Residual Soil Nitrogen Evaluations In Irrigated Desert Soils, 2002

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Abstract

Field experiments investigating N fertilizer management in irrigated cotton production have been conducted for the past 15 seasons at three Arizona locations on University of Arizona Agricultural Centers (Maricopa, MAC; Marana, MAR; and Safford, SAC). In 2002, residual N studies were conducted at two of these locations (MAC and MAR). 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 nitrogen (N) fertilization strategies and to validate and refine N fertilization recommendations for Upland (Gossypium hirsutum L.) and American Pima (G. barbadense L.) cotton. The experiments have each utilized N management tools such as pre-season soil tests for 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 varied from a conservative to a more aggressive approach of N management. 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. Therefore, all N taken-up by the crop was derived from residual soil N. In 2001, there were no significant differences among the original fertilizer N regimes in terms of residual soil* NO_3^- *-N concentrations, crop growth, development, lint yield, or fiber properties. The lint yields were very uniform at each location and averaged 1500, 1100, and 850 lbs. lint/acre for MAC, MAR, and SAC, respectively. In 2002, results were very similar at the MAC and MAR locations. Trends associated with residual fertilizer N effects are not evident at either location just two seasons following N fertilizer applications.*

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 (NO_3^- -N) and sulfate-S (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.

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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 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}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}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 and 2002). 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 straw, 2) added $Ca(NO_3)_2$, 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}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}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 NO_3^- -N. From this single site-year study they found the best correlation between soil 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 NO_3^- -N measured in the soil prior to planting the wheat crop. This also complicated attempts to use residual soil 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

Each 2002 experiment was conducted using existing N management sites on University of Arizona Agricultural Centers at Maricopa (MAC), Marana (MAR). These experiments are part of a long-term project addressing N management in irrigated cotton production systems. The soil at Marana is a Pima clay loam and at MAC a Casa Grande sandy loam. Upland cotton was planted at each location. The experimental design at each location was a randomized complete block (RCB) with four replications with the four basic treatments. Plots were eight, 40 inch 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 have been employed for each site-year. The actual rate of fertilizer N applied is dependent upon the growing conditions of a given location and season. However, N rates have generally ranged from 0 to 336 kg N ha^{-1}. Therefore, a broad range of N fertilizer rates have been 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 and 2002).

In 2002, Upland cotton (var. DP 458BR) was dry-planted and watered-up on a Casa Grande sandy loam on 3 April at MAC. At MAR, Upland cotton (var. DP 422BR), was dry-planted and watered-up on 11 April on a Pima clay loam soil. All pest control and irrigation management practices were carried out on optimum, an as-needed basis at each location.

Soil samples were collected preseason to a depth of two feet at both locations, to which soil nitrate-N analyses were performed (Table 2, 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 $ft.^2$ 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.

Final irrigations and harvest dates were 17 August, 24 October at MAC; 14 August and 14 October at MAR. Lint yields were 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 2 and 3. Lint yield results are presented in Table 3.

The crop growth and development data revealed relatively strong FR levels at each location through the season (Figures 2 and 3). This indicates a relatively strong demand (sink) for available N. However, the crop vigor index data, using a HNR, revealed plants that were somewhat shorter and stunted than normal at each location. Plants in these experiments produced fewer nodes, fruiting branches, and fruiting sites. This was expressed through the HNR data shown in Figures 2 and 3. Under N deficiency conditions it would be expected to experience low crop vigor (HNR levels below the middle baseline). This was consistently the case at both locations in 2002. Plant symptoms consistent with N deficiency were visually noted at both locations with slight discoloration of the leaf tissue.

In 2002, there were no significant differences among any of the original N fertilization regimes at any location in terms of residual NO_3^- -N, crop growth and development patterns (HNR, FR, NAWF, etc.), lint yield, or fiber properties. Lint yields averaged approximately 1473 and 1060 lbs. lint/acre at MAC and MAR respectively. Estimates of N uptake by the crop were approximately 215 and 154 lbs. N/acre (Unruh and Silvertooth, 1996). However, preseason soil samples revealed very low levels of NO_3^- -N (Figure 1). Considering the fact that zero fertilizer N was applied and the N contributions from the irrigation water was negligible at each location, the N taken-up by the crop is residual N. Based on pre-season NO_3^- -N concentrations in the soil, a significant portion of the total N taken-up by the crop at each location must have been derived from soil mineralization.

This project will be continued through the 2004 season, relying only on residual soil N. Fertilizer N will not be applied throughout the duration of this project.

Acknowledgements

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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_3^--N analysis, 1X rate
4	2X rate from soil and petiole NO_3^--N feedback

* The Marana location was initiated in 1994; No N application in 2002 for both locations.

Table 2. Preseason soil nitrate-N analysis for each location and treatment, 2002.

Location/ Treatment	**Depth (feet)**	**Nitrate-N (ppm)**
Maricopa		
1	1	7.99
	2	4.15
2	1	4.59
	2	3.89
3	1	5.57
	2	4.73
4	1	2.88
	2	5.46
Marana		
1	1	4.20
	2	3.89
2	1	2.98
	2	1.85
3	1	3.75
	2	2.75
4	1	4.12
	2	3.54

Table 3. Lint yields from Maricopa and Marana N-management studies, 2002.

Maricopa	**DP458BR**	
Treatment	**Lint Yield (lbs. lint/acre)**	**Micronaire**
1	1482	54
2	1480	53
3	1487	56
4	1444	54
OSL	0.743	
C.V. (%)	4.10	
LSD (0.05)	NS	
Marana	**DP422BR**	
Treatment	**Lint Yield (lbs. lint/acre)**	**Micronaire**
1	1037	49
2	1047	47
3	1069	47
4	1085	47
OSL	0.327	
C.V. (%)	3.57	
LSD (0.05)	NS	

NS= Not Significant

Means followed by the same letter are not significantly different (α=0.05) according to a Fisher's LSD.

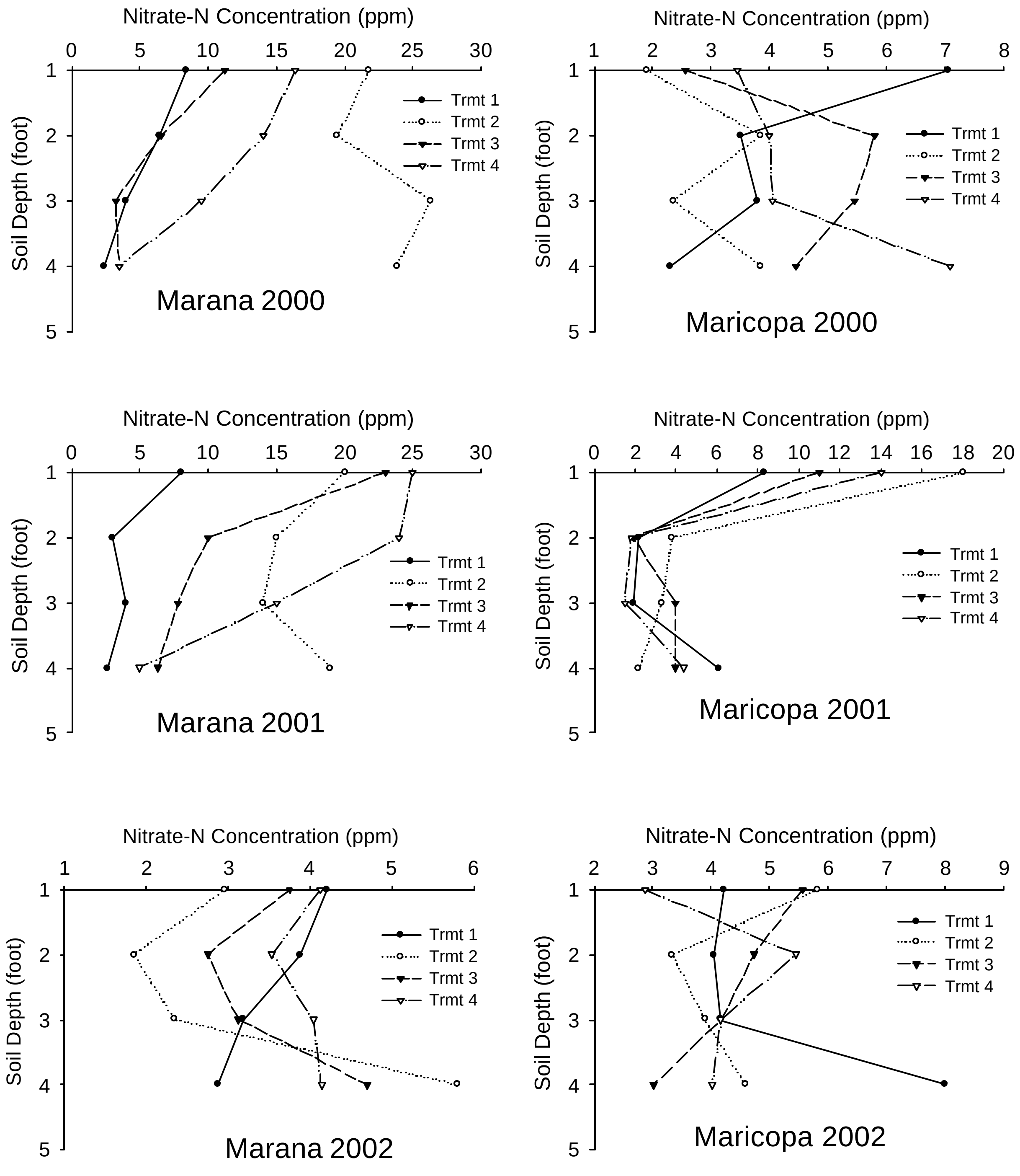

Figure 1. Nitrate-N concentration for each treatment at depths 1-4 feet for Marana Ag. Center and Maricopa Ag. Center, 2000-2002.

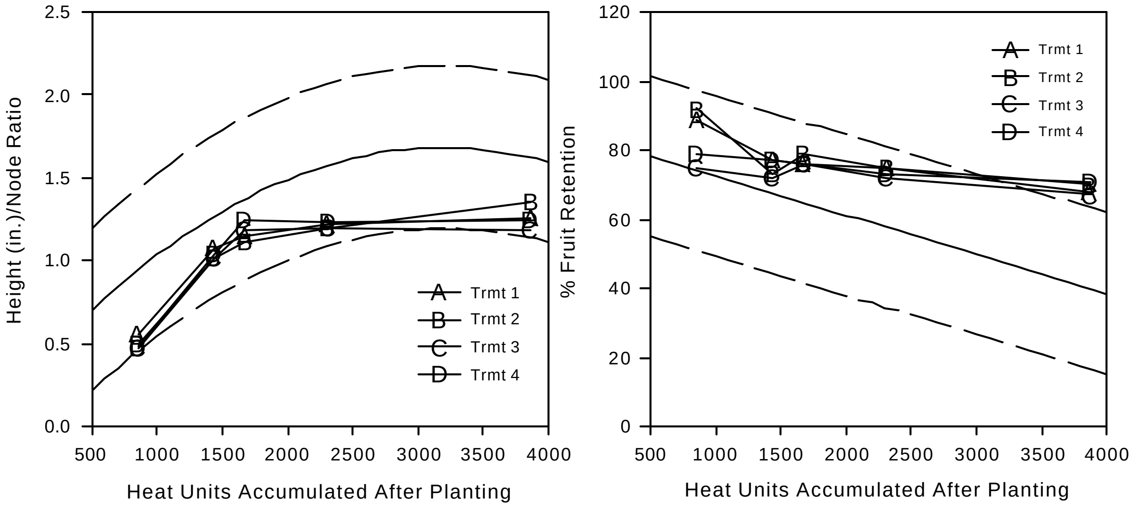

Figure 2. Height to node ratio and fruit retention levels for N-management study, Maricopa, 2002.

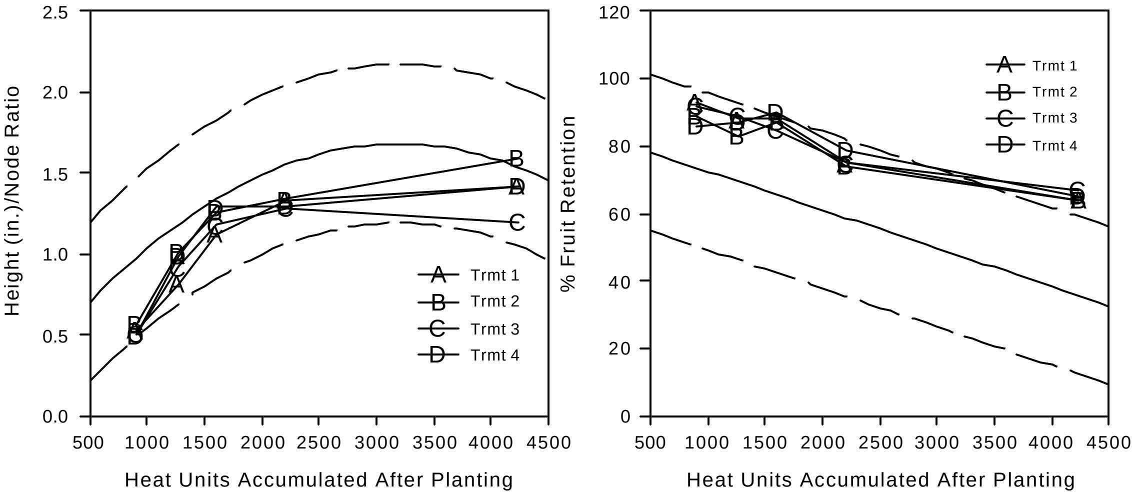

Figure 3. Height to node ratio and fruit retention levels for N-management study, Marana, 2002.