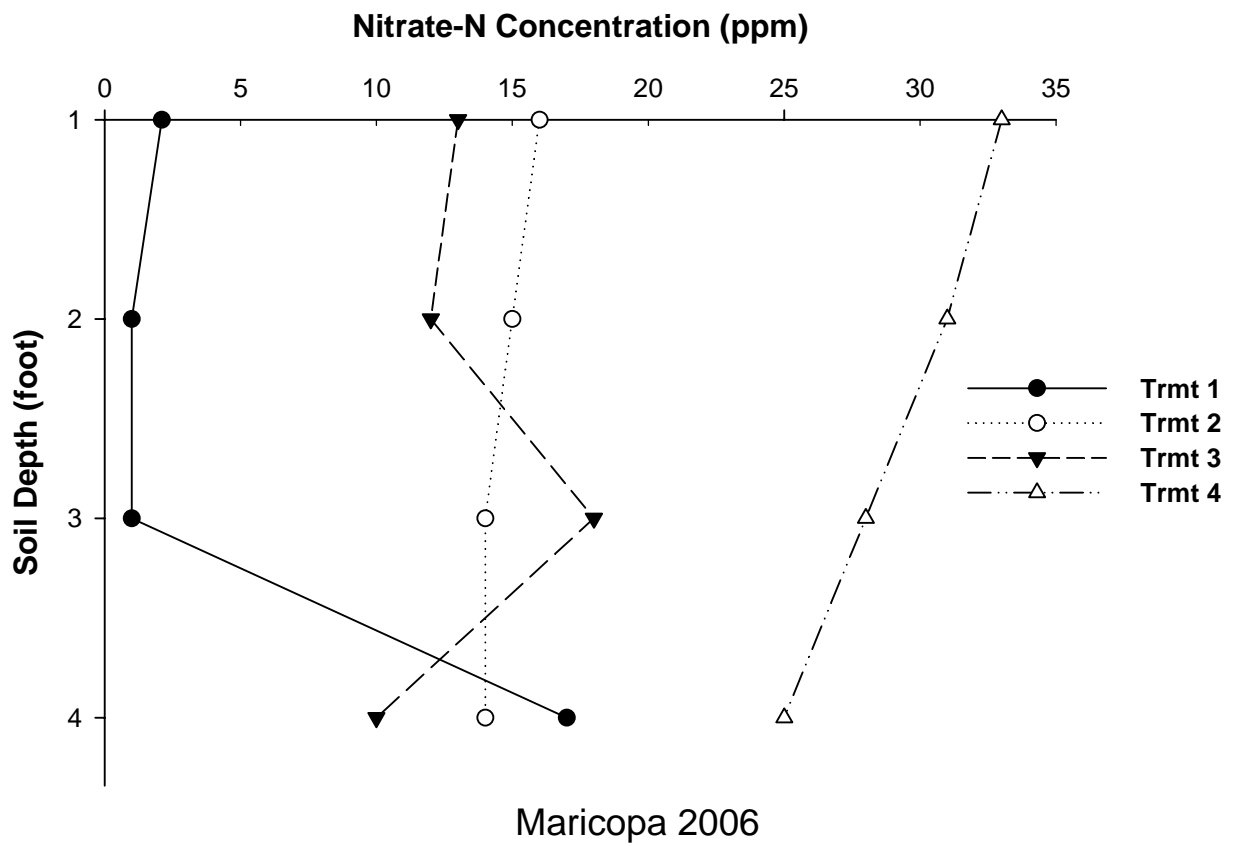
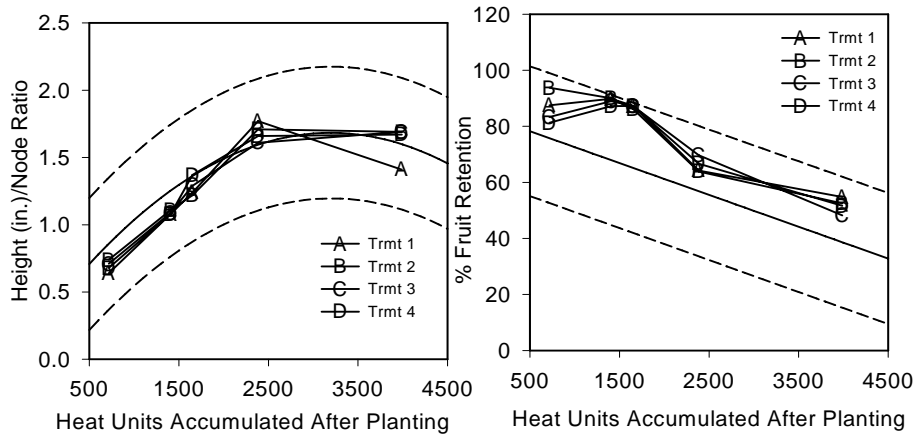
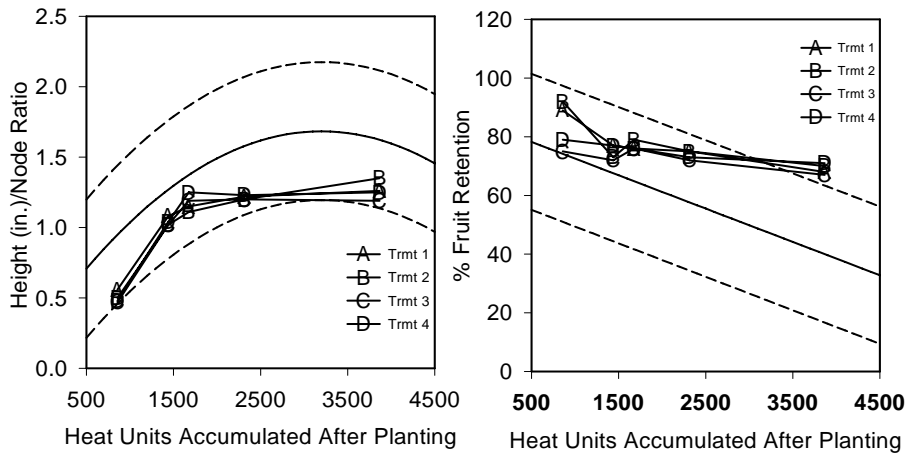


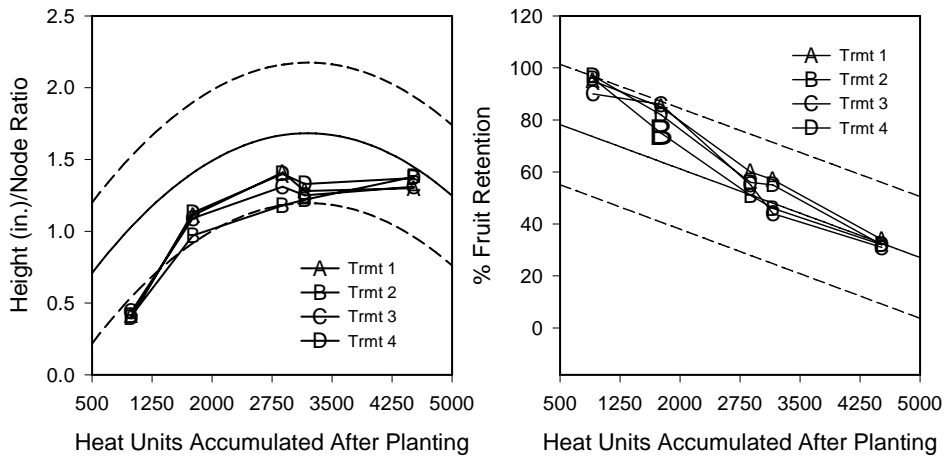
Fig. 2. Preseason nitrate-N concentration for each treatment at four depths (1-4 feet) for Maricopa Ag. Center, 2006



**2001**

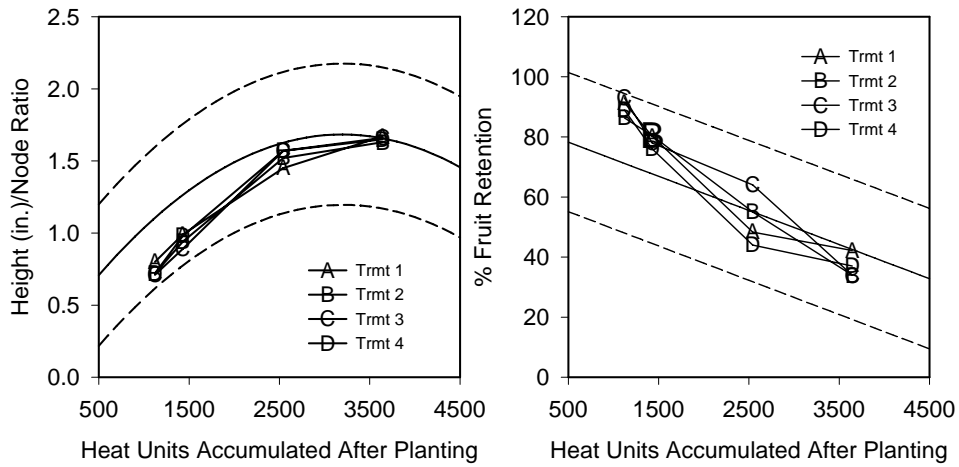


**2002**

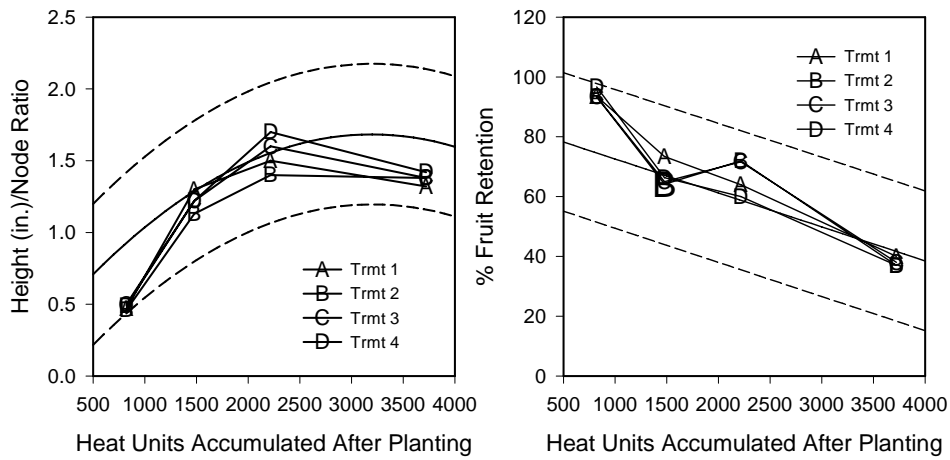


**2003**

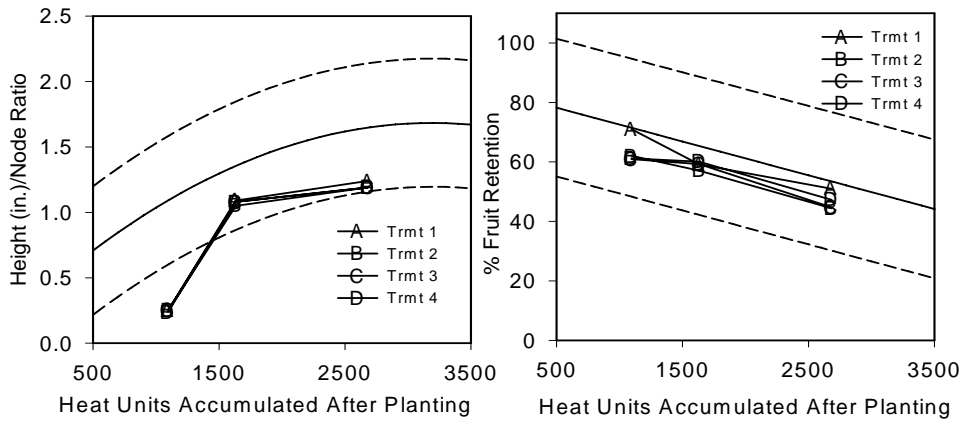
Fig. 3a. Height to node ratio and fruit retention levels for N-management study, Maricopa, 2001-2003.



2004

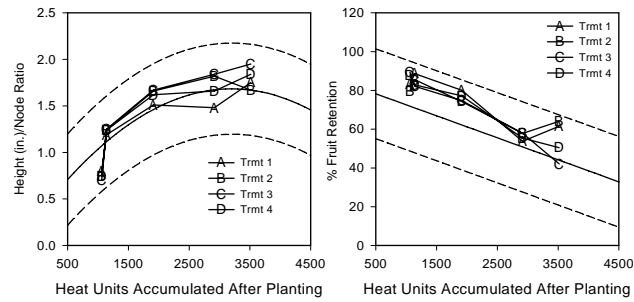


2005

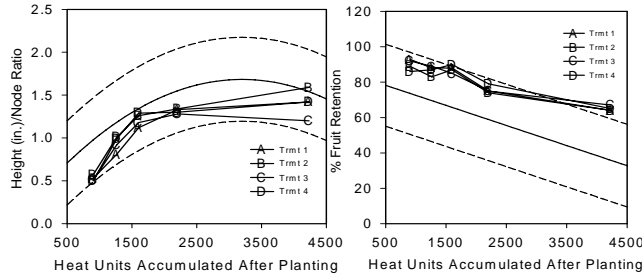


2006

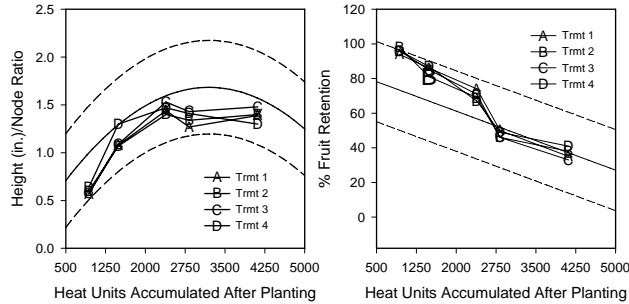
Fig. 3b. Height to node ratio and fruit retention levels for N-management study, Maricopa, 2004-2006.



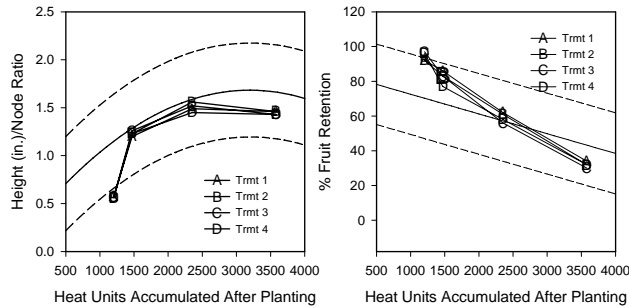
2001



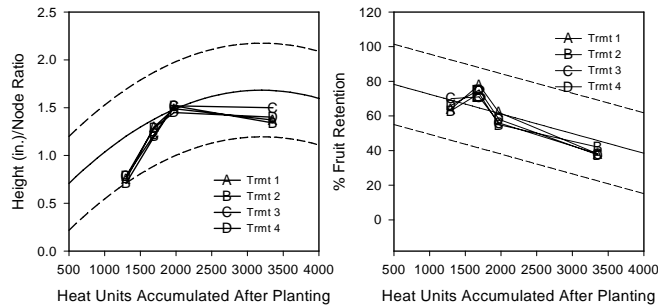
2002



2003



2004



2005

Fig. 4. Height to node ratios and fruit retention levels for N-management study, Marana, 2001-2005.

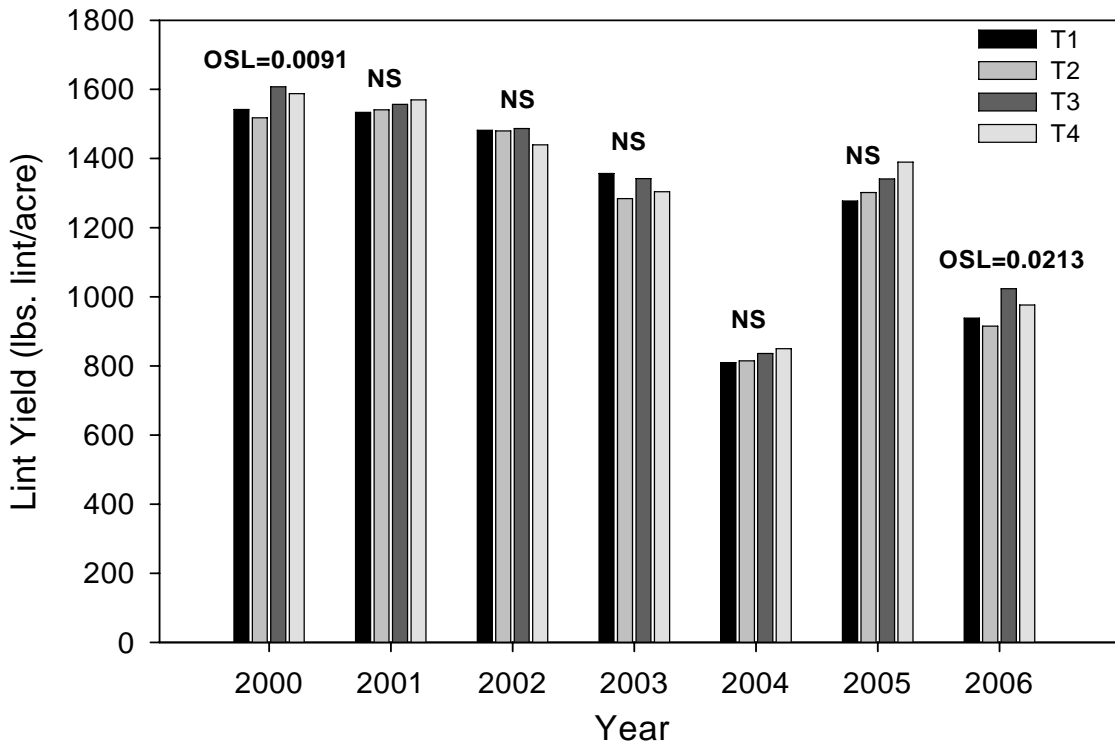


Fig. 5. Yield trend for all treatments, Maricopa Ag. Center, 2000-2006.

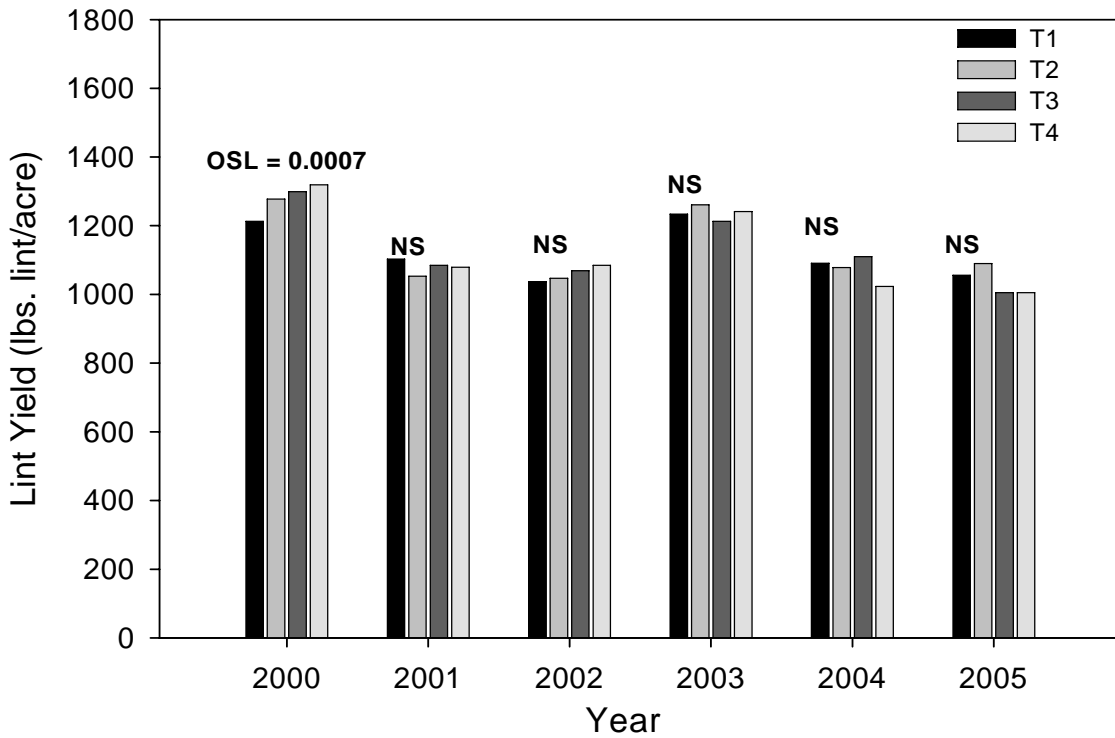


Fig. 6. Yield trend for all treatments, Marana Ag. Center, 2000-2005.