

10;

91/222

7/91 6/94

Cotton Research and Development Corporation

Project Title: Improved Nitrogen Management for Cotton

Project No: CSP 27C

Research Organisation: CSIRO

Principal Researcher: Ian Rochester (Appointed 4/11/91)
CSIRO, Division of Plant Industry
P.O. Box 1600
Canberra 2601
Telephone (06) 246 5222

Supervisors: Dr. J. R. Freney (Retired 6/12/93)

Dr. G. A. Constable
Cotton Research Unit
CSIRO, Division of Plant Industry
Locked Bag 59
Narrabri 2390
Telephone (067) 99 1522

A final report prepared for the Cotton Research and Development Corporation

ABSTRACT

Nitrification inhibitors were successfully used to improve the recovery of fertilizer N in the irrigated cotton-growing system. By slowing the rate of nitrification of applied ammonium-N, it was shown that the loss of N through denitrification was limited by the reduced concentration of nitrate in the soil. The effectiveness of recognised and experimental nitrification inhibitors to inhibit nitrification and reduce N loss through denitrification were compared in field and laboratory experiments. The more effective inhibitors (2-ethynylpyridine (2-EP), Terrazole and N-Serve) were able to retard nitrification for more than 8 weeks. They also improved N fertilizer recovery (from 35 to 50% in one situation) and enabled the cotton crops to better utilise fertilizer N where denitrification loss was severe. In some instances, lint yields were increased significantly (up to 18%) to where the profitability of cotton-growing was substantially improved.

One inhibitor, Terrazole proved cost effective in field experiments and will soon be commercially available. Significant and economic yield improvements were obtained in 3 of the 8 experiments where Terrazole was included; the lack of response to Terrazole was believed due to the use of low fertilizer rates (3/8), water stress (1/8) and hail damage requiring resowing of crops (2/8) and combinations of these factors.

The compounds 2-EP, N-Serve and an experimental compound (XDE-474) also proved effective nitrification inhibitors and improved fertilizer recovery in some instances. Calcium carbide (either wax-coated or not) proved relatively ineffective as a nitrification inhibitor in several experiments and conserved little fertilizer N. Both phenylacetylene and ethynylcyclohexanol were also ineffective, despite their chemical similarity to 2-EP.

The removal of cotton stubble, as compared with retaining it, reduced the efficiency of N use. Although soil mineral N concentrations and crop N uptake were not generally affected during the 3-year experiment, lint yields and fertilizer recovery were decreased where stubble was removed.

The more effective nitrification inhibitors were identified in terms of providing improved N fertilizer recovery, reduced N loss through denitrification and in some instances, significantly increased lint yield and profitability of cotton-growing. Poor fertilizer recovery was closely associated with inferior soil structure.

SUMMARISED REPORT

Project CSP 27C

Improved Nitrogen Management for Cotton

The recovery of N fertilizer applied to irrigated cotton is often poorly recovered; commonly, less than 30% of the N applied is recovered by the cotton crop. Substantial loss of N fertilizer can be largely attributed to denitrification, a biological process whereby soil nitrate is reduced to nitrogenous gases, di-nitrogen (N₂) and nitrous oxide (N₂O), the latter being associated with ozone depletion. Denitrification occurs in both natural and agricultural ecosystems, but is enhanced by agricultural practices such as cultivation, fallowing, fertilizer application and irrigation.

This project aimed to devise practical solutions to improve N fertilizer recovery by cotton, through the use of nitrification inhibitors and by altering N application and cotton stubble management practices. The development of improved coatings for calcium carbide was not pursued, as much superior and inexpensive inhibitors were identified in the initial experiments.

Results

Field experiments were conducted at Narrabri ARS, Auscott (Narrabri and Warren) and laboratory experiments at Canberra. All experiments in the 1993/94 season were affected by hail in November.

Experiments comparing inhibitors

Terrazole, 2-ethynylpyridine, N-Serve proved the most effective nitrification inhibitors; they also significantly increased fertilizer recovery. Commonly, no inhibitor effect was evident on crop N uptake or lint yield at the relatively low N rates used (up to 120 kg N/ha). Two chemical analogues of 2-ethynylpyridine (ethynylcyclohexanol and phenylacetylene) indicated little capacity to inhibit nitrification. Calcium carbide (either wax-coated or not) was also ineffective. An experimental inhibitor XDE-474 increased lint yield by ~12% above the control yield of 2.2 bales/ac in a late (resown) crop.

Multiple doses of either Terrazole or calcium carbide produced no additional benefit above the initial dose, but the leaching of fertilizer N below the plough layer (30 cm) was slowed with each Terrazole application, but this had no effect on the fertilizer recovery at crop maturity.

All the nitrification inhibitors used in the comparative field experiments were included in a laboratory study. The chemicals were ranked, in descending order of effectiveness of nitrification inhibition as: 2-ethynylpyridine, Terrazole, N-Serve, XDE-474, calcium carbide, phenylacetylene, ethynylcyclohexanol, as indicated in the field experiments.

Experiments with Terrazole

Nitrification was consistently delayed for more than 2 months when Terrazole was applied at the recommended rate of 1200 mL/ha. Crop N uptake could be

significantly increased by Terrazole - those treatments remained greener as the crop matured. Lint yield was increased in several instances which afforded substantially improved profits, although no yield response was gained in some experiments. Fertilizer recovery was increased where substantial N loss occurred. Many reports in the scientific literature have indicated that Terrazole may also directly inhibit the denitrification process. Our laboratory experiments give support to this claim.

Time of N application experiment

The application of fertilizer in November, compared with September or split (half Sept, half Nov) applications slightly increased soil N concentration later in the growing season, but only slightly improved crop N uptake, lint yield and fertilizer recovery.

Stubble management experiment - conducted over 3 years

The retention of slashed cotton stubble was compared with the removal of stubble (stalk-pulled and raked), with five N rates (0 - 200 kg N/ha) being imposed upon these areas. The stubble removed after picking contained ~5% of the carbon in the total system and about 17 kg N/ha. Soil mineral N concentrations tended to be higher where stubble was removed, possibly due to reduced immobilization by a smaller soil micro-biomass.

In the first season, N uptake was delayed in the stubble retained treatments, but more than caught up as the crop matured. Fertilizer recovery was slightly higher where stubble was retained in all three years. Lint yields were similar at each N rate in the first year. In the second and third years, lint yields, at the higher N rates, were substantially higher where stubble was retained.

Discussion

2-ethynylpyridine (2-EP) consistently proved most effective in terms of inhibition of nitrification and improving the recovery of fertilizer N, but it is prohibitively expensive, difficult to manufacture and no environmental or biological safety data is available. Apart from 2-EP, other acetylenic compounds phenylacetylene, ethynylcyclohexanol and acetylene itself (produced from calcium carbide) did not perform as well as in previous studies conducted by Freney and others.

The commercial products Terrazole and N-Serve also performed effectively (almost as well as 2-EP) as nitrification inhibitors and in reducing N fertilizer loss. Economic responses to Terrazole application appear possible where near-optimal N rates are applied, and reduced losses of fertilizer N may result in soils prone to waterlogging and/or compaction.

The N economy of a system which retains stubble rather than removes it, is more conducive to long-term sustainability, as both lint yields and fertilizer-use efficiency are enhanced.

While substantial gains in fertilizer recovery, lint yield and profitability may be procured with the use of inhibitors, poor soil condition remains a significant contributor to the denitrification problem; improvement in fertilizer recovery will follow the amelioration of these soil problems.

FINAL REPORT

Project CSP 27C

Improved Nitrogen Management for Cotton

Introduction

Nitrogen fertilizer applied to irrigated cotton has long been recognised as being poorly recovered. Recent projects that have monitored N fertilizer efficiency in irrigated cotton production have indicated that normally less than 50% of the N applied is recovered by the cotton crop. Constable and Rochester (1986) indicated that only ~30% of N applied was recovered in the crop. Freney and Humphreys attributed the poor fertilizer recovery to N loss through biological denitrification.

Denitrification is encouraged by flood irrigation; the soil profile becomes almost devoid of oxygen as air is driven from the soil pores upon irrigation. During the process, soil nitrate is reduced to nitrogenous gases, predominantly di-nitrogen (N_2), but also traces of nitrous oxide (N_2O) are evolved, a gas which has been associated with ozone depletion in the earth's stratosphere. It is important to note that denitrification is a process which occurs in both natural and agricultural ecosystems, but is enhanced by agricultural practices such as cultivation, fallowing, fertilizer application and irrigation. The process has been studied with increasing intensity during the past four decades and is well understood.

The Australian cotton industry invests some \$20 - \$30M in N fertilizer annually. It is therefore imperative that this input is used efficiently, and that wastage and inefficient fertilizer management practices are identified and remedied. Ineffective use of N fertilizers wastes the large energy input required for their manufacture and exacerbates environmental pollution when denitrification gases such as nitrous oxide are evolved.

Objectives

This project aimed to further quantify the efficiency with which N fertilizer was being used in the cotton-growing system, and determine to what extent N loss could be reduced and fertilizer use-efficiency improved. This would involve the use of chemical inhibitor compounds to selectively alter N transformations in the soil i.e. by controlling the concentration of nitrate, denitrification could be limited. Aside from the use of nitrification inhibitors, alteration of the practices involving N application and cotton stubble management would be assessed in terms of fertilizer use-efficiency. Extensive use of ^{15}N -labelled fertilizers would enable the fertilizer to be traced through the system, to more accurately detect N loss and fertilizer recovery.

The original research proposal indicated specifically, that improved coatings for calcium carbide would be developed. Results from the first year's experiments identified inhibitors much superior to wax-coated calcium carbide. These inhibitors, which were both effective and inexpensive, were investigated in preference to developing calcium carbide coatings. Similarly, experiments to assess slow-release N fertilizers were being conducted as this project proposal was being prepared, and reference was made to their continued assessment in that proposal. However, those fertilizers proved ineffective and expensive in those preliminary experiments and hence, were not further pursued in this project.

3. Results

Thirteen field experiments were conducted during this project; most were conducted at the Narrabri ARS, two at Auscott (Narrabri and Warren) and several laboratory experiments were conducted at Canberra. A brief description of each experiment and the results follows.

1991/92 season

Inhibitor comparison experiment

Terrazole, 2-ethynylpyridine, N-Serve, calcium carbide (wax-coated and uncoated) were compared, in terms of inhibiting nitrification of added N, crop N uptake, lint yield and fertilizer recovery. Terrazole, 2-ethynylpyridine, N-Serve proved the most effective nitrification inhibitors; they also significantly increased fertilizer recovery (from 35 to 50%) in the system (Appendix - Fig. 1). No inhibitor effect was evident on crop N uptake or lint yield at the N rates used (0 and 80 kg N/ha).

Terrazole rates experiment

Terrazole was applied at 0, 600, 1200 and 2400 mL/ha with each of two N rates (0 and 80 kg N/ha); 1200 mL/ha is the recommended Terrazole rate. Terrazole had no effect in the unfertilized plots. With 80 kg N/ha, Terrazole retarded nitrification for more than 2 months, especially with the higher application rates. Crop N uptake was significantly increased (by 28%) and the Terrazole treatments (compared with the control) remained greener as the crop matured. Lint yield was increased by 18% (252 kg lint/ha) at the recommended rate (Appendix - Fig. 2) and fertilizer recovery was increased by 44%. The better soil condition at this site than the inhibitor comparison site may have influenced the response to Terrazole.

Time of inhibitor and N application experiment

Three N application timing strategies, September application, November application or split (half Sept, half Nov) application were compared, with and without the inhibitor calcium carbide (wax-coated). The inhibitor retarded nitrification for a short period only after each application, but tended to improve crop N uptake and lint yield (by ~1.5% only). The November and split N timing strategies had a small but statistically significant effect on increasing soil N concentrations later in the growing season. However, little effect on crop N uptake or lint yield was evident - fertilizer recovery was only slightly improved by the inhibitor and November fertilizer application.

Stubble management experiment - Year 1

The retention of slashed cotton stubble was compared with the removal of stubble (stalk-pulled and raked). Five N rates (0 - 200 kg N/ha) were imposed upon these areas. The stubble removed after picking contained ~5% of the carbon in the total system and 17 kg N/ha. Soil mineral N concentrations were not significantly affected by the stubble treatments, N uptake was delayed in the stubble retained treatments (but more than caught up as the crop matured); lint yields were similar at each N rate. Fertilizer recovery was slightly higher where stubble was retained (54% c.f. 49%).

1992/93 season

Inhibitor comparison experiment

Terrazole, N-Serve, ethynylcyclohexanol (ECH), and phenylacetylene (PA) were compared at four N rates (30 - 120 kg N/ha). No inhibitor effects were evident in N uptake, lint yield or fertilizer recovery (which averaged 70%). Both Terrazole and N-Serve inhibited nitrification for several weeks, ECH and PA had no effect.

Terrazole response with anhydrous ammonia

Terrazole was applied with anhydrous ammonia at 7 rates (0 - 175 kg N/ha). Terrazole increased the economic optimum lint yield of cotton by 130 kg lint/ha, but required the application of an additional 50 kg N/ha (Appendix - Fig. 3). Profit was increased by \$95/ha under these circumstances. Fertilizer recovery was 70% with and without Terrazole.

Terrazole response - Auscott Warren

Urea was applied at rates of 90, 120 and 150 kg N/ha, with and without Terrazole (1200 mL/ha); lint yields were increased by both N and Terrazole. Nitrification of applied N was delayed for several weeks with Terrazole application, N uptake was increased by 13% (the Terrazole plots with low N rates were visibly greener at crop maturity) and lint yield was increased by 3% (46 kg/ha) at the higher N rates. Profit was increased by \$35/ha. Fertilizer recovery could not be measured.

Terrazole response with anhydrous ammonia - Auscott Narrabri

Anhydrous ammonia was applied presowing at rates 0 - 225 kg N/ha, with and without Terrazole. Nitrification was delayed for ~10 weeks, with the effect being more obvious at higher N rates (Appendix - Fig. 4). No inhibitor (or N) effects were evident in crop N uptake or lint yield (2.8 bales/ac), which were both relatively high. Some water stress may have reduced crop responses towards crop maturity.

Stubble management experiment - Year 2

As with the previous year, no significant differences were seen. Soil mineral N concentrations were slightly higher where stubble was removed (a possible consequence of reduced immobilization by a smaller soil micro-biomass as soil respiration was reduced where stubble was removed). Lint yields tended to be higher at the higher N rates where stubble was retained and fertilizer recovery was slightly higher (50% c.f. 46%).

Stubble placement experiment

An attempt was made to conserve fertilizer N by applying it in a band adjacent to where the previous cotton crop stubble had been buried; as the stubble decomposed, much of the fertilizer N would be incorporated into an organic pool, and recycled to the following cotton crop. No differences were observed in soil mineral N, crop N uptake or fertilizer recovery (65%), even when the stubble was finely milled before burial.

1993/94 season

All experiments were affected by hail in November 1993; two of the three experiments were resown. Any inhibitor effects which may have been apparent in the original crops were probably masked by the delayed planting.

Inhibitor comparison experiment

Anhydrous ammonia was applied at rates from 0 to 250 kg N/ha with either Terrazole, N-Serve or an experimental inhibitor XDE-474 (and control). XDE-474 increased lint yield by 12% (149 kg/ha) above the control yield of 2.2 bales/ac. Fertilizer recovery also tended to be higher with this treatment (80%), but all treatments recorded high recoveries (~70%).

Multiple applications of inhibitor experiment

Either Terrazole or calcium carbide (unwaxed) was applied zero, once, twice, or three times at monthly intervals with urea (applied only once - presowing) at rates up to 120 kg N/ha. Terrazole inhibited nitrification effectively for 2 months; calcium carbide was ineffective. The inhibitors had little effect on crop N uptake, lint yield or fertilizer recovery; the multiple doses produced no additional benefit above the initial dose. However, the considerable movement of fertilizer N (leaching) to below the plough layer (30 cm depth) was slowed with each additional Terrazole application, but this had no overall effect on fertilizer recovery at crop maturity (70%); apparently, the crop recovered the leached fertilizer N as effectively as the fertilizer retained in the surface soil.

Stubble management experiment - Year 3

Soil mineral N analyses again indicated little effect of stubble removal. Soil organic carbon was similar in the two systems, which suggested the retained stubble was decomposed each year and made no contribution to soil C content. Lint yield was substantially higher (83 kg/ha or 8%) at the higher N rates where stubble was retained. Again, fertilizer recovery was slightly higher with stubble retention (65% c.f. 62%).

Laboratory experiments

All the nitrification inhibitors used in the comparative field experiments were included in a laboratory assessment. The chemicals were ranked, in descending order of effectiveness of nitrification inhibition as: 2-ethynylpyridine, Terrazole, N-Serve, XDE-474, calcium carbide, phenylacetylene and ethynylcyclohexanol; virtually the same order as indicated in the field experiments.

Several reports in the scientific literature have indicated that Terrazole (and possibly N-Serve) may also directly inhibit the denitrification process and almost eliminate the evolution of nitrous oxide. Our laboratory experiments have indicated that Terrazole may reduce loss of nitrate by directly inhibiting denitrification in cotton-growing soils.

4. General Discussion

The most effective nitrification inhibitors were identified and their application to commercial cotton-growing was assessed. 2-ethynylpyridine consistently proved the most effective in terms of inhibiting nitrification and improving the recovery of fertilizer N. However, 2-ethynylpyridine is not commercially viable, because of its cost, difficulty in manufacture and the lack of biological data regarding its safe use in the environment.

The commercial products Terrazole and N-Serve performed satisfactorily (being only slightly less effective than 2-ethynylpyridine as nitrification inhibitors and in N fertilizer conservation). Terrazole was marginally more effective than N-Serve. Currently, Terrazole is sold in EC and wettable powder formulations; their cost is about \$60 and \$40/ha respectively. Significant and economic yield improvements were obtained in 3 of the 8 experiments where Terrazole was included, which afforded extra profits of \$35, \$95 and >\$400/ha. Terrazole did not reduce lint yield in any experiment; where no response was evident, only the cost of the chemical (~\$50) was foregone.

Economic yield responses to Terrazole are possible where N is relatively non-limiting. Fertilizer N may be conserved where substantial N loss is evident (i.e. in soil predisposed to excessive waterlogging and/or compaction). The lack of response to inhibitors in some of the eight experiments may have been due to the use of low fertilizer rates (3/8), water stress (where no N response was evident either - 1/8), hail damage requiring resowing of crops (2/8) and combinations of these factors.

Substituted acetylenic compounds (phenylacetylene, ethynylcyclohexanol) and acetylene itself (produced from calcium carbide) were proven inferior in these experiments and did not perform as well as in previous studies conducted by Freney and others. Calcium carbide (either wax-coated or uncoated) proved ineffective in several experiments and is not recommended for further experimentation. Similarly, slow-release polymer-coated urea compounds were not tested further because of their high cost and poor performance in previous projects; they are considered inappropriate for use in cotton-growing systems.

The N economy of a system whereby stubble is retained rather than removed, is more conducive to longer-term sustainability, with higher lint yields and increased fertilizer-use efficiency being attained.

5. Conclusions, Recommendations and Application to Industry

Conclusions

Of the several nitrification inhibitors field-tested, Terrazole was identified as possibly the most effective chemical and possessed the potential to conserve fertilizer N, improve fertilizer recovery and lint yields, thus improving profitability of cotton-growing.

Acceptable levels of fertilizer recovery (<70%) were obtained regularly from sites with relatively well-structured soil and good drainage. Poorer recovery was consistently obtained at the stubble management experiment site, where many years of minimum-tillage had produced only average soil structure and fertilizer recovery was mediocre (50-60%). The site used for the inhibitor comparison experiment in 1991/92 had very poor structure, was compacted and prone to prolonged periods of waterlogging with each flood irrigation and had reputedly elevated sodium concentrations. All of these factors probably contributed to the dismal fertilizer recovery (35%).

Recommendations

It is recommended that assistance be given where required to facilitate the commercialisation of Terrazole. Terrazole, in conjunction with Terrachlor, is currently registered for use in cotton as a non-systemic soil-applied fungicide; the Terrazole label will be altered in the next 1-2 years to permit its use in cotton as a nitrification inhibitor. Terrazole is sold in USA as the nitrification inhibitor under the name "Dwell". Limited field testing is continuing with cotton - Dallas Gibb is conducting trials at Moree. Further input is required to commercially evaluate the product over a wide range of circumstances to identify where its benefits are most evident. Possibly, some benefit may arise from inhibitor use in dryland agriculture.

While some gains in fertilizer recovery may be procured with inhibitor use, a major contributor to the denitrification problem, poor soil condition, remains. Improvement in fertilizer recovery will follow the amelioration of these soil problems. Most probably, the poor growth of cotton at such sites is probably not largely attributable to the loss of fertilizer N through denitrification, but both processes are caused by poor soil aeration, waterlogging and compaction in the crop's root environment. It is therefore recommended that the research effort and extension of that research be continued to aid growers in the identification, remediation and management of their soil structural problems.

Application to Industry

The use of nitrification inhibitors to reduce N loss and improve the recovery of N fertilizer, should only be seen as a temporary solution. The sustainability of a system that relies heavily on large inputs of fertilizer N must be questioned, as well as the health of our soil resource with continued cotton growing as it is currently practiced. The reliance of our current cotton-growing systems on chemical N fertilizers can be reduced by developing alternative systems which use leguminous crops to fix atmospheric N. This aspect of N management in cotton production is being addressed in a new CRDC project.

6. Communication of Results

The results of these experiments are in preparation for publication in scientific journals. An outline of the project and the chemicals available as nitrification inhibitors was published in the Australian Cotton Grower (Jan-Feb, 1993 - p 30). A paper relating to the Terrazole experiments specifically has been accepted for publication in the Australian Journal of Soil Research; three other papers regarding cotton stubble management, the comparison of nitrification inhibitors, and the timing of inhibitor and N applications will follow. Pertinent results will be published simultaneously in a more easily read form in the Australian Cotton Grower.

The significant outcomes of the inhibitor research and the relevance of the denitrification process in the cotton-growing system have been expressed at several meetings, including the World Cotton Conference (1994), 7th Australian Cotton Conference, and in Research Review Vol 1 No 2 (April 1994).

7. Appendix

Budget

Contributor	1991/1992	1992/1993	1993/1994
CRDC	\$133,160	\$135,517	\$140,325
CSIRO	\$254,623	\$259,130	\$268,324

CRDC	1991/1992	1992/1993	1993/1994
Salaries + costs (Rochester + Agnew)	\$85,523	\$84,874	\$86,088
Operating (including travel)	\$47,637	\$50,643	\$54,237
Capital	-	-	-

Appendix - Figures

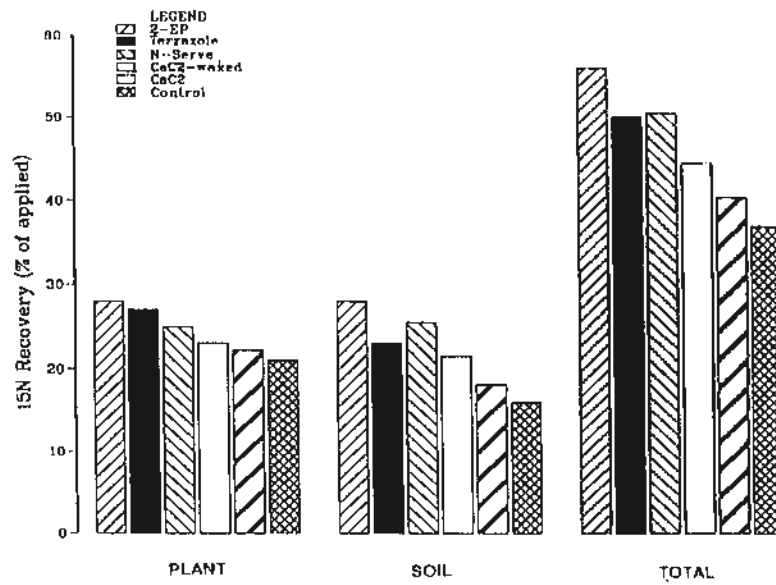


Fig. 1. Recovery of fertilizer N in plant and soil at crop maturity, as affected by the addition of several nitrification inhibitors.

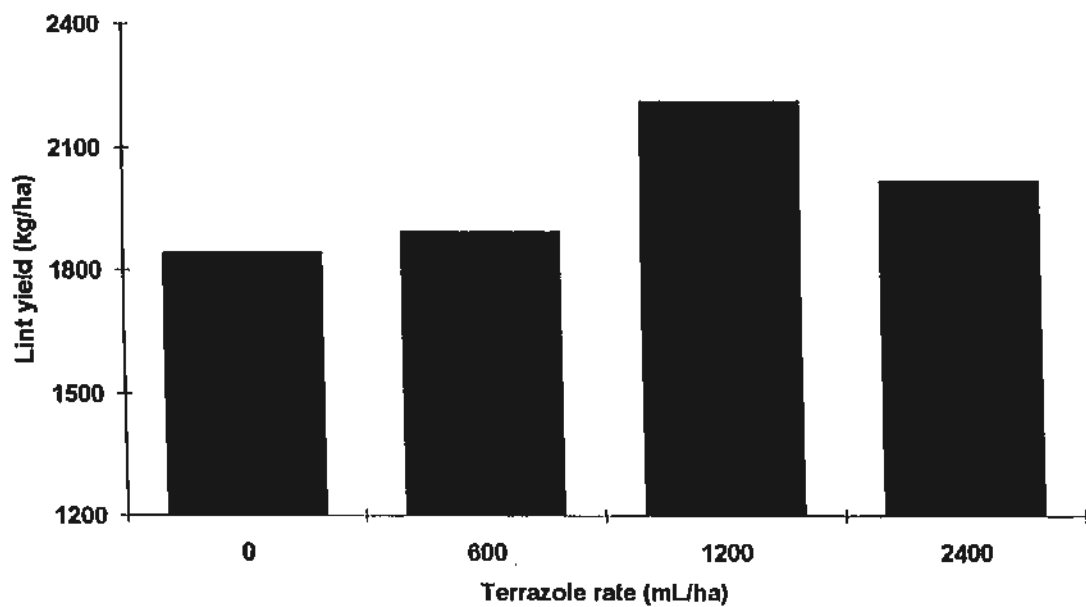


Fig 2. Lint yield of cotton fertilized with 80 kg N/ha, as affected by Terrazole applied at four rates.

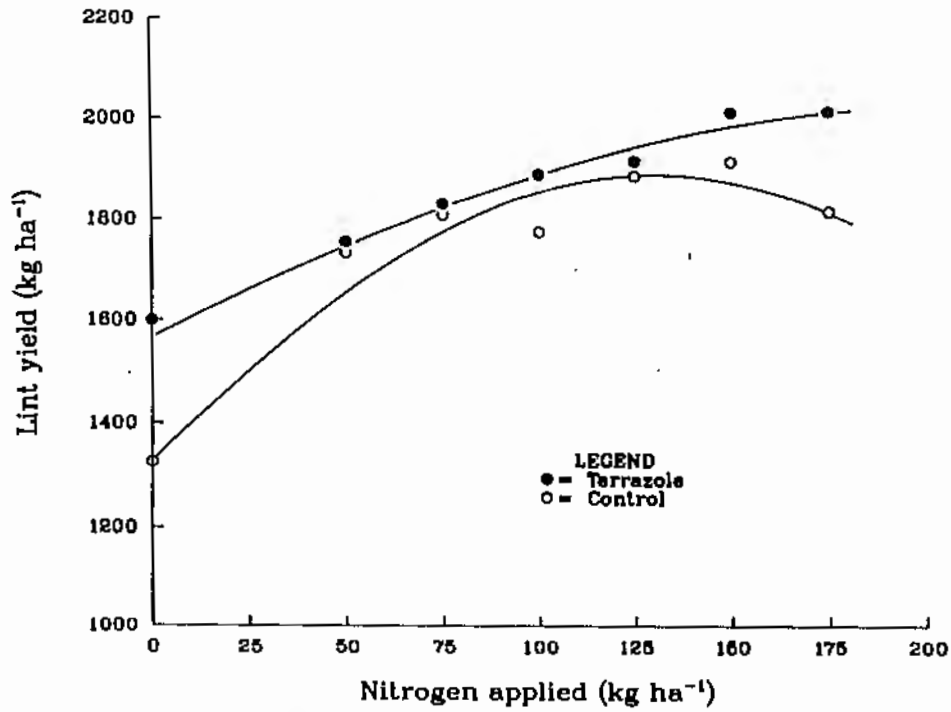


Fig 3. Lint yield of cotton as affected by N applied as anhydrous ammonia, with and without Terrazole, applied at 1.2 L/ha.

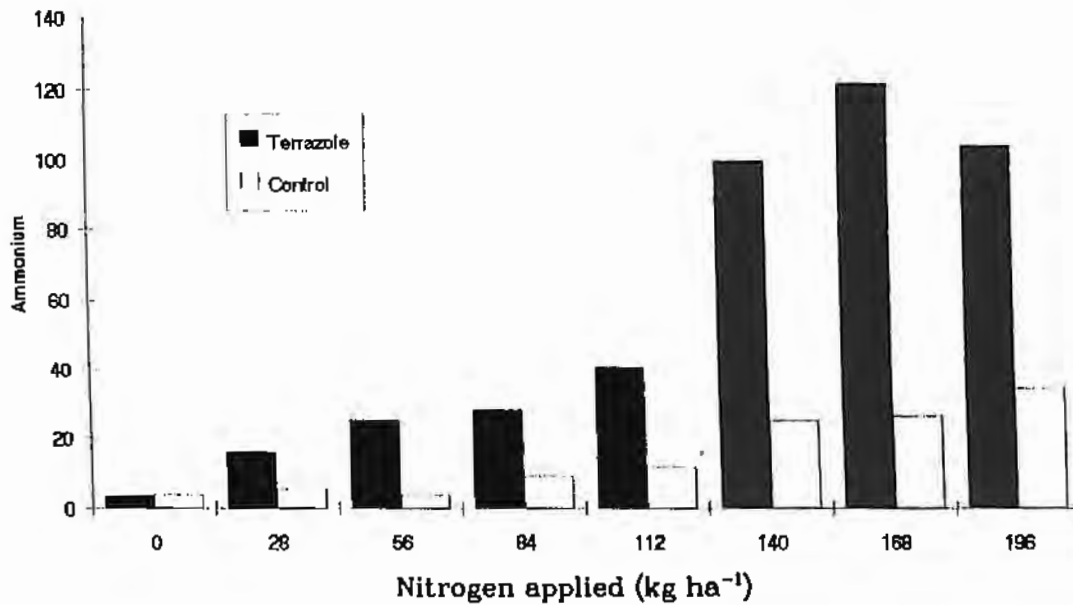


Fig 4. Soil ammonium concentrations 6 weeks after the application of anhydrous ammonia, with and without Terrazole, applied at 1.2 L/ha.