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COTTON RESEARCH AND DEVELOPMENT CORPORATION

PROJECT No. CSP3L

MANAGING NITROGEN FOR COTTON

FINAL REPORT

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Project Title: Managing Nitrogen for Cotton

Project Code: CSP 3L

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Aims:

(i) To determine the fate of fertilizer nitrogen applied to cotton on irrigated grey clays in north western New South Wales

(ii) To draw up a nitrogen budget for cotton under conditions that are known to affect the crop's response to nitrogen

(iii) To devise management practices to improve efficiency of fertilizer nitrogen

(iv) To improve the SIRATAC fruit model by refining the nitrogen sub-model

Abstract:

The initial phase of the project was devoted to the selection and testing of analytical techniques for assessing total nitrogen and leaching losses, and gaseous losses of nitrogen by ammonia volatilization and denitrification following the application of urea to cotton. Total nitrogen loss was measured in microplots by determining the amounts of labelled fertilizer nitrogen recovered in plants and soil, and subtracting this from the amount originally applied. Ammonia loss was determined directly by a micrometeorological technique which determines the ammonia concentration gradient in the air above the cotton crop. Denitrification loss was calculated by subtracting the measured ammonia loss from the total nitrogen loss. The movement of ^{15}N down the soil profile gave an indication of the importance of leaching loss.

In order to assess total nitrogen loss in microplots we needed to determine the size and shape of microplot to use so that the results obtained reflected the true field situation. The results showed that recovery of fertilizer nitrogen in the plants and soil varied depending on the type of microplot used. The lowest plant recovery was obtained in the unconfined microplots and this seemed to be due to removal of plant debris by wind and water erosion. The highest plant and soil recoveries were obtained in 1m x 0.5m rectangular plots confined by metal frames. This microplot design was used for all subsequent studies.

Previous work had shown that ammonia volatilization was negligible when fertilizer nitrogen was drilled into the soil. In the current work we showed that no ammonia was volatilized when urea was applied in the irrigation water. It is apparent that

ammonia volatilization is not an important mechanism for nitrogen loss from these soils. In all of the studies conducted very little of the applied nitrogen moved below the 0-0.30m layer, thus leaching is not an important mechanism for nitrogen loss. As run-off was controlled by the use of confined plots, and ammonia volatilization and leaching losses were shown to be negligible, it was concluded that the main process for nitrogen loss from the grey clays was denitrification.

The amount of fertilizer nitrogen lost by denitrification when urea was drilled into the grey clays at the different times used by local farmers was then assessed. The loss depended on the time of application, soil conditions and plant vigour . Losses were very large from early (summer / autumn) applications; when urea was banded in March or June 1988, by the time the cotton crop emerged in October, 74% and 21%, respectively, of the applied nitrogen had been lost from the soil. In 1989, urea was banded in January or May, and at sowing 92% and 73%, respectively, of the applied nitrogen had been lost from the soil. When urea was banded below the soil surface three weeks before sowing (September) to cotton growing in a continuous cotton rotation, the plants had recovered only 27% of the applied nitrogen by mid-February, 23% remained in the soil and 50% had been lost. When the experiment was repeated in the following season on a more fertile cotton/wheat rotation site, the plants had recovered 55% of the applied nitrogen by mid-February and 31% of the applied nitrogen remained in the soil (i.e. 14% had been lost). Thus the loss of nitrogen varies with the efficiency with which cotton plants can recover the applied nitrogen. The cotton plants on the cotton/wheat site grew much more vigorously than the plants on the impoverished continuous cotton site and presumably were able to compete much more strongly for the fertilizer in the soil before it could be lost by denitrification.

Experiments were then conducted to determine the fate of fertilizer nitrogen applied to soil in other ways e.g. as water-run urea. When water-run urea was applied to cotton crops in mid-December, negligible amounts of nitrogen were lost by ammonia volatilization. As described above loss of applied nitrogen depended on the ability of the plants to compete with soil microorganisms for the nitrogen. In the trial at Auscott where the plants grew vigorously, by the time of maximum nitrogen uptake, the plants had taken up 58% of the applied nitrogen and 26% had been immobilized in the soil. Only 16% was lost by denitrification. However, at the same time on an impoverished site in a continuous cotton rotation, the cotton plants recovered only 28% of the applied nitrogen, 24% was immobilized in the soil and 48% was lost by denitrification. Plant growth on the cotton/cotton site was poor and the dry weight of the plant tops was only 25% of that at Auscott at the time of fertilizer application.

Management practices to increase efficiency of applied nitrogen were then studied. It was apparent that whenever nitrogen was applied or transferred to the soil, losses of nitrogen by denitrification occurred. One method of overcoming denitrification losses is to apply the nitrogen to the plants, as a foliar spray, rather than to the soil, and we investigated the fate of nitrogen applied in this way. When nitrogen (as urea, ammonium nitrate, or ammonium sulfate) was applied in solution to cotton plants as a foliar spray, less than 0.2 kg N / ha was lost by ammonia volatilization in a 5 day period. In a subsequent experiment labelled nitrogen and an additional nitrogen source ("Easy-N", a solution of urea and ammonium nitrate) were used. When the plants were harvested 5 weeks after application, recovery of applied nitrogen in the plants ranged from 51% to 62%. The greatest uptake was obtained from Easy-N. Some of the applied nitrogen was transferred from the plant to the soil, but it is also apparent that some of the foliar spray penetrated the plant canopy and lodged on the soil surface; at the time of harvest 18% to 31% of the applied nitrogen was recovered in the soil. Recoveries of applied nitrogen varied from 73% to 87%, with the maximum being recovered from Easy-N.

A second method of reducing denitrification losses is to use nitrification inhibitors to prevent nitrate formation; if nitrate is not present in the soil denitrification cannot occur. The usefulness of nitrapyrin and the acetylenic compounds, acetylene (provided by wax-coated calcium carbide), phenylacetylene and 2-ethynylpyridine to prevent denitrification of nitrogen applied in September was evaluated in 1 m x 0.5 m microplots. The effect of wax-coated calcium carbide to prevent nitrification and increase lint yield was determined on 12.5 m x 8 m plots in a large scale field experiment at the same site. The microplot study showed that in the absence of nitrification inhibitors only 57% of the applied nitrogen was recovered in the plants and soil at maturity. The recovery was significantly increased ($P < 0.05$) to 70% by addition of phenylacetylene, to 74% by nitrapyrin, to 78% by coated calcium carbide and to 92% by 2-ethynylpyridine. In the large scale field experiment addition of the wax-coated calcium carbide to provide a slow release of acetylene significantly slowed the rate of ammonium oxidation in the grey clay for $>$ 8 weeks. In addition lint yield was increased by the addition of the inhibitor at all nitrogen levels except the highest level of nitrogen addition. The inhibitor helped to conserve the indigenous nitrogen as well as the applied nitrogen.

We also determined the feasibility of using nitrification inhibitors to conserve nitrogen applied early in the year. We studied the effect of applying nitrapyrin, wax-coated calcium carbide and phenylacetylene on the retention of fertilizer nitrogen banded 0.2m below the hill in February and May. All of the inhibitors conserved nitrogen, but with varying degrees of effectiveness, and the usefullness of the inhibitors declined with time. The inhibitors increased the amount of nitrogen available at planting from 16% and 28% in the controls to means of 38% and 48% of the applied nitrogen for the February and May applications, respectively. While some benefits will accrue from the use of these inhibitors with early applications, the losses of fertilizer nitrogen were still considerable. It appears that the current batch of inhibitors will conserve nitrogen for reasonably short periods only, and thus will be of benefit for fertilization at or near sowing time.

The feasibility of using plastic coated urea (Meister products) to prevent losses of fertilizer nitrogen by denitrification was also investigated. Depending on the type of material the plastic coating retained fertilizer nitrogen in the soil for 80 to 100 days longer than was the case for uncoated urea. However lint yield was not significantly increased by the use of plastic coated urea.

Background to Project

Most of the Australian cotton crop is grown on the alkaline, self-mulching, heavy clay soils in north western New South Wales and southern Queensland. In these soils the yield of lint is limited by the supply of soil nitrogen, although the limitation can be overcome to some extent by the application of fertilizer nitrogen. The highest yields of lint were obtained by drilling anhydrous ammonia or urea into the hill in the month before sowing (Constable et al. 1991). However, even when fertilizer nitrogen is applied at the optimum time, recovery of the applied nitrogen by cotton is poor. Farmers in Australia apply between 80 and 200 kg N ha^{-1} to cotton, but the apparent recovery of the applied nitrogen is only about 40% and seldom exceeds 50% (Hearn 1986; Constable and Rochester 1988; Constable et al. 1991). The fate of the remainder of the fertilizer nitrogen is not known, but much of it is probably lost from the system by gaseous emission of ammonia, nitrous oxide or dinitrogen, by leaching or run-off. As cotton growers currently spend in excess of $20 million on fertilizer nitrogen to supply the needs of the crop it can be seen that the losses in excess of $10 million are of tremendous economic significance.

In order to make more efficient use of the fertilizer nitrogen, to prevent contamination of the ground water and atmosphere, information is required on the fate of the added nitrogen, the amounts lost by the various processes and the timing of the loss. With this information it should be possible to design more effective management practices and save the industry up to $10 million each year.

More efficient use could be made of the nitrogen fertilizer if the computer based crop management system SIRATAC could be modified to include advice on nitrogen fertilization. Incorporating nitrogen into the fruit model has not been as successful as the work with water. The main problem is estimating nitrogen uptake. The first approach was to follow other workers and estimate uptake as a function of the concentration of mineral nitrogen in the soil solution and the transpiration rate. The result was an underestimate. The second approach was to develop a rate equation in which uptake was limited by concentration in the soil at low levels, but approached an asymptote at high levels. The resulting function was site specific and therefore not general.

When the problem of stimulating uptake has been overcome, nitrogen can be included in the fruit model. The SIRATAC pest management system can then be applied more confidently when nitrogen is limiting. More important, the fruit model will be developed in conjunction with appropriate soil and plant tests to monitor and manage nitrogen through the season. The SIRATAC system provides a means of making the results of past and present nitrogen research available to the grower.

Results

Comparison of microplot techniques

In order to assess total nitrogen loss in microplots we needed to determine the size and shape of microplot to use so that the results obtained reflected the true field situation. Therefore we compared recoveries of labelled nitrogen banded beneath the hill inside the microplots in September. Five types of microplots were used; a 0.33m diameter cylinder, a 0.54m x 0.54m square, a 1m x 0.5m rectangle, a 1m x 0.5m rectangle with ^{15}N urea applied in a buffer zone outside the microplot, and an unconfined 1m x 0.5m rectangular microplot with ^{15}N urea applied in a buffer zone outside the microplot. The labelled urea was applied in the buffer zone to discourage plants outside the plot from removing labelled nitrogen from inside the microplot.

The type of microplot had a significant effect on the recovery of fertilizer nitrogen (Table 1). The lowest recoveries were obtained in the square and unconfined plots. In the case of the unconfined microplot the low recovery seemed to be due to removal of plant debris by wind and water erosion. The highest recoveries were obtained in 1m x 0.5m rectangular plot with labelled urea applied in the buffer zones. This microplot design was used for all subsequent studies.

Table 1. Effect of microplot design on recovery of fertilizer nitrogen in plant and soil(% of applied nitrogen)

Type of microplot	Recovery		
	Plant	Soil	Total
Cylinder	40	14	54
Square	27	16	43
Unconfined with buffer	26	21	47
Rectangle	33	21	54
Rectangle with buffer	39	25	64
l.s.d.	7	2	8

Effect of time of application

For convenience some growers apply fertilizer nitrogen early, such as at the time of listing after a previous wheat or cotton crop; other growers side-dress nitrogen close to the time of peak demand. Experiments were conducted in each of two growing seasons to determine the effect of time of application on nitrogen loss and utilization by the plant. Urea fertilizer was banded 0.20 m below the hill either (i) after incorporating wheat residues between January and March, (ii) after incorporating cotton residues in May or June, or (iii) 21 days before sowing,

When urea was banded in March or June 1988, by the time the cotton crop emerged in October, 74% and 21% of the applied nitrogen, respectively, had been lost from the soil. In 1989, urea was banded in January or May, and at sowing 92% and 73% of the applied nitrogen, respectively, had been lost from the soil (Fig. 1). There was no evidence for leaching of the fertilizer nitrogen below the root zone, and it is concluded that the nitrogen was lost by denitrification following the heavy rain which fell in the autumn of 1988 and 1989. On both occasions the amount of rain was greater than 95% of that which fell in previous years. The significance of these losses can be gauged by the results of a parallel field trial (1988/89) using anhydrous ammonia. Lint yield from a February application was 10% lower than yields from August and September applications.

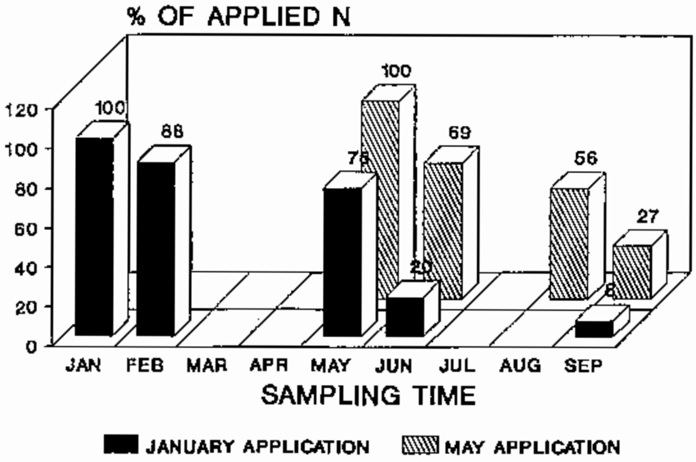

Fig.1 Nitrogen recovery in soil following urea application in January and May.

When urea was applied in September to cotton growing in a continuous cotton rotation, the plants had recovered only 27% of the applied nitrogen by mid-February, 23% remained in the soil and 50% had been lost. When the experiment was repeated in the following season on a more fertile cotton/wheat rotation site, the plants had recovered 55% of the applied nitrogen by mid-February and 31% of the applied nitrogen remained in the soil (i.e. 14% had been lost) (Fig.2).

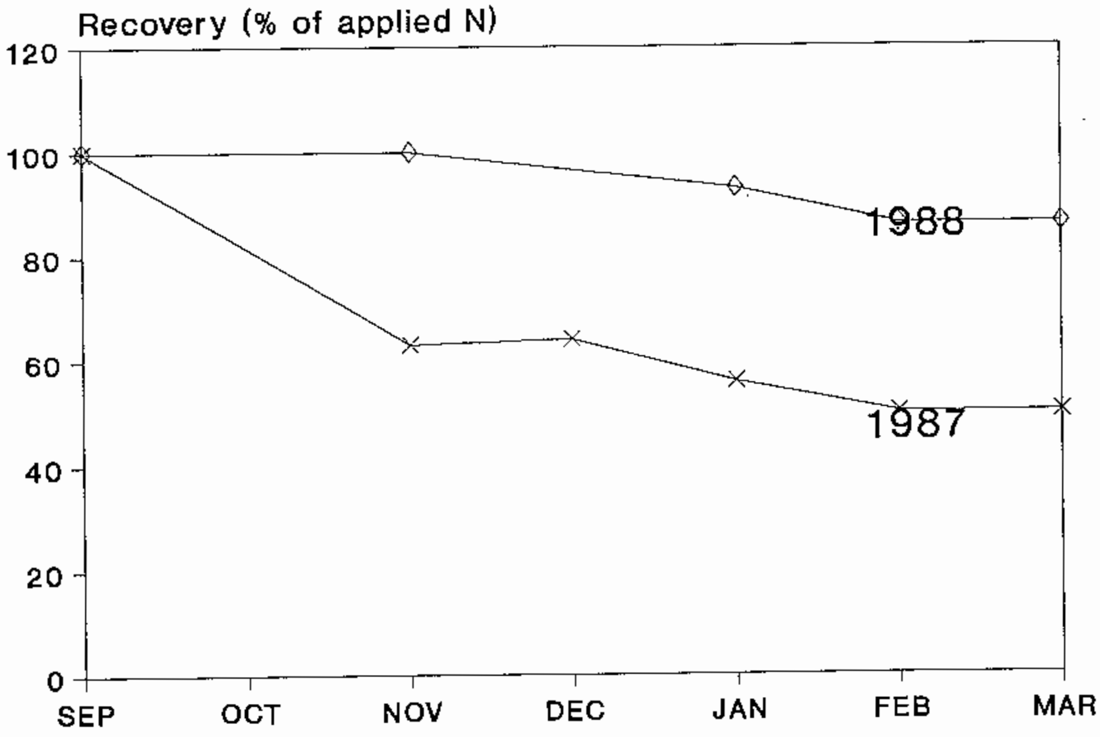

Fig. 2. Recovery of September applied nitrogen in plants and soil at maturity

Thus the efficiency with which cotton plants can recover the applied nitrogen varies greatly. The cotton plants on the cotton/wheat site grew much more vigorously than the plants on the impoverished continuous cotton site and presumably were able to compete much more strongly for the fertilizer in the soil before it could be lost by denitrification. In both experiments most of the fertilizer nitrogen was taken up by the cotton between mid November and early January.

The microplot results show that the maximum lint yield and maximum recovery of applied nitrogen was obtained when the fertilizer was applied as a side dressing in November (Fig. 3).

Essentially the same amount of nitrogen was recovered from the application on 22 January 1990 as with the November application, but the January application was too late to cause increased yield (Fig.3).

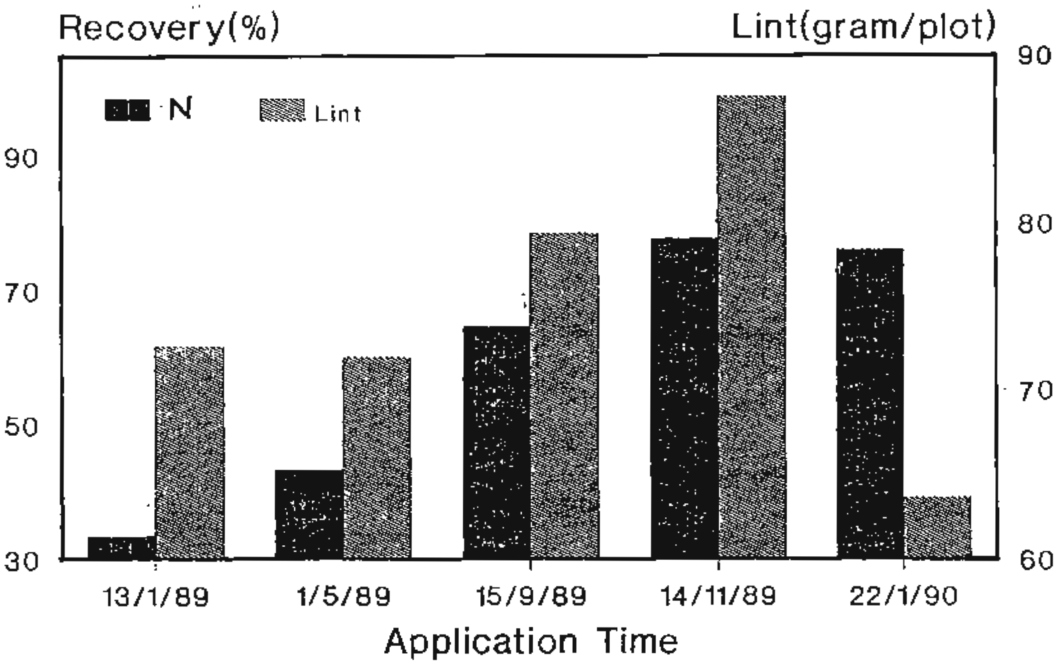

Fig. 3. Effect of time of fertilizer application on cotton lint yield and recovery of applied nitrogen (%) in the plant-soil system at maturity.

Water-run urea

Urea (84 kgN/ha) was applied in solution in furrows to a circular area (diameter 50 m) on 14 December and ammonia loss was determined with a micrometeorological method. The amount of ammonia lost during the first five days after application (the period of greatest risk) was negligible.

Microplot experiments with ^{15}N labelled urea were started at the same time as the ammonia volatilization experiment and harvested on 19 December, 12 and 28 January, and 16 February. The ^{15}N balance study carried out on 19 December confirmed the ammonia loss data. Totol nitrogen loss from the fertilized area five days after fertilization was less than 5% of the nitrogen applied. The fate of the applied nitrogen depended on the ability of the plants to compete with soil microorganisms for the nitrogen. In a trial at Auscott where the plants grew vigorously, by the time of maximum nitrogen uptake, the plants had taken up 58% of the applied nitrogen and 26% had been immobilized in the soil. Only 16% was lost by denitrification. However, at the same time on an impoverished site in a continuous cotton rotation, the cotton plants recovered only 28% of the applied nitrogen, 24% was immobilized in the soil and 48% was lost by denitrification. Plant growth on the cotton/cotton site was poor and the dry weight of the plant tops was only 25% of that at Auscott at the time of fertilizer application. At the impoverished site plant and soil recoveries of water-run urea were similar to the recoveries of nitrogen from urea banded at 0.20m depth three months earlier.

Fate of foliar applied nitrogen

It was apparent that whenever nitrogen was applied, or transferred to the soil, losses of nitrogen by denitrification occurred. One method of overcoming denitrification losses is to apply the nitrogen to the plant, as a foliar spray, rather than to the soil, and we investigated the fate of nitrogen fertilizers applied in this way. Two attempts were made to measure ammonia loss from foliar applications of urea, ammonium nitrate and ammonium sulfate, and both attempts were confounded by rain. On the second occasion the three fertilizers (11 kg N/ha) were applied to circular areas at Auscott on 9 February. Rain (65mm) fell soon after fertilizer application. Small ammonia losses were detected from all three sources, but the total ammonia loss after five days was less than 0.2 kg N/ha. The emission was probably due to the rain washing the fertilizers off the plants to the soil, rather than by direct emission from the plants to the atmosphere.

In a subsequent experiment labelled nitrogen, and an additonal nitrogen source, ("Easy N", a solution of urea and ammonium nitrate) were used. All fertilizers were applied at the rate of 20 kg N/ha. Even though all efforts were made to keep the applied nitrogen off the soil it was apparent that some of the foliar spray had penetrated the plant canopy and lodged on the soil surface. When the plants in the microplots were harvested seven weeks after application, recovery of applied nitrogen in the plants ranged from 51% to 62% with "Easy N" performing better than the other nitrogenous sources. Recoveries of applied nitrogen in the plant-soil system varied from 73% to 87%, with the maximum being recovered from Easy-N (Table 2).

Plant recoveries of urea nitrogen applied as a foliar spray in January or banded in September were similar (55%). However, the distribution of the nitrogen in the plants from the two experiments was quite different; 35% of the foliar applied nitrogen was found in the bolls compared with only 15% from banded urea (Table 2).

Table 2. Recovery of nitrogen applied in January as a foliar spray (20 kg N/ha) compared with urea banded in soil in September.

Source	AN	AS	Easy N	Urea	Banded
Stems	4	4	4	3	10
Leaves	18	20	21	17	28
Burr	8	9	11	8	10
Lint	4	3	4	5	1
Seed	17	14	22	22	4
Total plant	51	51	62	55	55
Soil	22	31	25	18	31
Plant & soil	73	81	87	74	86

Use of nitrification inhibitors to decrease losses from banded applications in September

As the nitrogen is lost by denitrification, reducing nitrate production by addition of nitrification inhibitors seems to be a logical method of reducing loss. However, few nitrification inhibitors are available commercially and all of them have limitations to their usefulness. It has been established that acetylene is a potent inhibitor of nitrification (e.g. Walter et al. 1979), but because it is a gas there are problems in introducing it into the soil in the field and maintaining it at the required concentration to limit nitrification during the growing period of the crop. This problem may be overcome by the use of wax-coated calcium carbide to provide a slow-release source of acetylene, or by the use of non-gaseous acetylenic compounds such as 2-ethynylpyridine or phenylacetylene, which have proved to be effective inhibitors in laboratory studies (McCarty and Bremner 1986).

The effectiveness of wax coated calcium carbide, 2-ethynylpyridine, phenylacetylene and the commercially available compound nitrapyrin to inhibit nitrification, reduce nitrogen loss and increase lint yield of cotton was evaluated in microplot studies and a large scale field experiment at Narrabri.

Addition of the compounds, nitrapyrin, wax-coated calcium carbide, phenylacetylene and 2-ethynylpyridine did not result in a significant increase in dry matter yield of cotton plants grown in the microplots (Table 3). However, the yield of cotton seed was increased by 21% ($P < 0.05$) over that of the control plants by the addition of nitrapyrin, and by 29% ($P < 0.01$) by the addition of 2-ethynylpyridine (Table 3). A 23% increase ($P < 0.01$) in lint yield and a 21% increase ($P < 0.05$) in the dry weight of bolls were also obtained by the addition of 2-ethynylpyridine. The dry matter yields of the other plant components were not significantly increased over those of the control treatment by the addition of any of the compounds.

Table 3. Effect of nitrification inhibitors on dry matter yield of cotton (g m^{-2}) grown in enclosed 0.5 m x 1 m microplots.

	Plant component							
Treatment	Husks	Seed	Lint	Bolls	Roots	Stems	Leaves	Total
Control	123	213	159	495	58	261	124.	938
Nitrapyrin	119	257	178	554	54	256	112	976
Calcium carbide	117	215	173	505	55	261	137	958
Phenyl-acetylene	102	222	155	479	51	246	136	912
2-Ethynyl pyridine	127	275	196	599	54	275	152	1079
lsd								
($P < 0.05$)	NS	34	24	79	NS	NS	NS	NS
($P < 0.01$)	NS	50	36	115	NS	NS	NS	NS

Apart from 2-ethynylpyridine, the addition of nitrification inhibitors with urea did not significantly increase the assimilation of applied nitrogen by the individual plant components or uptake of applied nitrogen by the whole plant (Table 3). However, the addition of 2-ethynylpyridine increased the incorporation of applied nitrogen in the seed by 98% ($P < 0.01$) and uptake by the plant by 75% ($P < 0.01$; Table 3).

Table 4. Recovery of applied nitrogen (%) in cotton plants and soil from microplots as affected by addition of nitrification inhibitors

Treatment	Plant	Soil (0 - 0.6 m)	Plant plus soil
Control	29.4	27.8	57.2
Nitrapyrin	36.7	37.0	73.7
Coated calcium carbide	35.4	42.7	78.1
Phenylacetylene	34.0	36.0	70.0
2-Ethynylpyridine	51.3	40.5	91.8
l.s.d. ($P < 0.05$)	10.6	9.3	11.1
l.s.d. ($P < 0.01$)	15.5	13.6	16.2

The addition of the wax-coated calcium carbide and 2-ethynylpyridine increased the recovery of applied nitrogen in the soil (0 - 0.6 m) by 54% and 46%, respectively ($P < 0.05$; Table 4). Recovery of applied nitrogen in the soil/plant system was significantly increased by addition of all of the inhibitors (Table 4), with the greatest recoveries being obtained in the presence of wax-coated calcium carbide (78%) and 2-ethynylpyridine (92%).

The results for the large scale field experiment show that there was significantly more ($P < 0.001$) ammonium nitrogen in the coated calcium carbide treated soil than in the control soil for 8 weeks after fertilizer application. As a result less nitrate was produced in the treatments receiving the inhibitor than in those without the inhibitor. The difference in nitrate content was significant ($P < 0.001$) for more than 5 weeks.

Addition of the wax-coated calcium carbide increased the mean recovery of applied nitrogen by 35% ($P < 0.08$). Lint yield was significantly increased by the addition of fertilizer nitrogen ($P < 0.001$) and wax-coated calcium carbide ($P < 0.05$) (Fig. 4). In the absence of the nitrification inhibitor lint yield responded to the addition of nitrogen up to 180 kg N ha $^{-1}$ (Fig. 4). However, in the presence of wax-coated calcium carbide the shape of the nitrogen response curve was altered, and the maximum yield was obtained at a much lower level of nitrogen addition (Fig. 4). Figure 4 indicates that the inhibitor effect was greatest at zero nitrogen addition and that the effect diminished at higher level of nitrogen addition. It is important to note that the inhibitor helped conserve the indigenous nitrogen in addition to the applied nitrogen.

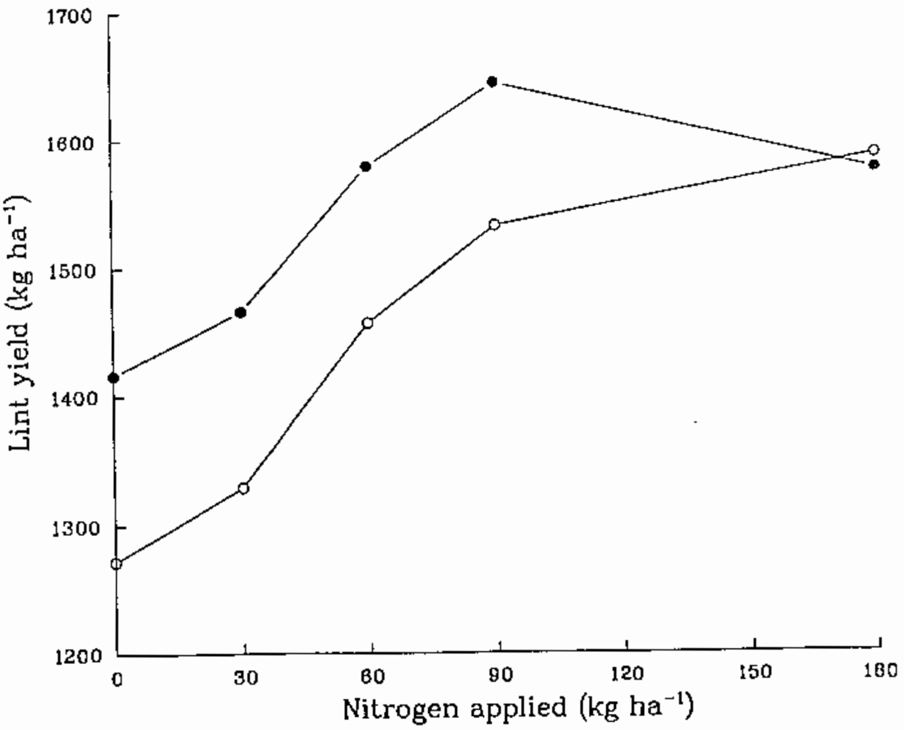

Fig. 4. Effect of wax-coated calcium carbide and nitrogen fertilizer rate on lint yield. O, control; ●, plus inhibitor.

Use of nitrification inhibitors to decrease losses of nitrogen from early applications of urea

We determined the feasibility of using nitrification inhibitors to conserve nitrogen applied early in the year. We studied the effect of applying nitrapyrin (N-Serve), wax-coated calcium carbide and phenylacetylene on the retention of fertilizer nitrogen banded 0.2 m below the hill in summer and autumn. Microplots were established by enclosing the soil with 0.15m diameter polyvinylchloride cylinders and ^{15}N labelled urea (60 kgN/ha) and the required amounts of the inhibitors were placed 0.2 m below the soil surface in February and May. Cylinders of soil were removed at regular intervals up to November and analyzed for ammonium, nitrate and recovery of applied nitrogen.

In the case of the February application little nitrogen was lost during the first five weeks, but in the following four weeks large losses of nitrogen occurred. In the control treatment (minus inhibitor) 60% of the applied nitrogen was lost compared with a mean loss of 32% for the inhibitor treatments. The nitrapyrin was the most effective inhibitor of the three tested. The large loss was associated with an increase in soil moisture content. Nitrogen loss in the subsequent periods was much slower and this reflects the immobilization of the applied nitrogen into organic forms (Fig. 5).

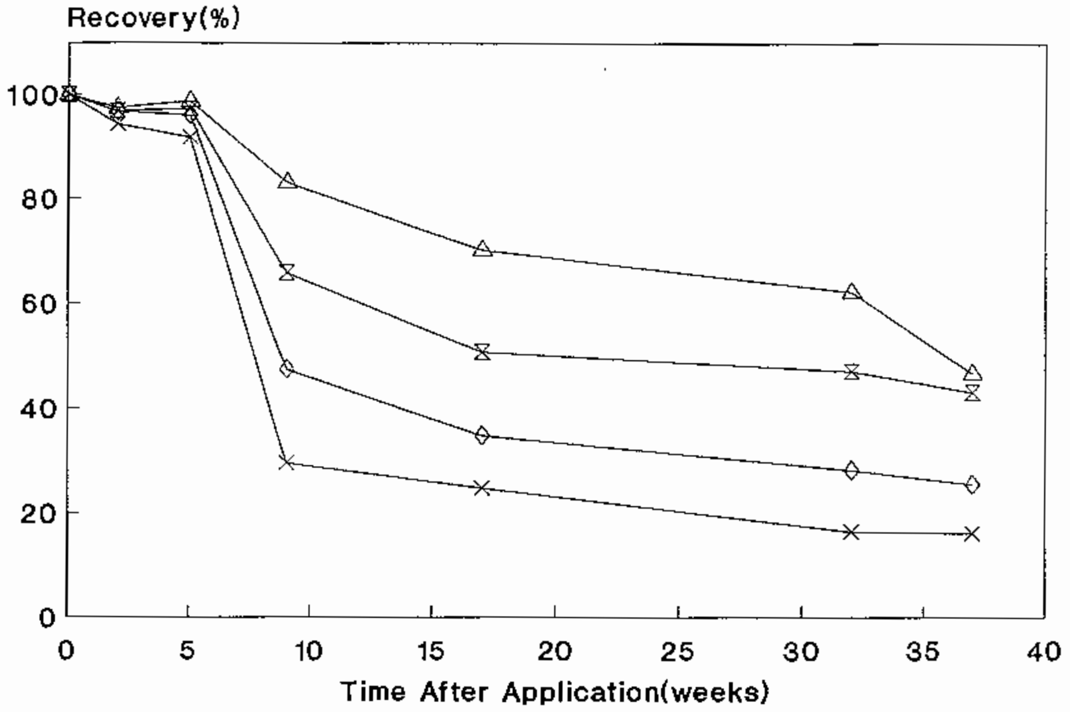

Fig.5. Effect of nitrification inhibitors on recovery of urea nitrogen banded 0.20 m below the hill in February. × , control; ◇ , wax-coated calcium carbide; △ , nitrapyrin; ⧖ , phenylacetylene.

Addition of the inhibitors significantly ($P < 0.05$) increased the amount of fertilizer nitrogen available at planting from 16% in the control to 26%, 43%, and 47%, respectively, for the wax-coated calcium carbide, phenylacetylene and nitrapyrin treatments. The poor performance of the wax-coated calcium carbide was associated with the problem of supplying sufficient of the active compound to the small sized microplot and the probability of selecting wax particles without calcium carbide. As a consequence the rate of inhibitor addition for the May application was doubled.

The results for the May application show that the calcium carbide treatment was markedly improved and there was no significant difference between the inhibitors. The rate of fertilizer nitrogen loss for the May application was slower than that for the February application and this may be attributed to the lower soil temperatures in the winter period (Fig.6). Addition of the inhibitors significantly ($P < 0.05$) increased the amount of fertilizer remaining in the soil at planting time from 28% in the control treatment to 43%, 48%, and 52%, respectively, for the wax-coated calcium carbide, phenylacetylene, and nitrapyrin treatments. While some savings of applied nitrogen result from the use of these nitrification inhibitors, the losses of ~ 50% of the applied nitrogen are still too large. Additional loss of fertilizer nitrogen will occur between planting and harvest. It appears that the current batch of nitrification inhibitors will conserve nitrogen for reasonably short periods only, and thus will be of benefit for applications of fertilizer at or near sowing time only.

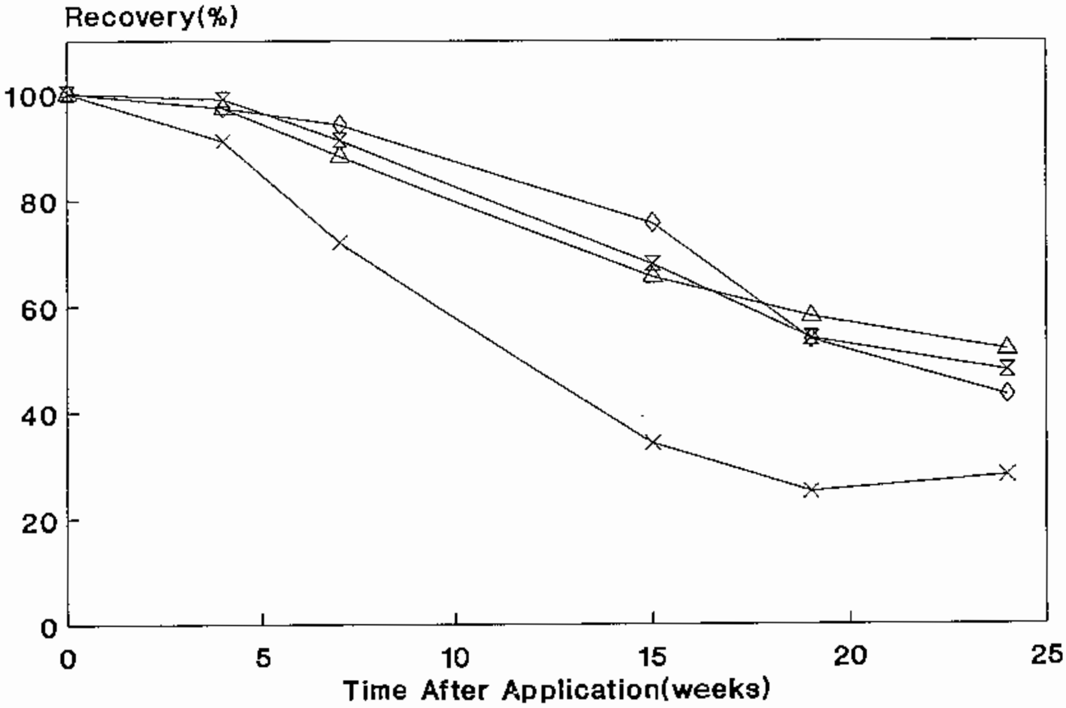

Fig. 6. Effect of nitrification inhibitors on recovery of urea nitrogen banded 0.20 m below the hill in May. X , control; ◇, wax-coated calcium carbide; △ , nitrapyrin; ⧖ , phenylacetylene.

Use of plastic coated fertilizer

We conducted experiments in large scale field plots to determine the effectiveness of plastic coated urea (Meister products)as a source of nitrogen for cotton. As ^{15}N labelled products were not available we were not able to determine recoveries of applied nitrogen. Two of the products were tested viz. Meister 70 and Meister 270. The designations imply that 80% of the nitrogen will be released in either 70 or 270 days. The plastic coating retained fertilizer nitrogen in the soil for 80 to 100 days longer than when uncoated urea was applied. However, neither nitrogen uptake nor lint yield was increased by the application of these products (Fig.7).

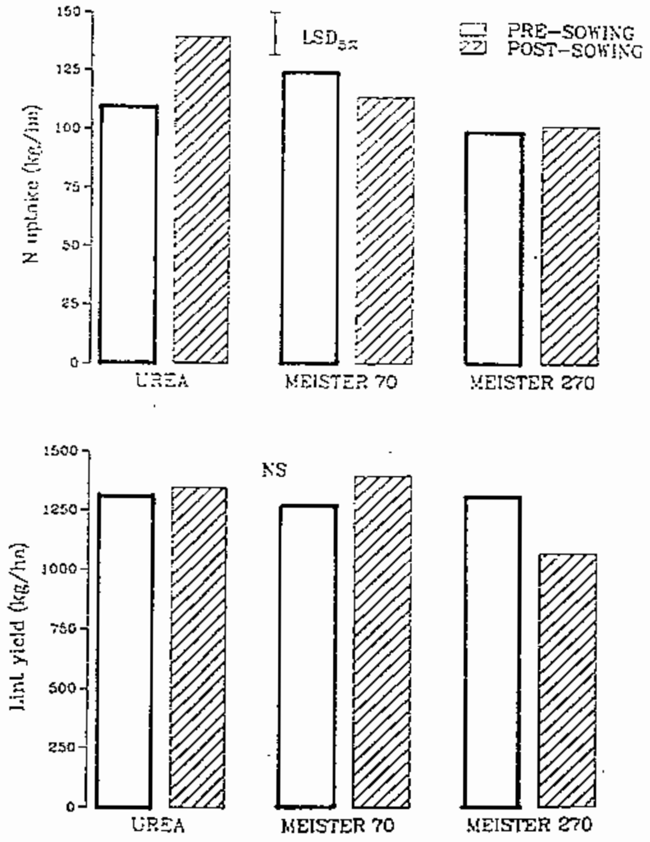

Fig. 7. Effect of plastic coated urea fertilizer on nitrogen uptake and lint yield.

Residual effect of nitrogen applied to cotton on a succeeding wheat crop

An experiment was conducted to determine the residual effect of nitrogen applied to cotton on a succeeding wheat crop, as up to 30% of the nitrogen applied to cotton remained in the soil after active uptake by the cotton had ceased.

Labelled urea was applied to cotton at two rates (60 and 120 kg N / ha) in September 1988. Half of the microplots were harvested in April 1989 and the nitrogen recovered in cotton plants and remaining in the soil determined. In the remaining microplots, the cotton was also harvested in April 1989 and wheat was then sown into these plots. The wheat was harvested in November 1989

After the cotton harvest in April, the amount of fertilizer nitrogen remaining in the soil was 16 kg N / ha (27% of the applied nitrogen) for the low application rate and 19 kg N / ha (16% of the applied nitrogen) for the high rate. The cotton plant tops were slashed and returned to the soil surface. The amount of fertilizer nitrogen remaining in the trash on the soil surface was 12 and 24 kg N / ha, respectively for the initial application rates of 60 and 120 kg N / ha. Thus the total nitrogen in or on the soil after cotton harvest was 28 and 43 kg N / ha for the low and high application rates, respectively.

At harvest in November the wheat plants, on both the low and high application rates, recovered only 1% of the fertilizer nitrogen which had been applied to the preceeding cotton crops. It is apparent that the nitrogen incorporated into the soil organic matter and that in cotton debris is unavailable to a succeeding wheat crop.

Development of the nitrogen model

The aim of the modelling was to incorporate a nitrogen sub-model in the existing cotton crop model at Narrabri (SIRATAC, OZCOT and *hydroLOGIC* - all implementations of basically the same conceptual model) in order to make them sensitive to shortage of nitrogen. These models currently incorporate a very simple nitrogen model that estimates the potential uptake for the season which sets an upper limit to rates of processes in the model and to yield; it is not a daily soil and crop nitrogen budget.

1. Selection of a model. In consultation with Dr R.J.K. Myers of CSIRO Brisbane the soil nitrogen sub-model in CERES models was selected as the most suitable model to modify for our purposes. It was selected in preference to Dr Myers' own models (STAGNATE and NREQ) because it is already being used in Australia by several research groups and because it is integrated with the Ritchie water balance model which we are already using. The level of complexity at which the processes are modelled in CERES is very similar to that in our models.

2. Simulation of soil nitrate. A data set for nitrate and ammonium nitrogen in a fallow soil collected over a three year period by Mr Ian Rochester at the Narrabri Agricultural Research Station was used for validation. The unmodified model faithfully mimicked the pattern of increase in nitrate during spring and summer and decrease during winter but underestimated the level by up to one third.

Several modification were suggested and tried:

1. McCowan proposed changes to the rates of decomposition of various organic matter fractions.

2. Myers suggested modelling nitrification and denitrification as a function of water filled porosity after Nommik (1956).

3. Rochester suggested using nitrate rather than ammonium as the substrate for immobilisation of mineral nitrogen on the basis of his results.

None of these changes made any appreciable improvement to the performance of the model.

Tests with the model showed that it is very sensitive to water movement down the profile; halving the rate of movement in the model gave simulated soil nitrate values close to observed values. It is concluded that CERES N sub-model as received overestimates leaching of nitrate below 30 cm. This conclusion is consistent with our labelled nitrogen studies which show very little, if any, leaching of fertilizer nitrogen below 30 cm. Water movement down the profile was therefore investigated further by theoretical study, literature search and experiment in order to revise the model.

3. Simulation of water movement. The model recognises three forms of water movement: saturated and unsaturated drainage in response to gravity and flow in response to differences in matric potential. Saturated drainage occurs between saturation and the drained upper limit (an empirical estimate of field capacity) and unsaturated drainage below the drained upper limit.

There are distinctive features to water movement in vertisol soils, which include the grey cracking clays on which most cotton is grown in Australia. Water entry through the cracks is rapid, especially with furrow irrigation, and water can enter each layer directly from cracks without having to percolate down through the soil mass. Saturated hydraulic conductivity is very low for the profile as a whole so that there is no clearly identifiable field capacity and the empirical drained upper limit is close to the saturated upper limit.

The model was therefore modified so that irrigation water enters each layer directly without having to percolate down through the soil mass, leaching nitrate as it does so. The model was further modified to take into account the ridge and furrow conformation of the surface layer to allow water to move laterally from the furrow into the ridge.

Drainage was studied in the laboratory with a 900 mm undisturbed soil monolith using Youngs' (1982) method. The rate of drainage decreased exponentially from 263 mm/d in the 0 to 200 mm layer to 4.9 mm/d at 400 to 600 mm. At 600 to 800 mm the rate was too small to measure. These data provide limits to the rate of drainage in the soil layers in the model.

Mason (1979) obtained a soil moisture characteristic curve (the relationship between water content and matric potential) and a relationship between hydraulic conductivity and water content for the soil at the Research Station. These relationships have been used with Darcy's law to improve the estimation of flow between layers.

The effect of these changes in simulation of water and nitrate movement down the profile was not tested before Theiveyanathan resigned.

The improvement of the simulation of water movement within the profile is of great value for estimating water distribution down the profile as well as the estimating nitrate content of the layers. Until now modelling water has been concerned more with the total water content of the profile rather than the distribution down the profile. However in order to reconcile the water balance model with the neutron probe distribution among the layers is important because the model considers the whole profile to 1.3 m while probe users normally only consider the upper 0.7 m.

4. Future developments. The cotton nitrogen modelling project is now poised for advance. However it is not proposed to recruit a replacement for Theiveyanathan because of the difficulties previously experienced.

Instead it is proposed that Dr Doug Godwin be retained as a consultant. Dr Godwin was the major author of the soil nitrogen sub-model in CERES that we are using and has successfully developed it for wheat, maize and rice. There is no one better qualified to develop the sort of soil nitrogen sub-model required.

Difficulties encountered

The main problem encountered during the conduct of the project was the difficulty of appointing and keeping staff. Mr S.Thieveyanthan was appointed to the Experimental Scientist's position at Narrabri in December 1988 to undertake the modelling work, but he resigned on 12 January 1990. He has not been replaced but Dr D.Godwin was retained as a consultant for the modelling work. Dr Humphrey's was appointed to the research scientist's position in Canberra on 4 November 1987 and resigned on 27 August

1989. Mr Chen De-li was appointed to replace her on 31 January 1990 and remained to the end of the project. In spite of the turnover of staff the project has been satisfactorily completed.

Transfer of results

The results of this work have been presented to growers and other scientists at the Australian Cotton Conferences at Surfers Paradise in 1989 and 1991, at the Annual Meetings of the American Society of Agronomy at San Antonio, Texas in 1990, in the Australian Cotton Grower and in the Cotco Report.

Recommendations for future research

The results of the research on the use of wax-coated calcium carbide as a nitrification inhibitor are very encouraging in that it inhibited nitrification for long periods and increased lint yield. At present the coatings are difficult to apply and melt if left in the sun. More effective coatings need to be developed.

Publications and reports

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The Fate of Nitrogen Fertiliser Applied to Cotton.
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2. Freney, J.R., Mosier, A.R., Bronson, K.F.,Constable, G.A.
Rochester, I.J., Smith, C.J., Chen, D.L., and Banerjee, N.K.
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Irrigated Corn, Cotton and Wheat.
Agron. Abs. 1990 : 268.

3. Freney, J.R., Chen, D.L., Mosier, A.R., Rochester, I.J., Constable, G.A., and Chalk, P.M.
Use of nitrification inhibitors to increase fertilizer nitrogen recovery and lint yield in irrigated cotton.
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4. Chen, D.L., Freney, J.R., Mosier, A.R., and Chalk, P.M.
Reducing denitrification losses of early applications of fertilizer nitrogen to cotton fields.
For publication in Fertilizer Research. In preparation.