

SUMMARY OF RESIDUAL SOIL NITROGEN EFFECTS IN IRRIGATED COTTON

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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 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 SAC in 2004 and MAR at the end of the 2005 season). Irrigation water analysis showed that 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 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, suggesting a possible pattern associated with the residual fertilizer N effects in relation to the original treatments at the Maricopa site. Mineralization estimates of the residual soil-N (by difference from total plant N uptake minus irrigation water and pre-season NO_3^- -N soil-N) revealed rates of 115-35 lbs. N/acre/year from 2000 to 2006 and a decline at a rate of approximately 10 lbs. N/acre/year. Thus, residual soil-N contributions from low organic matter desert soils can be significant and difficult to predict.

Introduction

The issue of managing nitrogen (N) in a soil-plant system is one of continuing importance and challenge. One of the most common methods of managing N in a crop production setting is the use by the use of a “yield goal”, “check book”, or “N balance approach”. In this approach we make an attempt to balance the plant-available N in the soil plant system to meet of the needs of the crop based on a realistic yield goal. This approach requires the following information: crop N requirements (e.g. lbs N/unit of yield), residual plant-available soil-N, and N inputs into the system besides fertilizer N (e.g. irrigation water). One of the most difficult aspects associated with this N management method is making an accurate assessment of residual soil N, which is most commonly done with a simple soil nitrate-N (NO_3^- -N) test, which is a simple snapshot of plant-available N. The difficulties associated with managing N in a soil-plant system are certainly not new. In a 1955 article in *Advances in Agronomy* F.E. Allison addressed the topic “The enigma of soil nitrogen balance sheets” and further addressed the issue 11 years later (Allison, 1966). Over the past 40-50 years agronomists and soil scientists have made considerable progress in improving our understanding of the behavior and fate of fertilizer N in a soil-plant system. However, many issues and challenges in this arena still remain. For example, to gain a better level of efficiency in fertilizer N management, a better understanding of the balances associated with N mineralization-immobilization transformations are needed and also better methods of estimating residual soil N.

The plant 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.

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, 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}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 relates to the complications with 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

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 Torrifluvent) 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⁻¹. 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). Soil organic matter (SOM) was determined at the onset of the experiment (combustion method). 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. 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

The SAC and MAR locations were taken out of service in 2004 and 2005, respectively. The residual N summaries are presented and discussed for the MAC (0.87 % SOM) site. During the 2001-2006 seasons, there were no significant differences among any of the original N fertilization regimes in terms of residual soil-N (Table 3; Figures 1 and 2) or lint yield and fiber properties (Table 4 and Figures 1 and 2). The pre-season soil sample data revealed varied concentration levels of NO₃⁻-N over the experimental period (Table 3). 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 Figure 3. Total crop N uptake declined from approximately 200 to 120 lbs. N/acre from 2000 to 2006 at MAC.

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. The NO₃⁻-N contained in the irrigation water averaged 7 ppm at MAC, contributing approximately 9.5 lbs. NO₃⁻-N/acre/irrigation. The estimated contributions of plant available N from the irrigation water each season totaled 67 lbs. NO₃⁻-N/acre. Mineralization estimates of the residual soil-N (by difference from total plant N uptake minus irrigation water and pre-season NO₃⁻-N soil-N) revealed rates of 115-35 lbs. N/acre/year from 2000 to 2006 and a decline at a rate of

approximately 10 lbs. N/acre/year. 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, residual N experiment, Maricopa Agricultural Center, 2000-2006.

| 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 |

Table 2. Summary of agronomic information, residual N experiment, Maricopa Agricultural Center, 2000-2006.

| Location / Year | Planting date | Wet Date | Final Irrigation Date | Harvest Date | Variety Planted |
|-----------------|---------------|----------|-----------------------|--------------|-----------------|
| Maricopa | | | | | |
| 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 |

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

| Location / Treatment | | Nitrate-N Concentration (ppm) | | | | | | |
|----------------------|--------------|-------------------------------|------|------|------|------|------|------|
| Maricopa | Depth (feet) | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 |
| 1 | 1 | 4.7 | 8.3 | 8.0 | 3.2 | 10.0 | 18.0 | 2.1 |
| | 2 | 3.8 | 2.2 | 4.1 | 2.1 | 9.4 | 15.0 | 1.0 |
| 2 | 1 | 7.9 | 18.0 | 4.6 | 1.5 | 11.0 | 19.0 | 16 |
| | 2 | 5.2 | 3.8 | 3.9 | 4.0 | 11.0 | 18.0 | 15 |
| 3 | 1 | 5.3 | 11.0 | 5.6 | 4.0 | 11.0 | 17.0 | 13 |
| | 2 | 3.5 | 1.9 | 4.7 | 4.0 | 10.0 | 18.0 | 12 |
| 4 | 1 | 7.7 | 14.0 | 2.9 | 2.8 | 11.0 | 19.0 | 33 |
| | 2 | 5.3 | 1.8 | 5.5 | 0.9 | 4.7 | 14.0 | 31 |

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 _{0.05} | 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 _{0.05} | 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.

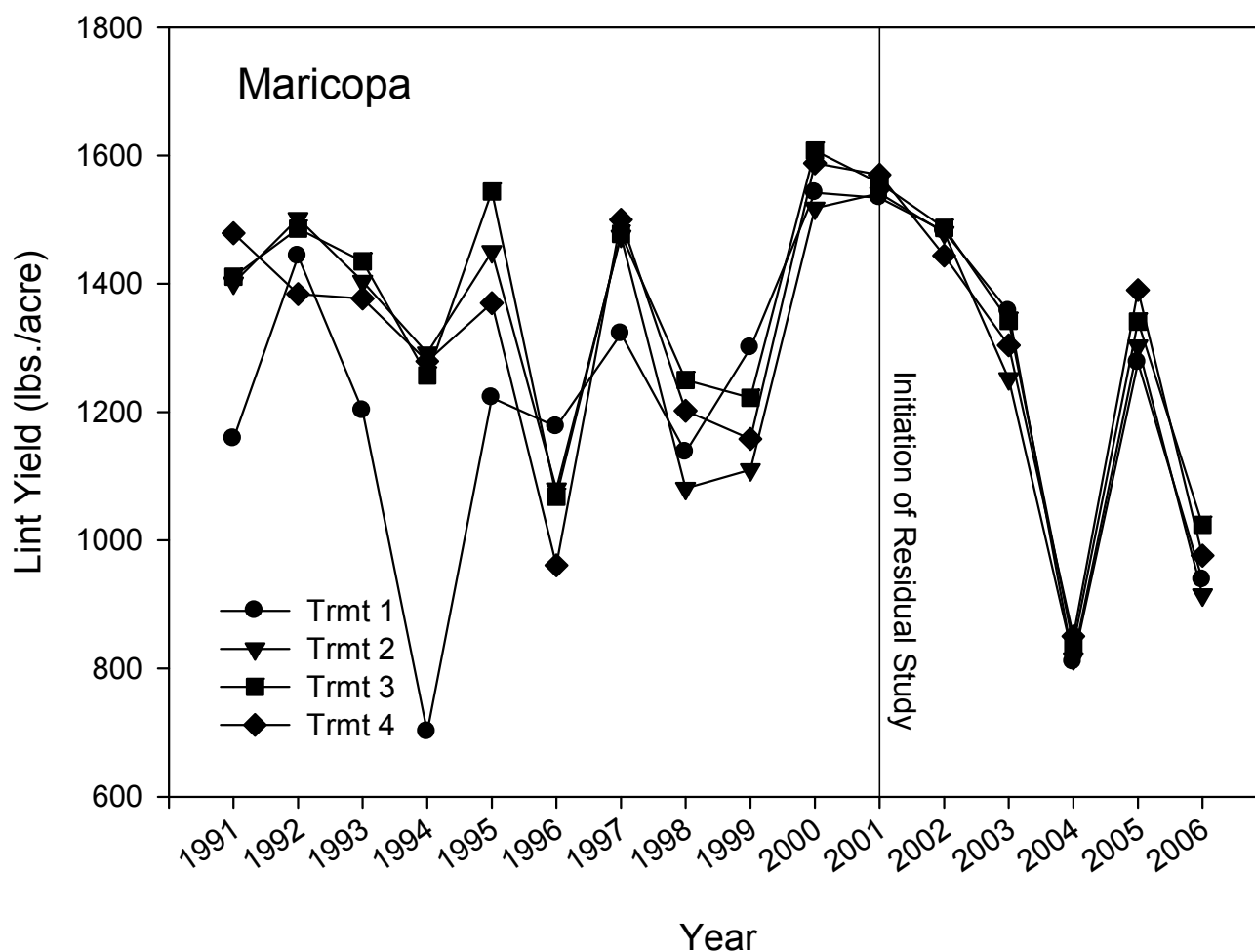


Fig. 1. Lint yield results (lbs./acre) Maricopa, 1991-2006.

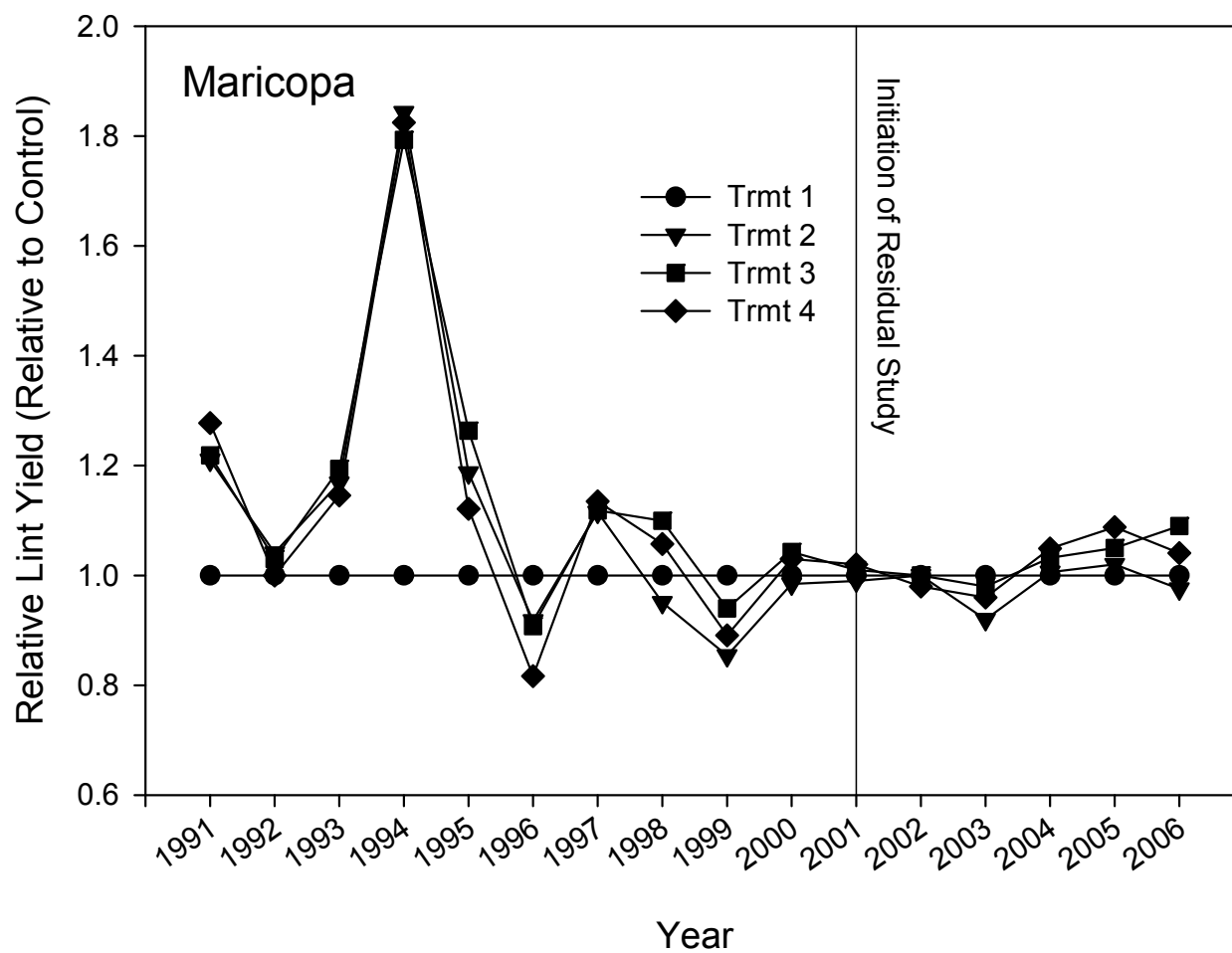


Fig. 2. Relative lint yields (in relation to the check/control treatments) N-management and residual N studies, Maricopa, 1991-2006.

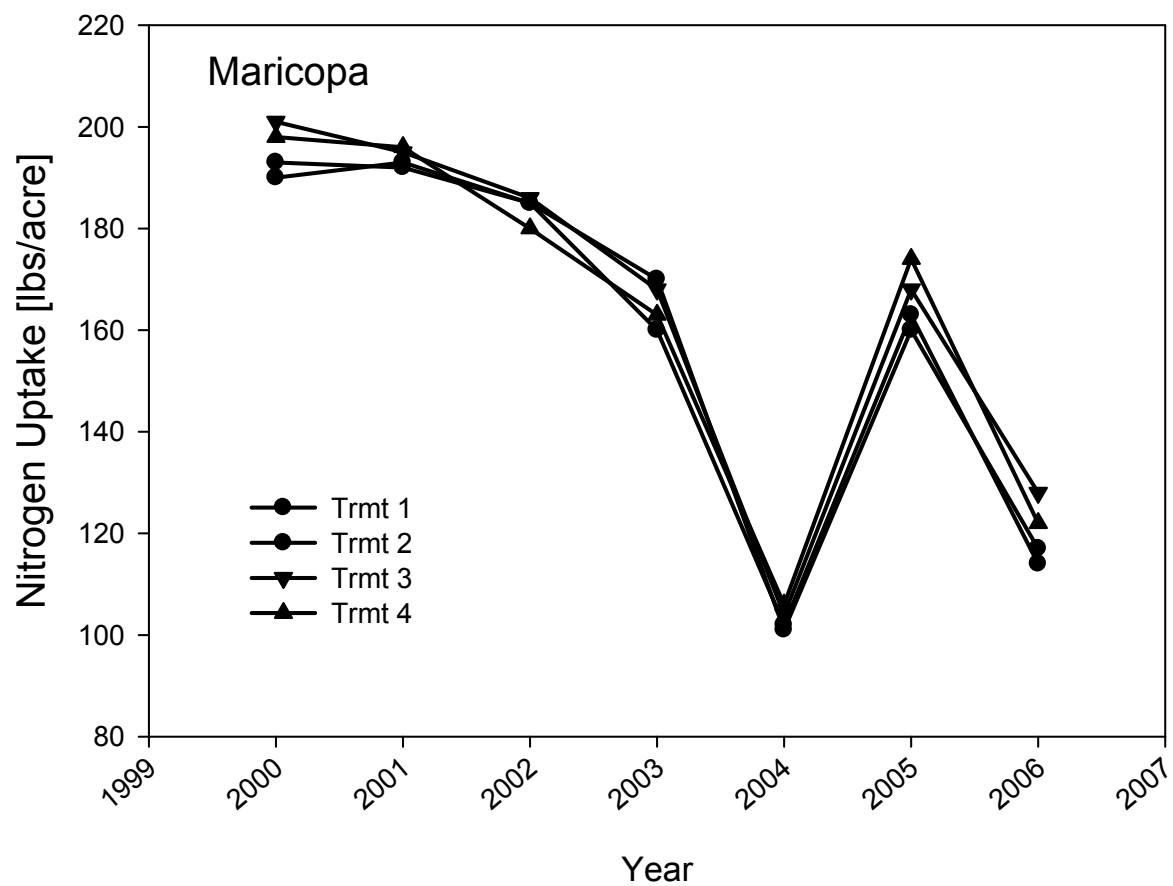


Fig.3. Nitrogen uptake estimates from the residual N experiment, Maricopa, AZ, 2000-2006.