COTTON RESEARCH AND DEVELOPMENT CORPORATION

Project: DAN 76C Rotopak – developing rotations to overcome soil degradation for irrigated cotton systems.

SUMMARY REPORT

Insect pests, disease, weeds, declining soil structure and fertility are some of the problems the Australian cotton industry faces. Growing other crops in rotation with cotton appears to offer the best prospect for long term viability of the cotton industry. Much of the Australian cotton crop is produced under irrigation in the Macquarie, Namoi and Gwydir valleys of NSW, so a survey was conducted in those valleys, to find out how widely rotation crops are used and which rotation crops growers favour.

In addition to the survey, soil samples were taken from paddocks which had grown cotton continuously for several years, and paddocks which had grown a rotation crop the previous season. The soil samples ware subjected to a wide range of physical and chemical tests to see what differences could be measured.

A major objective of this project was to co–ordinate, and ensure proper planning of, future rotation research in the cotton industry. To help achieve this, a review meeting was held at Narrabri, which involved all key workers in cotton soils and rotation research, plus representatives of the cotton industry.

The cotton survey had a good response with over half the growers in NSW contacted. The extent to which individual growers used rotations varied widely, but on average, cotton fields grew a rotation crop one year in 4, with the use of rotations likely to increase in future. Wheat was the crop most frequently grown in rotation with cotton, but there was widespread interest in the use of legumes. Many farmers were developing rotation cropping systems, but they had a lot of questions which only research could answer eg. which crop is best for soil structure, how much nitrogen do different legumes provide, do rotations crops differ in their effect on weeds, disease, insects, VAM etc, and does management of the rotation crop affect subsequent cotton crops.

The comparison of continuous cotton fields and those growing rotation crops found that the differences are small and difficult to measure. Field measurements of soil structure (shear strength and Soilpak score) could not detect any differences. The only tests to show up differences were dispersion index, plastic limit, % of coarse particulate organic matter and soil respiration rate.

Looking at the history of the sites revealed that management of stubble from the previous crop is important. Soil structure was better at sites which retained the stubble compared to sites where the stubble was burnt. This is important given the widespread use of raking and burning for back to back cotton.

Although cropping history had little effect on the soil properties measured, there were many significant differences between the soils of the Macquarie and Namoi valleys. This means that great care should be taken when extrapolating results from one valley to another.

The research co-ordination meeting at Narrabri has resulted in close liaison between NSW Agriculture, CSIRO, University of Sydney, Qld Department of Primary Industries, University of New England and Brisbane University. Several follow up meetings have been held, one result of which is that the NSW Agriculture rotation experiment and the Co-operative Research Centre for sustainable cotton production are using a common site in the Macquarie valley.

ABSTRACT

Growing other crops in rotation with cotton appears to offer the best prospect for long term viability of the cotton industry. Growers in the Macquarie, Namoi and Gwydir valleys of NSW, were surveyed to find out how widely rotation crops are used and which rotation crops growers favour. Also, soil samples were taken from paddocks which had grown cotton continuously for several years, and paddocks which had grown a rotation crop the previous season. The soil samples were subjected to a wide range of physical and chemical tests to see what differences could be measured.

The survey contacted over half the cotton growers in NSW, and found that on average, cotton fields grew a rotation crop one year in 4. Wheat was the crop most frequently grown in rotation with cotton, but there was widespread interest in the use of legumes. The survey also obtained data on problems growers had encountered with rotations, what benefits they saw, and what research growers would like done.

The comparison of continuous cotton fields and those growing rotation crops found that the differences are small and difficult to measure. The only tests to show up differences were dispersion index, plastic limit, % of coarse particulate organic matter and soil respiration rate. Stubble management appeared to be just as important as cropping history. Soil structure was better at sites which retained the stubble compared to sites where the stubble was burnt.

INTRODUCTION

Soil degradation is a serious problem facing cotton production in most regions of Australia, especially the river valleys of north western N.S.W. where most of Australia's cotton is produced. Several studies have documented the decline in soil structure and yield decreases of up to 30% with continuous cotton production in the Namoi and Macquarie valleys (Chan 1982, McGarry and Chan 1984, McKenzie et al. 1990). The Cotton Research Council funded project DAN 13L, "Restoration of soil structure in cracking clays" has shown that wheat and safflower crops can improve soil structure, but interacted with nitrogen nutrition in their effect on a subsequent cotton crop. The recommendations for future research from this project and the Cotton Research Council funded project DAN 6L, 'Improved irrigation techniques for cotton production in the Macquarie Valley' indicate that more work is needed on rotation crops for use with cotton.

Two thirds of the cotton grown in the Macquarie valley, and most of that in the Namoi, Gwydir and Macintyre valleys is grown on soils which have, or could develop soil structure problems. A 30% yield reduction in just the Namoi and Macquarie regions would represent a loss of 158,400 bales of cotton or $63 million.

Once a soil has been degraded it is an expensive, difficult, and often slow process to restore the soil. For the long term sustainability of the cotton industry, therefore, it is important to minimise and if possible avoid soil degradation.

Past research has shown that some rotation crops can improve soil structure, and the need for research on rotation crops in the cotton industry was given number 1 priority at an Engineering and Soils Research Workshop in Toowoomba (McGarry and Porter 1991).

The project reported on here (DAN 76C) was a preliminary study to provide background information for future long term field trials. Those trials will determine the best crops to use in rotation with cotton to maintain soil structure, and how to manage the rotation crops to get maximum benefits.

OBJECTIVES

1. To survey cotton growers and determine: the extent to which growers currently use rotation crops, what features they want in a rotation crop, and what research they would like done.

2. To document the effect of continuous cotton production on soils in the Namoi and Macquarie valleys, by comparison of paired sites which had grown rotation crops or continuous cotton.

3. To review the literature and analyse data from previous rotation experiments. This will provide a sound basis for future research and avoid any duplication.

4. To conduct a workshop on rotations and related soils/tillage research. An outcome of the workshop will be an agreed approach to implementation of new cotton rotation research.

RESULTS AND DISCUSSION

Survey of rotations used by cotton growers

Approximately 60% of all cotton produced in NSW was covered by the survey, with 157 growers contacted. In the Macquarie Valley 95% of cotton growers were surveyed, while in the Namoi and Gwydir Valleys just over 50% of growers were contacted. For a survey this is a high proportion of growers contacted, and the results should accurately represent the whole industry.

Details of the number of growers contacted in each valley and the proportion that had used rotations are presented in Table 1.

Table 1. Number of cotton growers contacted in each valley, the area of cotton produced by those growers, and the number of growers using rotations.

	Macquarie	Namoi	Gwydir
No. of growers surveyed	59	49	49
Area of cotton planted by those growers in 1992/93	30,666ha	22,005ha	36,033ha
% of growers that have used rotations	53%	82%	78%

The technique used for the survey was to send a copy of the survey form to all cotton growers, along with a letter explaining the purpose of the survey. Mr Cooper then telephoned each grower and recorded the answer to each question. This allowed Mr Cooper to explain if a grower had difficulty understanding a question. This personal contact was probably responsible for the high proportion of survey forms completed.

A copy of the survey form and the letter sent to all growers is in Appendix 2. Detailed results of the survey (a copy of which was sent to all participating growers) are presented in Appendix 2 also.

Many of the growers' comments about how often they use rotations were subjective. In order to get some precise data, growers were asked what each paddock growing cotton this season (1992/93) had grown the previous season. The results in Figure 1 show that 62% of this year's cotton was grown back to back on country that grew cotton last year. Just over a quarter of this years cotton was grown on country that had grown some type of rotation crop last season. By far the most widely grown rotation crop is wheat, but growers listed 20 different crops that they had tried.

Figure 1. Previous history of the 1992/93 cotton crop
Crops with 0.5% of the area or less grouped as Other

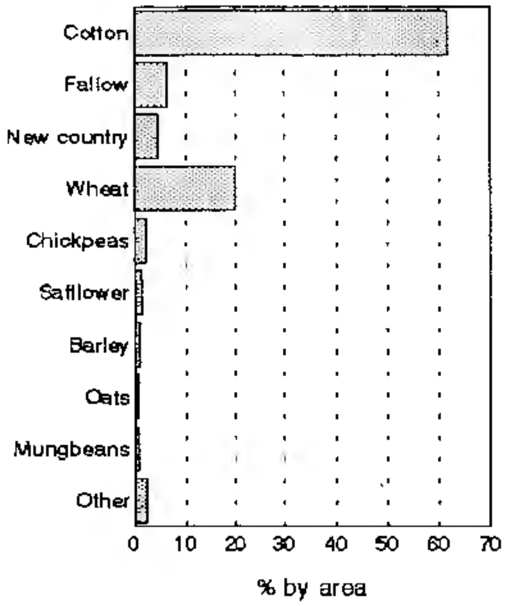
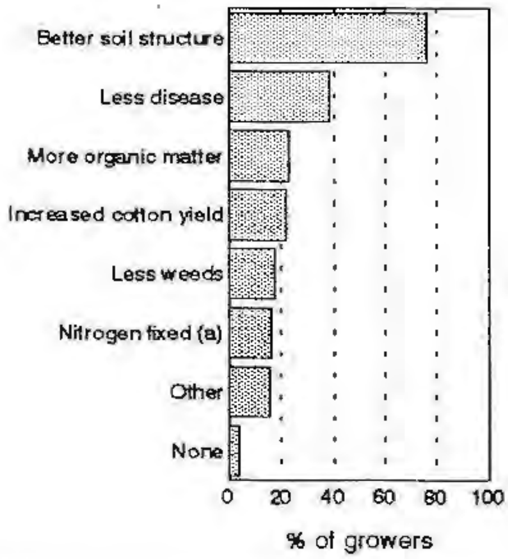
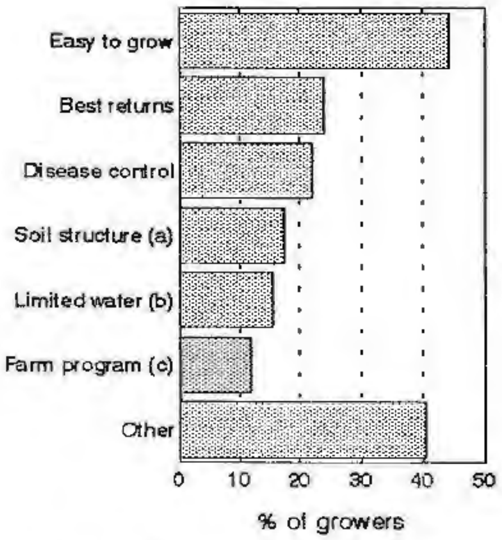


Figure 2. Benefits growers claimed to get by using rotation crops



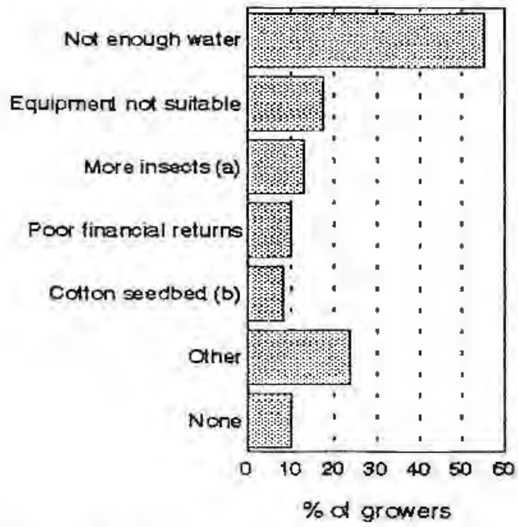
(a) Only applies to those people using a legume as the rotation crop

Figure 3. Reasons why growers preferred the rotation crop they used most frequently



(a) the rotation crop was the best for soil structure
(b) rotation crop chosen because it does not need irrigation
(c) rotation crop does not compete for labour or machinery

Figure 4. The problems farmers encountered when growing other crops in rotation with cotton



(a) for example, more mites following safflower.
(b) difficult to prepare a good seedbed - mainly after summer crops

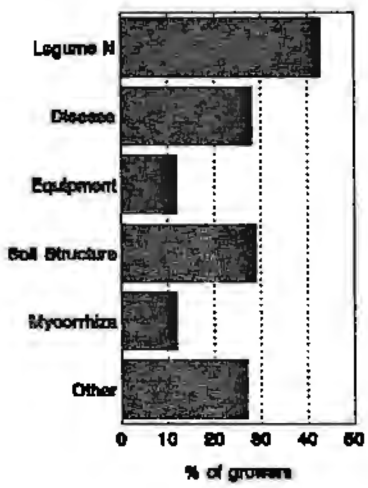
About two thirds of the growers surveyed have used rotation crops in the past 5 years. To try and establish why producers had selected various rotation crops, they were asked what benefits or problems they had seen with rotation crops, and what factors influenced their choice of rotation crop.

The benefit from using a rotation crop which most people claimed was improved soil structure (Figure 2). It is interesting to note however, that only 22% of growers reported an increase in cotton yields, although several times as many claimed to have improved soil structure, reduced disease carry over or reduced weed infestations.

Assuming that a grower planned to put in a rotation crop, convenience was the main factor that decided which crop he would use (Figure 3). 44% of people said they looked for a crop that was easy to grow when deciding which rotation crop to use. This largely explains why wheat is so popular as a rotation crop. Most growers have had some experience with dryland wheat, seed is readily available, many people already have the equipment to sow and harvest wheat, it is a hardy plant and has few pest problems.

The problem nominated by most people was lack of irrigation water (Figure 4). At the time of the survey the Namoi Valley had a 15% water allocation, and the Gwydir Valley zero allocation, so it is not surprising that many growers saw restricted water allocations as a major problem. A lack of suitable equipment to sow rotation crops ranked as the second biggest problem, largely due to the high number of growers in the Macquarie Valley who saw it as a problem. I suspect the reason it was seen as a bigger problem in the Macquarie Valley is because many of these people only started growing cotton recently. It takes some time to find the right equipment and the best sequence of operations to handle new problems such as sowing into cotton stubble. Many of the other problems were specific to certain rotation crops. For example: mites in the cotton following safflower or sunflowers; wireworms in the cotton were more frequent after wheat; volunteer plants of sunflower and some other crops can become weeds in a following cotton crop.

Figure 5. Areas in which growers would like more research



When asked what research on rotation crops growers would like to see, the most frequent reply was more studies on nitrogen fixation by different legumes and the rate of release of that nitrogen (Figure 5). Also of concern were the effects of rotation crops on soil structure, and disease incidence in the following cotton crop. The effect of rotation crops on Mycorrhiza populations, and better equipment to sow rotation crops into cotton stubble, were the other fields where a large number of growers would like to see more research.

Paired site comparison

This part of the project aimed to document soil conditions under continuous cotton production, compared to those where a rotation crop precedes the cotton crop. Five properties in the Namoi valley and 5 properties in the Macquarie valley, with uniform soil and the required cropping histories were chosen. On each property, 2 paddocks with similar soil but a different cropping history were selected. One paddock had grown cotton continuously for 2 or more years, while the other paddock was growing its first cotton crop after a rotation crop such as wheat. Paddock histories for each property are presented in Table 2.

Table 2. Number of years of continuous cotton, and the preceding rotation crop, for each property in the paired site comparison.

Property	Years of Cont. Cotton	Rotation Crop
Namoi valley		
202	3	Faba beans
221	2	New development
223	2	Chickpea/Lab lab
262	3	Wheat
273	3	Barley
Macquarie valley		
110	3	Field peas
121	5	Wheat
135	3	Safflower
149	3	Wheat
160	7	Sorghum

In each field, 3 pits were dug by hand. At the surface, 20 cm and 40 cm depth, soil strength was measured with a shear vane, and soil structure was rated using the Soilpak system. Soil samples were collected from each depth and taken back to the laboratory for further analyses. Sub–samples were sent to:

1. Rydalmere – for chemical analysis by the NSW Agriculture laboratories.
2. Narrabri – for physical analyses by Dr N. Hulugalle at Narrabri Agricultural Research station.

3. Armidale – for fractionation of the organic matter. These analyses formed the experimental work for an honours thesis by Miss W. Crook, a University of New England, Rural Science student, supervised by Dr D. Macleod.

Soil Structure – Field Assessment Cropping history had no effect on soil structure, whether it was measured with a shear vane, or visually rated using the Soilpak system (Appendix 3). Soil strength was significantly better (lower) in the Macquarie valley than the Namoi, but there was no difference between the valleys in Soilpak score. There were big differences between depths in soil structure; as depth increased soil structure declined.

Chemical Analyses There were significant differences between the 2 valleys in the cation exchange capacity of the soil, sodium %, calcium magnesium ratio, and total nitrogen (Appendix 3). Cropping history did not affect any of the chemical parameters measured. Depth on the other hand, affected all chemical parameters except exchangeable calcium and electrical conductivity.

Physical Analyses Significant differences between cropping histories were found for several physical tests, especially in the Macquarie valley (Appendix 3). Planting a rotation crop reduced the dispersion index and plastic limit, it increased the amount of coarse particulate organic matter, and resulted in a higher clay content at the soil surface. These effects were more pronounced in the Macquarie valley than in the Namoi valley. This is probably because the average duration of continuous cotton on the properties selected in the Macquarie valley was longer than that in the Namoi valley (Table 2).

Dispersion index and other physical tests indicated that soil conditions were better where cotton stubble was retained (incorporated or mulched) compared to sites where the stubble was burnt (Appendix 3).

Organic Matter Fractionation Miss Crook is still analysing her samples, but preliminary results show close agreement between results obtained using the University of New England methods and the organic matter measurements made by Dr Hulugalle at Narrabri.

Review of the literature and past research

A review of the literature on rotations was carried out by D. McKenzie, and is to be included in a paper for Australian Journal of Soils Research entitled 'The response of irrigated cotton to changes in the structure of a vertisol after wheat, safflower and bare fallow'. Data from past soils research by NSW Agriculture, in the Macquarie Valley, were analysed by Phillipa Tolmie who was employed as a Technical Officer for 3 months. The data will be used in a series of papers about this work, but the titles have yet to be finalised.

Cotton soil research coordination meeting

The above meeting was convened by D. McKenzie and held at Narrabri Research Station on 8 and 9 December 1992. A full written report on this meeting is currently being prepared.

The meeting involved 45 participants from CSIRO, NSW Agriculture, Qld Department of Primary Industries, several universities, the cotton industry, and others. Reports were presented on all recent or proposed research on soils and rotations, which relate to the cotton industry. A general discussion at the end of the meeting formulated general guidelines for future research.

Unfortunately, few firm decisions could be made because the future of the Co-operative Research Centre (CRC) for sustainable cotton production was not known at the time of the meeting. Much of the proposed rotation research overlapped with projects planned by the CRC. An additional meeting was held at Narrabri on 5 May 1993 to co-ordinate research funded by Cotton RDC and that proposed by the CRC.

DISCUSSION

The project was successful in each of its objectives. The survey was well received by cotton growers, and the percentage of growers contacted was very high. Therefore the results should be very accurate. As well as focusing rotation research on the needs of the farmers, the survey provides baseline data so changes in rotation practices over time can be measured.

The paired site comparison did not show big differences between paddocks which had grown continuous cotton and those which grew rotation crops. However, this work did provide a lot of useful information for future research. It found that the soils of the Namoi and Macquarie valleys are different in their physical and chemical properties, therefore caution is necessary when extrapolating results from one valley to another. It also showed that detailed measurements, particularly of soil physical properties, are necessary to detect the effects of different rotations. Because there were few measurable changes in soil properties, it is important for future research on rotations to have an integrated approach studying insect populations, weed densities, mycorrhiza populations and overall economics.

More than 45 research workers and industry representatives were involved in the research co-ordination meeting held at Narrabri. This meeting was very effective in making researchers aware of what other work is under way. There have been several follow up meetings. One immediate result of these meetings is the Co-operative Research Centre for sustainable cotton production, and the NSW Agriculture cotton rotation project (funded by Cotton Research and Development Corporation) are using a common site in the Macquarie valley. This avoids duplication and means more research can be done with the same money.

CONCLUSIONS, RECOMMENDATIONS AND APPLICATION TO INDUSTRY

This project does not have many direct benefits for the cotton industry, most of the benefits will be better design, and better co-ordination of rotation crop research in the next few years.

The survey of cotton growers found most are aware that rotations are desirable, but they lacked information about the actual benefits derived from rotations, when to use rotations, what is the best rotation crop, and how best to manage rotation crops. The survey identified a number of areas where more research is needed, and these are listed below -

What are the benefits of rotation crops. Is it better soil fertility, better soil structure, reduced disease carry over, increased mycorrhizal activity etc.

Do different rotation crops give different benefits.

Does management affect the benefits from rotation crops.

What is the best way to establish rotation crops.

What is the best way to handle crop residues.

Develop better equipment to handle cotton stubble.

How much nitrogen do legume crops provide.

This information will help research focus on the real problems as seen by farmers. The survey has also provided baseline data on current rotation practices. This will allow people to look at changes in rotation practices, and see whether the needs of the industry are changing.

The cotton soil research coordination meeting has brought together the CSIRO, Qld Department of Primary Industries and NSW Agriculture, who are all working on cotton rotations. The original meeting and several subsequent meetings, have led to much more discussion amongst the organisations, and better co-ordination of their research efforts. A good example of this is in the Macquarie valley, where the cotton rotation experiment set up by NSW Agriculture and funded by Cotton Research and Development Corporation, is also the site for work by the Co-operative Research Centre for sustainable cotton production.

The paired site comparison showed that many of the effects of rotation crops are subtle, so careful and detailed experiments are needed to detect differences and explain why rotation crops have caused differences. The paired site comparison found no effect of cropping history for a wide range of chemical tests, nor for field measurements of soil structure. Only detailed soil structure measurements in the laboratory showed any difference between fields which had, or had not, grown a rotation crop. As well as careful and detailed experiments, this work emphasises the need for integrated research with concurrent research studying carry over effects for weeds, disease and insects.

COMMUNICATION OF RESULTS

- Cooper, J. (1993) Cotton rotations: what are growers using and why? The Australian Cottongrower **14**(2): 7–8.

This article summarised the main results of the survey of cotton growers in a form which could be easily understood by all producers.

- Cooper, J. (1993) Survey of crops used in rotation with cotton in the Macquarie, Namoi and Gwydir valleys of New South Wales. Report prepared by NSW Agriculture, Agricultural Research Centre, Trangie. 8 pages.

A copy of this report, with detailed results of the survey of cotton growers, was sent to all growers who participated in the survey, plus some industry representatives.

- Hulugalle, N.R. and Cooper, J. (1993) Effect of crop rotation and residue management on soil properties of cracking clays in irrigated cotton–based farming systems of New South Wales. Submitted to Land Degradation and Rehabilitation.

This research paper is based on data from the paired site comparison.

- McKenzie, D.C. (1993) Cotton soil research coordination meeting. Proceedings of the meeting held at Narrabri Research Station, 8 and 9 December 1992.

These proceedings, which are at the final draft stage, will be distributed to all industry leaders, and all researcher institutions involved in this work throughout Australia.

- McKenzie, D.C. et al. ( ) The response of irrigated cotton to changes in the structure of a vertisol after wheat, safflower and bare fallow. Australian Journal of Soils Research. In preparation.

- Crook, W. (1993) Crop rotations and their effect on the organic matter aspects and aggregate stability of a cracking clay in the Namoi Valley, NSW. University of New England, Bachelor of Natural Resources, Honours thesis.

This thesis is still being prepared and will be submitted late in 1993. The experimental work for this thesis used soil samples collected as part of the paired site comparison.

APPENDIX 1. Budget

Total Budget

Cotton Research and Development Corporation	$ 20,950
NSW Agriculture	$156,000
TOTAL	$176,950

Cotton Research and Development Corporation

This project was for 1 year and the funds contributed by Cotton RDC are shown in the table below.

Item	1992/93		1993/94		1994/95	
	Original estimate $	Now requested $	Original estimate $	Now requested $	Original estimate $	Now requested $
A STAFFING						
Casual assistance	9 280	9 280				
TOTAL STAFFING	9 280	9 280	nil		nil	
B TRAVEL						
Literature review	400	400				
Survey	2 000	1 000				
Paired site comparison	800	1 800				
TOTAL TRAVEL	3 200	3 200	nil		nil	
C OPERATING						
Survey	4 700	3 700				
Paired site comparison	3 520	4 520				
Literature review	250	250				
TOTAL OPERATING	8 470	8 470	nil		nil	
D CAPITAL (Itemise)						
TOTAL CAPITAL	nil	nil	nil		nil	
TOTAL REQUESTED	20 950	20 950	nil		nil	

NSW Agriculture

NSW Agriculture provided the salaries and support facilities for Mr Cooper and Mr McKenzie who conducted this project. The contribution from NSW Agriculture is estimated as $156,000.

APPENDIX 2.1 Survey of cotton growers – Accompanying letter

NSW Agriculture
Research Centre
Trangie NSW 2823
Phone 068 887404
Fax 068 887201
31 August 1992

SURVEY OF CROPS GROWN IN ROTATION WITH COTTON

Dear Cotton Grower,

The Cotton Research and Development Corporation is concerned that cotton yields may decline unless we use rotations or similar measures to maintain soil structure and fertility. The Corporation has asked NSW Agriculture to survey growers to find out how much cotton is grown in rotation with other crops such as wheat, safflower or field peas, and what problems growers have encountered with rotation crops.

I am asking 150 farmers in the Macquarie, Namoi and Gwydir valleys to fill in the survey. I would be most grateful if you could spare the time to participate in this survey.

Enclosed is a copy of the survey form. DON'T fill it in. Instead I will contact you by telephone between 6 and 9 pm during the next 2 weeks and fill in the survey when I speak to you.

I have sent the survey form to you so that you can be prepared for the questions I will ask. I would appreciate it if you could look up your cotton acreage and have the information readily available when I call. All information collected will be confidential.

The survey will bring together the experience of growers throughout the state. A summary of the results will be published for the benefit of all cotton growers. The published results will be averages for the state or each river valley, not information for an individual grower. Also, the information will help us design experiments to accurately measure the benefits of rotation crops in cotton production.

Thank you for your time and co-operation.

Yours sincerely

Jack Cooper
Research Agronomist

APPENDIX 2.2 Survey of cotton growers – Survey form

SAMPLE SURVEY FORM – these are the questions I will ask when I ring up to conduct the survey.

COTTON ROTATIONS SURVEY

1. What area are you sowing to cotton this year

______________________________ ha / acres

2. For each paddock you are planting to cotton this year, what did it grow last season (eg. cotton, wheat, pasture, fallow etc.)

Paddock 1____________________________________ area:_______

Paddock 2____________________________________ area:_______

Paddock 3____________________________________ area:_______

3. Have you grown other crops in rotation with cotton during the past 5 years

YES Go to question 5
NO Go to question 4

4. What problems, if any, do you see in using rotations with cotton
For example – Not enough irrigation water, Hard to prepare seedbed for rotation crop, Need extra labour, Need extra machinery

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END OF SURVEY FOR PEOPLE WHO HAVE NOT USED ROTATIONS

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5. What crops have you used in rotation with cotton during the past 5 years

6. Which one do you grow most frequently

Why do you prefer this crop

7. What benefits have you seen from rotation crops

For example – Less disease in following cotton, Need less fertiliser for following cotton, Soil structure improved

8. What problems have you encountered with rotation crops

For example – Not enough irrigation water, Hard to prepare seedbed for rotation crop, Need extra labour, Need extra machinery

9. What research on rotation crops do you think is needed.

10. Have you used retained beds, permanent beds or minimum tillage when growing rotation crops

YES / NO

If Yes – What advantages did you see

What problems did you encounter

SURVEY OF CROPS USED IN ROTATION WITH COTTON IN THE MACQUARIE, NAMOI AND GWYDIR VALLEYS OF NEW SOUTH WALES

Summary of Results by Jack Cooper, Agricultural Research Centre, Trangie

The survey was conducted by telephone during August, September and October, 1992. The extent of the survey is shown in
table 1.

Table 1. Number of cotton growers contacted in each valley, the area of cotton produced by those growers, and the number of growers using rotations.

	Macquarie	Namoi	Gwydir
No. of growers surveyed	59	49	49
Total area of cotton planted by those growers in 1992/93	30,666ha	22,005ha	36,033ha
No. of growers that have used rotations	31	40	38
% of growers that have used rotations	53%	82%	78%

The first part of the survey looked at what rotations were used for the current cotton crop. Table 2 shows what the area now sown to cotton grew last year.

Table 2. Previous history of the current cotton crop.

% by area

Previous Crop	Macq.	Namoi	Gwydir
Cotton	61.5	47.2	68.1
Wheat	16.7	22.2	21.2
Fallow	5.2	9.7	4.8
New (1)	7.6	1.9	3.5
Chickpeas	0.3	6.1	1.3
Fababeans	0	1.3	0.1
Soybeans	0	0.6	0
Cowpeas	0	2.1	0
Maize	0	0.2	0
Safflower	0.9	3	0
Sorghum	0.4	0.5	0.1
Barley	1.0	0.9	0.7
Mungbeans	0	2.4	0
Lab lab	0.3	1.6	0
Lucerne	0	0	0.1
Oats	2.0	0	0
Cotton + GM (2)	3.2	0	0
Sunflowers	0.2	0	0
Fieldpeas	0.8	0	0

(1) New country that has never grown cotton previously, usually this is new irrigation development.

(2) Cotton + GM cotton and green manure – this country did grow cotton last year but it also had a green manure crop during the winter.

The next group of questions looked at what crops people had tried in rotation with cotton, which crop they use most frequently, and why they prefer that crop. For the following tables only the replies from growers who had used rotations were counted.

Table 3. Crops used in rotation with cotton during the past 5 years.

	% of growers who had used the crop		
Rotn. Crop	Macq.	Namoi	Gwydir
Wheat	93.5	85.0	86.8
Soybeans	12.9	22.5	39.5
Fababeans	3.2	17.5	7.9
Safflower	32.3	10.0	13.2
Mungbeans	0	12.5	7.9
Sunflower	12.9	7.5	5.3
Chickpeas	9.7	22.5	15.8
Barley	16.1	20.0	21.1
Oats	12.9	5.0	2.6
Lab Lab	9.7	7.5	7.9
Sorghum	3.2	12.5	2.6
Cowpeas	6.5	2.5	0
Maize	6.5	10.0	7.9
Fieldpeas	41.9	7.5	7.9
Vetch	0	2.5	0
Fenugreek	0	0	5.3
Lucerne	0	0	2.6
Canola	12.9	0	5.3
Pidgeonpeas	3.2	0	0
Tomatoes	3.2	0	0

Table 4. Main crop used in rotation with cotton.

	% of growers who nominated this as their main rotation crop		
Crop	Macq.	Namoi	Gwydir
Wheat	71.0	65.0	81.6
Soybeans	3.2	7.5	5.3
Fababeans	0	10.0	0
Barley	3.2	10.0	7.9
Maize	0	5.0	0
Fieldpeas	9.7	2.5	0
Legume (1)	0	5.0	0
Sorghum	0	0	2.6
Sunflower	3.2	0	0
Safflower	9.7	0	0
Various (2)	0	0	2.6

(1) These farmers usually grew a legume in rotation with cotton, but could not nominate 1 particular species.

(2) These growers did not have any 1 rotation crop they used most often.

Table 5. Reasons people gave for selecting their preferred rotation crop.

	% of growers who nominated this as a reason		
Reason	Macq.	Namoi	Gwydir
Easy to grow	51.6	40.0	42.1
Extra returns	29.0	27.5	15.8
Less disease (1)	12.9	25.0	26.3
Grazing possible (2)	6.5	5.0	2.6
Late sown	9.7	5.0	0
Ready market	12.9	5.0	10.5
Nitrogen fixing (3)	9.7	17.5	0
Time (4)	19.4	5.0	13.2
Water requirements (5)	6.5	17.5	21.1
Less weeds	6.5	5.0	13.2
Extra Org. matter	3.2	7.5	0
Dries the soil	0	2.5	0
Soil structure (6)	0	12.5	36

(1) The rotation crop reduced the amount of disease in the following cotton crop.

(2) The rotation crop could be grazed if necessary – this comment usually applied to forage sorghum or barley.

(3) This reason only applied to people using legumes.

(4) Time – growing the rotation crop did not clash with the machinery and labour requirements of the cotton crop. This comment usually applied to winter crops such as wheat.

(5) The rotation crop could be grown without irrigation and therefore did not compete with the cotton crop.

(6) The rotation crop improved the structure of the soil.

The following tables show what benefits growers saw from using rotation crops and what problems they encountered in using rotation crops. Again only the replies from growers who had used rotations were counted.

Table 6. Benefits fom the use of rotation crops with cotton.

	% of growers who observed this benefit		
Benefit	Macq.	Namoi	Gwydir
Better soil structure	67.7	72.5	86.8
Less disease in the cotton	32.3	45.0	36.8
Nitrogen fixed	16.1	27.5	5.3
More organic matter	38.7	27.5	5.3
Weeds reduced	16.1	15.0	21.1
Cotton yield increased	25.8	17.5	23.7
Less fertiliser needed	0	10.0	5.3
Work load spread	0	0	7.9
More biological activity	3.2	0	0
Increased returns	6.5	5.0	7.9
None	0	2.5	7.9

Table 7. Problems encountered when growing crops in rotation with cotton.

Problem	% of growers who experienced the problem		
	Macq.	Namoi	Gwydir
Not enough water	45.2	47.5	71.1
Poor returns	6.5	12.5	10.5
Poor seedbed for cotton	9.7	12.5	2.6
Equipment not suitable	38.7	12.5	5.3
More insects in cotton (1)	9.7	17.5	10.5
Following cotton poor	3.2	10.0	2.6
Chemical residues (2)	6.5	2.5	2.6
More disease in cotton (3)	6.5	0	7.9
Little time to sow (4)	0	5.0	0
Weeds in rotation crop	0	7.5	0
Need extra labour	0	7.5	0
Establishment problems	0	0	2.6
Volunteers (5)	0	0	2.6
Less time for maintenance (6)	3.2	0	0
None	9.7	15.0	5.3

(1) This applied to particular rotation crops eg. safflower and sunflower caused an increase in mites, wireworms were more frequent after wheat.

(2) The residue of chemicals used on the cotton can cause problems for following rotation crops.

(3) This applied to particular rotation crops eg. soybeans favour the build up of some diseases which also affect cotton.

(4) After cotton harvest there is little time to prepare the ground and sow a rotation crop.

(5) Some rotation crops eg. sunflowers, can become a weed in following cotton crops.

(6) The need to irrigate winter rotation crops restricts the opportunities to do channel maintenance.

The survey also looked at the use of permanent beds and techniques such as retained hills. The aim was to find out how widely these practices have been adopted and in what situations they are used. Also to see what advantages and disadvantages growers had found with these techniques. The figures in the following tables only relate to those growers who had used rotations at some stage.

Table 8. The number of growers using permanent beds or retained hills and situations in which they were used.

	% of growers using each system		
System	Macq.	Namoi	Gwydir
Cotton + rotation crop (1)	71.0	33.3	31.6
Cotton only (2)	3.2	12.8	28.9
Rotation crop only (3)	9.7	2.6	5.3
Full permanent beds	3.2	17.9	23.7
No permanent beds or hills	12.9	33.3	10.5

(1) Beds or hills were retained as long as cotton was grown and for the first rotation crop, then the area was cultivated and hills reformed.

(2) These growers sowed the rotation crop at an angle to the cotton rows and therefore destroyed the hills in the process.

(3) All these growers used a system of 1 cotton crop then a rotation crop – hills were reformed after the rotation crop but retained after cotton.

Table 9. Advantages of using permanent beds or retained hills.

	% of growers who nominated this as an advantage		
Advantage	Macq.	Namoi	Gwydir
Less compaction	44.4	38.5	41.2
Reduced costs	70.4	57.7	85.3
Wet winter less worry	22.2	26.9	17.6
Better soil structure	3.7	3.8	14.7
Increased yields	0	19.2	5.9

Table 10. Disadvantages of using permanent beds or retained hills.

Disadvantage	% of growers who nominated this as a disadvantage		
	Macq.	Namoi	Gwydir
Keeping rows straight (1)	14.8	19.2	14.7
Problems with trash	18.5	15.4	35.3
More weed problems	7.4	11.5	2.9
Equipment wheel spacing (2)	3.7	0	0
Heliothus survival (3)	3.7	0	2.9
Surface sealing problems	3.7	0	0
Poor soil tilth	11.1	0	5.9
Reduced yields	3.7	0	0
More disease	0	3.8	8.8
Chemical residue build up (4)	0	3.8	0

(1) The rows need to be very straight to start with because any bends get worse over time. Most people considered 5 years the maximum life of rows.

(2) The wheels of equipment such as headers often do not fit the row spacing so one wheel will compact the middle of a bed.

(3) With minimal soil disturbance some heliothus larvae may survive.

(4) Because there is little mixing of the soil, chemical residues will build up near the surface and may become a problem.

APPENDIX 3. Paired site comparison

<u>Chemical Analyses</u> The following table shows the effect of valley, cropping history and depth on a number of soil chemical components.

	pH	Cond. dS/m	Tot. C dag/kg	Tot. N dag/kg	NO_3–N mg/kg	$CaCO_3$ %
Macquarie Namoi	7.15 7.47 NS	0.25 0.27 NS	1.00 0.78 NS	0.11 0.08 P<0.05	38.0 36.1 NS	0.87 0.47 NS
Cont. Cotton Rotation	7.33 7.29 NS	0.28 0.24 NS	0.87 0.91 NS	0.09 0.09 NS	43.6 30.5 NS	0.58 0.76 NS
Surface 20 cm 40 cm	7.23a 7.11a 7.60b P<0.001	0.27 0.26 0.25 NS	0.99a 0.92b 0.75c P<0.001	0.11a 0.09b 0.08c P<0.001	50.5a 42.7a 17.9b P<0.05	0.58a 0.62a 0.81b P<0.001

	-----Exchangeable Cations cmol/kg -----						
	Ca	Mg	K	Na	Total	Na%	Ca/Mg
Macquarie Namoi	16.6 19.5 P<.05	7.5 11.7 P<.01	0.8 1.1 P<.01	1.4 2.9 P<.01	26.3 35.2 P<.001	5.4 7.9 P<.05	2.3 1.9 NS
Cont Cotton Rotation	18.0 18.1 NS	9.8 9.4 NS	1.0 0.9 NS	2.1 2.2 NS	30.9 30.6 NS	6.7 6.5 NS	2.1 2.1 NS
Surface 20 cm 40 cm	18.2 17.7 18.2 NS	9.0a 9.2a 10.6b P<.001	1.2a 0.9b 0.8c P<.001	1.6a 1.7a 3.2b P<.001	30.0a 29.6a 32.7b P<.01	5.0a 5.6a 9.3b P<.001	2.3a 2.2a 1.9b P<.001

Soil Structure – Field Assessment The following table shows the effect of valley, cropping history and depth on soil strength as measured with a shear vane, and soil structure measured using the Soilpak system.

	Shear strength kPa	Soil structure Soilpak score
Macquarie Namoi	3.0 3.4 P<.01	1.21 1.27 NS
Cont. Cotton Rotation	3.2 3.2 NS	1.22 1.26 NS
Surface 20 cm 40 cm	1.9a 3.1b 4.6c P<.001	1.26a 1.29a 1.16b P<.001

APPENDIX 3. Paired site comparison

Effect of rotation on soil properties in the 0–50 mm depth

Valley	Cropping system	GMD[1] (mm)	Plastic limit (%)	Clay (%)	Silt (%)	Sand (%)	Dispersion index (%)	Coarse[2] SOM (%)	Fine[3] SOM (%)	Total[4] SOM (%)	Soil respiration (mmol CO2/kg soil)
Macquarie	Continuous cotton	26.0	19.6	30.2	41.6	28.2	18.3	0.23	3.06	3.29	159.6
	Rotation	25.7	14.3	41.3	30.1	28.5	7.8	0.55	3.34	3.89	138.7
	± SE	0.83	0.95	1.32	3.06	2.42	2.37	0.063	1.068	1.041	35.53
	P <	NS	0.05	0.01	0.05	NS	0.05	0.05	NS	NS	NS
Namoi	Continuous cotton	13.4	19.4	50.7	23.3	26.0	22.6	0.33	1.75	2.08	13.0
	Rotation	18.7	17.3	55.2	23.1	21.7	21.1	0.46	2.32	2.78	21.7
	± SE	2.80	1.39	2.68	3.07	5.32	2.38	0.030	0.582	0.583	1.57
	P <	NS	NS	NS	NS	NS	NS	0.05	NS	NS	0.05

1 Geometric mean diameter of soil aggregates after puddling and drying.
2 Soil organic matter of particle diameters of 212–2000 μm.
3 Soil organic matter of particle diameters of 53–212 μm.
4 Soil organic matter of particle diameters of 53–2000 μm.

APPENDIX 3. Paired site comparison

Effect of rotation on soil properties in the 150–250 mm depth

Valley	Cropping system	GMD[1] (mm)	Plastic limit (%)	Clay (%)	Silt (%)	Sand (%)	Dispersion index (%)	Coarse[2] SOM (%)	Fine[3] SOM (%)	Total[4] SOM (%)	Soil respiration (mmol CO2/kg soil)
Macquarie	Continuous cotton	26.0	16.3	38.9	34.1	27.0	21.6	0.20	2.50	2.70	115.1
	Rotation	26.8	12.3	43.8	28.6	27.6	12.6	0.35	2.83	3.19	163.5
	± SE	0.37	0.43	2.33	3.72	2.99	0.82	0.116	0.534	0.590	28.94
	P <	NS	0.01	NS	NS	NS	0.01	NS	NS	NS	NS
Namoi	Continuous cotton	17.0	20.2	55.0	16.7	28.3	21.4	0.18	0.78	0.96	5.5
	Rotation	18.7	17.8	58.1	17.2	24.7	17.8	0.14	0.84	0.98	56.0
	± SE	3.18	1.48	3.62	1.16	4.53	1.80	0.055	0.163	0.195	1.58
	P <	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

1 Geometric mean diameter of soil aggregates after puddling and drying.
2 Soil organic matter of particle diameters of 212–2000 µm.
3 Soil organic matter of particle diameters of 53–212 µm.
4 Soil organic matter of particle diameters of 53–2000 µm.

APPENDIX 3. Paired site comparison

Effect of rotation on soil properties in the 350–450 mm depth

Valley	Cropping system	GMD[1] (mm)	Plastic limit (%)	Clay (%)	Silt (%)	Sand (%)	Dispersion index (%)	Coarse[2] SOM (%)	Fine[3] SOM (%)	Total[4] SOM (%)	Soil respiration (mmol CO2/kg soil)
Macquarie	Continuous cotton	26.5	14.0	41.9	32.4	25.7	26.9	0.14	2.21	2.35	167.2
	Rotation	26.7	14.0	49.2	25.3	25.5	15.3	0.20	2.70	2.90	156.9
	± SE	0.25	1.05	2.42	2.40	0.96	2.08	0.066	0.690	0.700	29.00
	P <	NS	NS	0.10	0.10	NS	0.05	NS	NS	NS	NS
Namoi	Continuous cotton	18.0	14.7	55.4	20.4	24.2	18.8	0.06	0.67	0.74	5.5
	Rotation	19.0	17.0	62.2	16.8	21.0	18.5	0.06	0.61	0.67	7.3
	± SE	2.37	1.60	3.62	2.73	6.23	1.65	0.025	0.154	0.172	2.53
	P <	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

1 Geometric mean diameter of soil aggregates after puddling and drying.
2 Soil organic matter of particle diameters of 212–2000 µm.
3 Soil organic matter of particle diameters of 53–212 µm.
4 Soil organic matter of particle diameters of 53–2000 µm.

APPENDIX 3. Paired site comparison

Effect of residue management system on soil properties in the 0–50 mm depth

Valley	Residue management system	GMD[1] (mm)	Plastic limit (%)	Clay (%)	Silt (%)	Sand (%)	Dispersion index (%)	Coarse[2] SOM (%)	Fine[3] SOM (%)	Total[4] SOM (%)	Soil respiration (mmol CO2/kg soil)
Macquarie	Burning	25.4	21.8	30.1	40.4	29.5	19.3	0.27	2.45	2.71	148.3
	Retention	26.0	14.9	38.2	33.9	27.9	10.4	0.44	3.52	3.96	149.5
	± SE	0.51	1.30	2.65	3.86	3.06	2.07	0.054	0.556	0.531	17.89
	P <	NS	0.01	NS	NS	NS	0.05	0.05	NS	NS	NS
Namoi	Burning	14.3	20.5	52.4	22.1	25.5	25.8	0.43	1.64	2.07	16.4
	Retention	17.2	16.9	53.4	24.0	22.7	19.2	0.37	2.30	2.67	18.1
	± SE	1.99	0.97	3.12	1.80	3.60	1.65	0.040	0.411	0.421	2.87
	P <	NS	0.05	NS	NS	NS	0.05	NS	NS	NS	NS

1 Geometric mean diameter of soil aggregates after puddling and drying.
2 Soil organic matter of particle diameters of 212–2000 μm.
3 Soil organic matter of particle diameters of 53–212 μm.
4 Soil organic matter of particle diameters of 53–2000 μm.

APPENDIX 3. Paired site comparison

Effect of residue management system on soil properties in the 150–250 mm depth

Valley	Residue management system	GMD[1] (mm)	Plastic limit (%)	Clay (%)	Silt (%)	Sand (%)	Dispersion index (%)	Coarse[2] SOM (%)	Fine[3] SOM (%)	Total[4] SOM (%)	Soil respiration (mmol CO_2/kg soil)
Macquarie	Burning	26.0	16.8	40.4	30.0	29.6	22.2	0.14	1.60	1.74	99.6
	Retention	26.6	13.2	41.8	31.9	26.3	14.9	0.33	3.13	3.46	150.6
	± SE	0.37	0.79	2.40	4.70	3.61	1.65	0.071	0.610	0.640	18.68
	P <	NS	0.05	NS	NS	NS	0.05	0.10	NS	NS	NS
Namoi	Burning	16.2	19.4	57.2	16.6	26.2	20.6	0.10	0.85	0.95	3.8
	Retention	18.9	18.8	56.2	17.2	26.6	19.0	0.20	0.78	0.98	7.1
	± SE	1.94	1.13	3.17	1.13	3.47	1.21	0.038	0.110	0.131	1.46
	P <	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

1 Geometric mean diameter of soil aggregates after puddling and drying.
2 Soil organic matter of particle diameters of 212–2000 µm.
3 Soil organic matter of particle diameters of 53–212 µm.
4 Soil organic matter of particle diameters of 53–2000 µm.

APPENDIX 3. Paired site comparison

Effect of residue anagement system on soil properties in the 350–450 mm depth

Valley	Residue management system	GMD[1] (mm)	Plastic limit (%)	Clay (%)	Silt (%)	Sand (%)	Dispersion index (%)	Coarse[2] SOM (%)	Fine[3] SOM (%)	Total[4] SOM (%)	Soil respiration (mmol CO2/kg soil)
Macquarie	Burning	26.0	15.5	42.9	31.1	26.0	25.2	0.13	1.26	1.39	162.8
	Retention	26.8	13.4	46.9	27.9	25.4	19.3	0.19	2.97	3.16	161.7
	± SE	0.36	0.59	2.55	3.23	2.86	3.07	0.050	0.460	0.460	14.24
	P <	NS	0.10	NS	NS	NS	NS	NS	0.10	0.05	NS
Namoi	Burning	19.2	17.3	58.0	17.9	24.1	19.4	0.05	0.64	0.69	4.2
	Retention	18.1	14.9	59.4	19.0	21.6	18.1	0.07	0.65	0.72	7.9
	± SE	1.79	0.82	3.07	1.62	3.94	1.13	0.011	0.092	0.100	1.51
	P <	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

1 Geometric mean diameter of soil aggregates after puddling and drying.
2 Soil organic matter of particle diameters of 212–2000 µm.
3 Soil organic matter of particle diameters of 53–212 µm.
4 Soil organic matter of particle diameters of 53–2000 µm.