MANAGING COMPACTION IN SODIC GREY CLAYS

D.C. McKenzie, Soil Chemist,
NSW Department of Agriculture,
Agricultural Research Centre, Trangie

INTRODUCTION

A large proportion of the cotton produced in Australia is grown in grey clay soils. Most of these grey clays have stable self-mulching topsoils, but are usually sodic+ in the subsoil. Sodic soils are prone to dispersion, due to an excess of sodium attached to the clay particles.

Soils that disperse tend to have poor drainage; excessive swelling closes soil pores, which also block up with dispersed clay, sand and silt. Poorly drained soils remain moist close to the surface for prolonged periods after rain and/or irrigation. When in this condition, the soil is easily smeared and made more compact by heavy machinery passing over the surface.

Apart from sodicity, factors which encourage the development of compacted layers include:

1. Insufficient organic matter, which leads to slaking*, and a reduction in soil strength when moist.
2. Lack of stable and continuous subsoil pores (old root channels and crack lines).
3. Insufficient slope to encourage the rapid removal of excess water.
4. High water tables.
5. Use of tillage implements (eg disc ploughs) at a constant depth.
6. Use of landplanes and tillage equipment under wet conditions.
7. Excessive use of heavy, narrow wheeled two-wheel- drive row crop equipment under wet conditions (eg cotton pickers).

\+ sodicity refers to the exchangeable sodium ions attached to the clay; salinity refers to free salts in the soil solution.

* If wetted clods slump to form microaggregates (diameter of approx. 0.1 mm), slaking is said to have occurred. If these miccroaggregates break down further, causing milkiness in the water, dispersion is taking place.

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TABLE 6: Spray schedules and costs for SIRATAC and commercial fields, Theodore

DATE	COMMERCIAL Insecticide	COMMERCIAL Cost ($/ha)	SIRATAC Insecticide	SIRATAC Cost ($/ha)
1.11.83	-		ENDOSULFAN	3.50
7.11.83	ENDOSULFAN	3.50	-	
8.11.83	-		ENDOSULFAN + DIMETHOATE	15.90
17.11.83	ENDOSULFAN	10.50	ENDOSULFAN + CHLORDIMEFORM	18.50
22.11.83	ENDOSULFAN	10.50	-	
24.11.83	-		ENDOSULFAN	10.50
3.12.83	ENDOSULFAN + CHLORDIMEFORM	18.50	ENDOSULFAN + CHLORDIMEFORM	18.50
9.12.83	ENDOSULFAN	10.50	-	
17.12.83	ENDOSULFAN	10.50	-	
24.12.83	CHLORDIMEFORM	7.80	CHLORDIMEFORM	7.80
29.12.83	ENDOSULFAN	10.50	-	
12.1.84	-		CHLORDIMEFORM	7.80
23.1.84	ENDOSULFAN + DIMETHOATE	13.20	-	
24.1.84	-		ENDOSULFAN + DIMETHOATE	13.20
13.2.84	DIMETHOATE	2.70	-	
14.2.84	-		DELTAMETHRIN + DIMETHOATE	19.20
APPLICATION	10 sprays (1 ground, 9 aerial)	60.50	9 sprays (1 ground, 8 aerial)	54.00
	TOTAL	158.70		168.90

TABLE 5: Timing of planned and actual phenological events and yield data for Biloela 1 and Biloela 2, 1983/84

	BILOELA 1 (30 plant insect cards)	BILOELA 2 (15 plant insect cards)
Planting date	25.10.83	25.10.83
1st square	3.12.83	5.12.83
1st flower	25.12.83	27.12.83
1st open boll	29.2.84	25.2.84
Planned:		
1st effective flower	2.1.84	2.1.84
last effective flower	4.3.84	4.3.84
yield (bales/ha)	6.8	6.8
(bolls/m)	108.8	108.8
Actual:		
1st effective flower	30.12.83	30.12.83
last effective flower	20.2.84*	20.2.84*
yield (bales/ha)	5.2	5.2
bolls/m on 5.3.84	137	153

*Estimated last effective flower date

was at permanent wilting point to a depth of over 1m.

The wet treatment was flood irrigated and the water ponded for an extended period. Preparation began as soon as the surface soil was dry enough to be trafficable.

The moist treatment was achieved a different way each season as dictated by conditions. In the first year, a quick flush of irrigation water down the furrows proved satisfactory. In the second year, a wheat crop partially dried the soil in a wet winter. In the third year, regrowth of sorghum stubble after flood irrigation produced the intermediate soil moisture state required.

Profiles of gravimetric soil moisture contents in the three treatments (just prior to land preparation in each of the three seasons) are presented in Fig. 1.

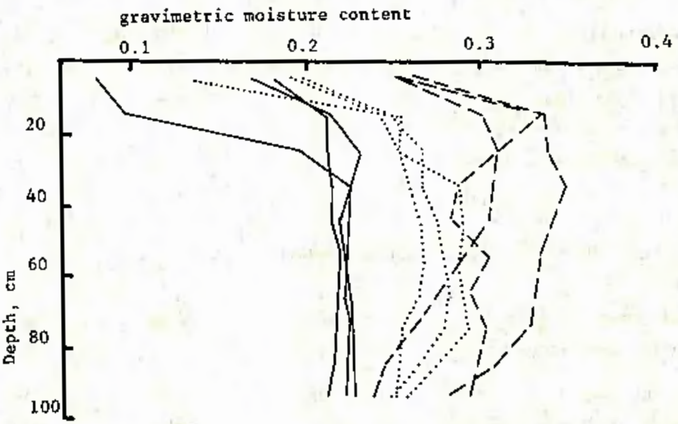

Fig 1. Soil moisture profiles at time of land preparation in each of three years for the different treatments.

prepared dry ——— prepared moist .... prepared wet -------

On all treatments, surface soil conditions were dry enough to allow good trafficability when land preparation commenced. All treatments received the same operations: the difference was in the soil moisture content at the time the land was prepared. Preparation consisted of disc ploughing the cereal stubble, deep ripping (to 50 cm) scarifying, land-planing, chisel ploughing and furrowing out. During the cotton season, all plots were treated alike: being irrigated, fertilized, sown, sprayed and inter-row cultivated as one paddock.

Cotton (Deltapine 61) was sown on 11 November 1983 and watered up.

Results

The results in this paper refer to the third cotton crop of this experiment, 1983-84 (i.e. after the same land preparation treatments were imposed three times on the same areas of land).

Plant samples were taken on 16 January 1984 and again on 13 March 1984, as indicators of vigour and yield potential.

Table 1. Plants sampled on 16-1-84.

Soil moisture state during land preparation:	Dry	Moist	Wet
Height, cm	39	34	26
Total dry weight, kg/ha	850	625	454
Leaf area index	1.1	0.8	0.6
Plant total nitrogen %	3.1	2.7	2.5
Nitrogen uptake, kg/ha	26	17	12

Table 2. Plants sampled on 13-3-84.

Soil moisture state during land preparation:	Dry	Moist	Wet
Height, cm	91	71	71
Total dry weight, kg/ha	6516	4875	4783
Leaf area index	2.6	1.4	1.8
Plant total nitrogen %	1.4	1.3	1.3
Nitrogen uptake, kg/ha	91	64	61
Boll dry weight, kg/ha	1659	1208	1231

All measurements indicate that the plants growing on land prepared dry ranked highest in size, vigour and yield potential.

The plants growing on land prepared moist tended to be intermediate between the other two treatments in January. By March, plants on the moist treatment tended to be very similar to those on land prepared wet.

Lint yields at the end of the season were assessed by machine picking and machine ginning.

Table 3. Machine-picked lint yields.

Soil moisture state during land preparation:	Dry	Moist	Wet
Lint, kg/ha	826	546	588
Lint, bales/acre	1.49	0.98	1.06
% of best treatment	100	66	71

Examination of the soil profile (exposed by digging pits) at the end of the season showed visual differences between treatments. The upper 20 cm (the hilled-up portion of the rows) on areas prepared moist or wet contained many more dense-looking clods than on areas prepared dry. The latter areas had more crumbly clods. The upper subsoil showed greater differences, particularly between 20 cm and 30 cm below the top of the hill. Here those areas prepared moist or wet appeared more massive. There was a noticeable absence of flat, shiny faces between adjacent clods. Instead, the clods were large, contained few cracks (within themselves), were irregularly shaped and dull surfaced. Many of the faces were rounded instead of flat.

Discussion

The wet winter of 1983 delayed the final stages of land preparation (furrowing out) and the crop was sown late (11 November). The late sowing and the cool, cloudy, wet growing season of 1983-84 were not conducive to high yields: hence the rather low yield of the paddock as a whole. It is possible that such a wet season may depress yields more where the soil is in poor condition, through the effects of increased waterlogging. Hence we may expect slightly smaller differences between treatments in a hot, dry season. Such an interaction between soil structural degradation and waterlogging has not yet been demonstrated.

Plant measurements made during the season and the final lint yields both indicate a decreased yield potential of land which is prepared for cotton when the subsoil is either moist or wet.

The important point to note is that the yield depression was very similar whether the land was prepared moist or wet. The intermediate moist treatment has caused as much damage as the wet preparation. Therefore the only soil moisture state that we know to be safe for land preparation is permanent wilting point. There may be a narrow range of moisture contents over which minimum damage is done to the soil, but this is not known.

To protect soil structure it is necessary for the soil to be at or near permanent wilting point before land preparation. In practice this means using a crop to dry the soil over the full depth to be cultivated.

Most growers know that working the soil when wet can damage the soil structure and reduce yield. However the extent of yield loss was not known. These results indicate that a very substantial yield loss (about one quarter) is possible when soil structure is damaged. Management of soil structure is, along with the management of water, nitrogen and pests, an input that affects profit: it also affects the long-term viability of cotton growing, by protecting the soil resource.

Acknowlegement

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Soils

BACKGROUND PAPERS

THE EXAMINATION OF SOIL STRUCTURAL DETERIORATION IN IRRIGATED COTTON FIELDS

D. McGarry

C.S.I.R.O. Division of Soils, GPO Box 639
CANBERRA, A.C.T. 2601

At the 1982 Australian Cotton Growers' Research Conference the effects of land preparation at different soil water contents on soil structure and cotton growth was reported. In summary, land preparation on 'wet' rather than 'dry' soil led to (i) a significant reduction in the amount of water available to cotton plants, (ii) strong changes in soil structure visible in the soil profile, and (iii) smaller cotton plants with up to 50% fewer green bolls.

On termination of the experiment soil samples were collected to study the nature of any differences due to the land preparation treatments. This paper presents details and results from two of the analyses used.

The first technique used a microscope to examine the micro-features and optical properties of very thin sections (0.025mm) cut from intact soil samples impregnated with hard-setting epoxy resin. Samples from both the 'wet' and 'dry' treatments have been examined and compared with samples taken from uncultivated sites (stock routes). The uncultivated ('virgin') soils of the Namoi Valley are dominated by clay material which has random orientation with predominantly edge to face contacts (Fig.1, type A). In contrast, the soil which had been prepared 'wet' had up to 25% of the top 20cm of soil composed of clay zones which have preferred orientation with predominantly face to face contacts (Fig.1, type B). For the same depth the soil prepared 'dry' had a maximum of 2% of the soil composed of clay with preferred orientation. In both treatments the size range of the oriented clay zones was 0.5 x 0.3mm to 400 x 240mm.

What is the source of these zones, and what implications do they have for crop growth? The most probable source is the smearing of wet soil by metal implements, and tractor wheels which lose traction and spin. An increase in the amount of clay with parallel rather than random orientation indicates an increase in the packing density of particles. The likely implications of this include: water held in the soil is less available to plants, plant roots experience greater difficulty in penetrating the soil, nutrients held in the soil are less available, there is less air-space so that both amount and movement of soil air is reduced.

In terms of amelioration of structural deterioration, it is important that the majority of oriented-clay zones were less than 20mm across, so are unlikely to be affected by ripping implements. It may require exploration by fine root hairs and by soil-living animals (e.g. earthworms) as well as wetting and drying cycles to ameliorate such zones.

The second technique used to assess structural deterioration was to examine the bulk density and aeration status of natural soil clods over a wide range of soil water content. The technique involves coating the clods with Saran resin which has the property of allowing water vapour to pass through (so the clod dries slowly) but is impermeable to liquid water (so allowing the clod's volume to be measured by immersion in water). The clod bulk density is calculated from its weight and volume and is plotted against its water content to give a picture of the solid to air-space relations of the soil at any one water content.

Figure 2 presents typical data from a clod from each of the 'wet' and 'dry' treatments in the 0-10cm layer. The most obvious difference between treatments is that for all water contents the land prepared 'dry' has lower bulk density values than the land prepared 'wet'. This indicates that for any one soil water content there was less soil air in clods from the land prepared 'wet' than there was for clods from the land prepared 'dry'. This trend was true for the majority of clods in the 0-10 and 10-20cm layers.

The lower aeration status of the top 20cm of the 'wet' prepared soil may be related to the greater incidence of oriented clay zones as seen under the microscope over the same depth. The usual implications apply for the poorer aeration of the 'wet' treatment i.e. poorer root growth, reduced water and nutrient uptake, and increased incidence of root disease.

Thus, these data have provided some understanding of the nature of soil structural deterioration in cotton-growing clay soils, and an explanation of the differences in cotton plant growth measured between the treatments in the 1981/82 season.

Fig 1. Using the examination of clay orientation as an index of structural degradation.

(A) Random orientation: edge to face alignment predominant

(B) Preferred orientation: face to face alignment predominant.

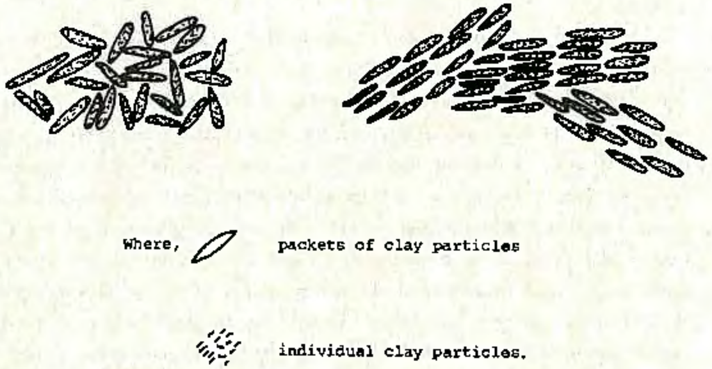
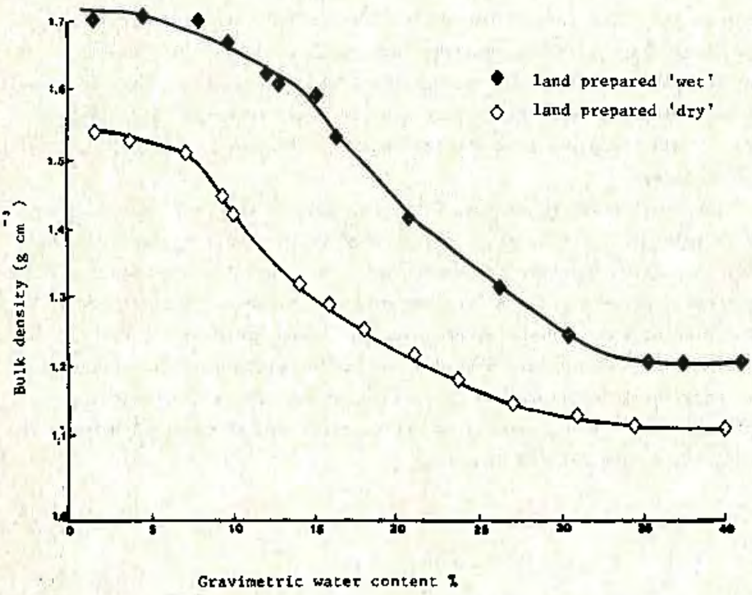


Fig 2. Bulk density of two soil clods plotted against their water content.



Agronomy & Water

PRESENTATION PAPERS

IRRIGATION MANAGEMENT OF COTTON FOR EFFICIENT WATER USE.

A. SOIL AND IRRIGATION FACTORS

D.F. Yule
Dept. of Primary Industries, Emerald, Qld.

Average cotton yields at Emerald, Queensland have generally been low when compared to other cotton growing areas in Australia. In particular, average yields in the 1980 to 1982 seasons were only 3.3. bales/hectare. Since yields in excess of 7 bales/hectare have been recorded, poor irrigation management appeared to contribute to the low yields.

The Emerald Irrigation Area is predominantly cracking clay soils and a large proportion of these soils are shallow (< 1.0m deep) and have considerable slope (1-2%) (McDonald, 1975). These soil factors and the tropical environment suggested that direct application of irrigation management from other cotton areas may not be appropriate. These two papers present a summary of the irrigation management studies conducted by the Department of Primary Industries at Emerald in 1982/83 and 1983/84. In addition I have included a brief review of the reported research into soil compaction at Emerald.

SOIL COMPACTION.

Soil compaction at Emerald has been investigated by observing soil structure in pits (McGarry and McDonald, 1983), by comparing water use rates and distribution from neutron moisture meter data (Wilcox and Gull, 1984), and by a combination of these methods supported by bulk density, root length and soil strength determinations (H.B. So, pers. comm., 1984).

McGarry and McDonald (1983) found that visible soil structure changes from the virgin state to the time of their investigations were minor and were confined to the 8 - 25 cm depth zone. Also the incidence of structural degradation (compaction) was rare (2 of 26 profiles examined) and in these was highly localised. The majority of their sites were chosen as being suspected compacted sites. There were no apparent cumulative effects, some sites had been irrigated for 16 years. They observed prolific roots at all sites growing cotton. They conclude that the majority of soils in the E.I.A have good potential for plant root exploitation and crop growth and that the cause of yield decline in 1980-1982 was not soil structural degradation.

Wilcox and Cull (1984) found that lower yield was associated with lower water use rates and proportionally greater water extraction at depth. They concluded that these water use changes were possibly due to some degree of structural degradation associated with land preparation when the soil was wet.

Dr. So concluded that compaction layers in the soil profile are likely to result in reduced growth and yield. Compaction layers with associated reduced plant vigour were found at two sites. Plant growth was apparently reduced by increased water stress. The presence of compaction layers was indicated by increased computed bulk density, by lower root density and water extraction at depth, and by visual observations of soil structure and the root system.

The contradictions in these reports are obvious. The importance of soil structural degradation in the E.I.A. remains unclear. At one of the sites studied by Dr. So, a yield reduction of more than 1 bale/ha was reported by the farmer. However soil structural degradation does not appear to have been the major cause of the low yields in 1980-1982.

IRRIGATION MANAGEMENT STUDIES.

Location and Methods.

The experiments were conducted at the Department of Primary Industries Emerald Research Station. The soil type is BUg (McDonald 1975) which is a basaltic cracking clay with clay content 70%, cation exchange capacity 75 m. equiv %, soil depth 85 cm over decomposing basalt, and slope 1%. Furrow irrigation treatments were applied to blocks 12 rows (12 m) wide and 200 m long. The datum area consisted of the central four rows. Irrigation treatments were based on soil water deficits predicted by a crop factor - evaporation pan model (Table 1). The treatments imposed are listed in Table 2.

TABLE 1. The crop factors used in the water use model.

	Crop Growth Stage	Crop Factor
I	Emergence for 28 days	0.3
II	Stage I to 1 flower/m	0.4
III	Stage II for next 14 days	0.6
IV	Stage III for next 14 days	0.8
V	Stage IV to 5 open bolls/m	1.0

TABLE 2. The predicted soil water deficit for each irrigation treatment. The deficit was designated for three crop development phases as follows -

Phase A	Emergence to 1 Flower/metre
Phase B	1 Flower/metre to 1 Flower/metre + 28 days
Phase C	1 Flower/metre + 28 days to 5 Open bolls/metre

Treatment		Predicted Deficit mm Phase A	Phase B	Phase C	Approx. Irrig. Frequency at Peak Growth. days
Very Frequent	VF	75*	45	45	5-6
Frequent	F	75*	75	75	8-9
Infrequent	IF	120*	120	120	14-15
Very Infrequent	VIF	150*	150	150	17-18
Rainfall	82-83	29	148	Nil	
	83-84	141	35	93	

* Due to rainfall, the phase A deficit in 1983/84 did not exceed 75 mm and no treatment was irrigated in phase A.

Water application rates during irrigations were measured with rectangular weirs (1982/83) and V-notch weirs (1983-84), one weir per furrow. Irrigation runoff rates were measured with HS flumes (1982/83) and Parshall flumes (1983/84), one flume per treatment. Total water addition, total runoff, total infiltration and the final infiltration rates were calculated for each irrigation. Soil aeration was measured in the 0-0.3m zone in 0.1m depth increments using 0.1m diameter cores. In 1983/84, cores were sampled from the hills 20m below the head-ditch and 20m above the tail drain in the VF and IF treatments during one irrigation cycle.

Typical water application and runoff data are shown in Figure 1 for three treatments in 1983/84. The increase in application rate at each irrigation was due to adding syphons to prevent possible uneven wetting. All treatments produced runoff curves of similar shape, varying mainly in total time of runoff. In general irrigation was stopped when the runoff rate was relatively stable. The total runoff depended maialy on the period of runoff and did not vary greatly across treatments. The water application rates were similar at all irrigations and differences between treatments were in period of irrigation which varied from 7 hours for the VF treatment to 22 hours for the VIF treatment. Total water application increased with increasing deficit prior to irrigation. The total infiltration (water application minus runoff) was approximately equal to the deficit prior to irrigation. Irrigation application efficiency (total infiltration/total water application) was high in all treatments. Since the total runoff varied little across treatments, application efficiency tended to increase with increasing total infiltration. The final infiltration rate was calculated as the difference between the application and runoff rates at the end of each irrigation. Since runoff rate was increasing this calculated infiltration rate will depend somewhat on the period of runoff.

The parameters from all irrigations in 1983/84 are summarised in Table 3. Over the whele season, total infiltration approximated the predicted deficit in the VF and F treatments. This was expected since total infiltration should estimate crop water use, assuming drainage is zero, and the predicted deficit should estimate crop water use, assuming evapotranspiration rates were near potential. In the IF and VIF treatments mean total infiltration

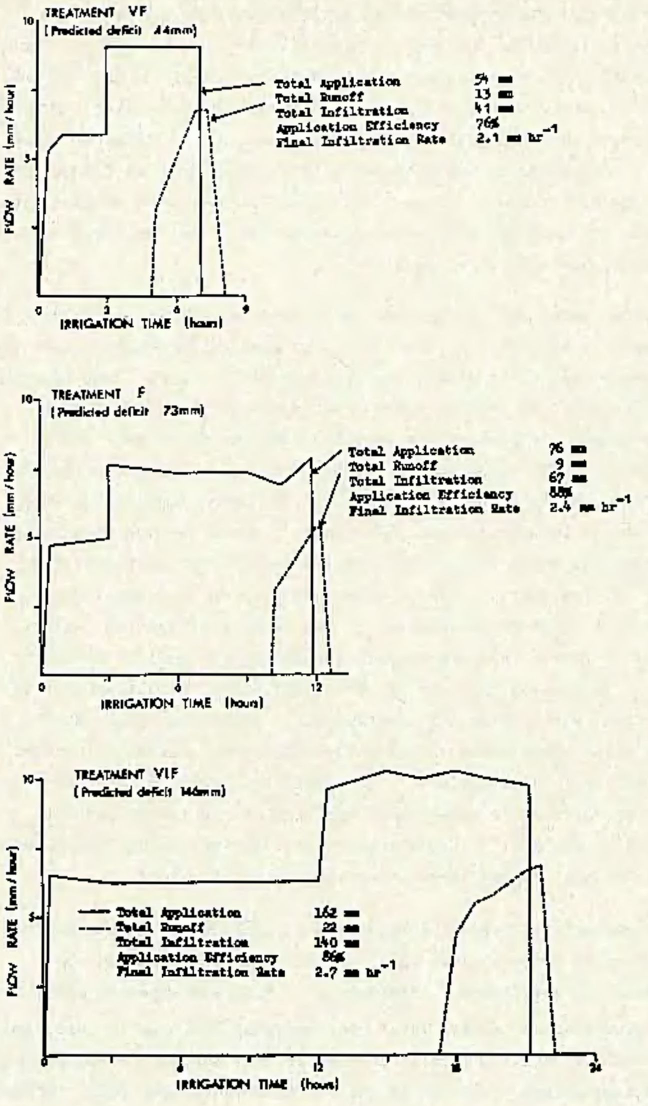


Figure 1. Typical water application and runoff curves for three treatments in 1983/84. The values listed are calculated from the curves.

TABLE 3. Mean irrigation parameters for each treatment in 1983/84.

Treatment	Mean Irrig. Deficit mm	Mean Total Infilt. mm	Mean Final Infilt Rate mm hr^{-1}	Mean Applic. Effic. %
VF	51	49	2.3	74
F	75	70	2.6	88
IF	107	92	2.8	87
VIF	140	126	2.3	89

was less than the mean predicted deficit, possibly because our predictive model makes no adjustment for plant water stress or reduced plant size in these treatments, and the model did not accurately predict the recharge after rainfall. Our model is intended to provide a reasonably reproducible basis for irrigation management across seasons in commercial applications and these weaknesses are unlikely to be significant in these applications.

The final infiltration rates are low and vary little across treatments. Since these rates are averaged over the length of the irrigation furrows, they are not simplistically related to soil hydraulic properties. However they are applicable to irrigation management since continued irrigation at these rates will contribute little to the total infiltration. Table 3 shows that the application efficiency can be high except in the VF treatment where the short period of each irrigation made limiting runoff difficult. High efficiency can be achieved by minimising runoff and this management will have little effect on total infiltration.

These results appear to support the findings of Shaw and Yule (1978) that cracks dominated the water entry process into these soils under flood irrigation, and that total infiltration was related to the volume of crack present at irrigation or to soil water deficit (as shown in Table 3). The infiltration process once the cracks are filled with water (as indicated by infiltration rate and application efficiency) was similar in all treatments.

Soil Aeration.

Soil aeration was measured near the head-ditch and the tail drain to study effects associated with period of inundation. Figure 1 shows that in VF treatment water was in the furrows near the head ditch for about 7 hours compared to about 3 hours near the tail drain.

The soil air content data are summarised in Tables 4 and 5.

TABLE 4. Soil air content profiles one day after irrigation. Values are in $m^3 m^{-3}$.

	VF treatment		IF treatment	
Soil Depth (m)	Head ditch	Tail drain	Head ditch	Tail drain
0 - 0.1	0.26	0.30	0.35	0.35
0.1 - 0.2	0.06	0.08	0.11	0.10
0.2 - 0.3	0.02	0.02	0.03	0.03

TABLE 5. Soil air contents ($m^3 m^{-3}$) at a depth of 0.2 - 0.3m during irrigation cycles. DAI is days after irrigation.

	VF treatment		IF treatment	
DAI	Head ditch	Tail drain	Head ditch	Tail drain
1	0.02	0.02	0.03	0.03
4	0.04	0.04	0.05	0.07
7	0.08	0.11		
11			0.09	0.10
1	0.03	0.06		

The soil air content profiles (Table 4) are generally similar to those reported for Narrabri cotton soils (Hodgson and Chan, 1982). Table 4 shows that the surface 0.1 to 0.2 m of the hill was well aerated but very low air contents occurred at 0.2 to 0.3m depth. There was some indication of higher air contents near the tail drain but the effects of period of inundation appear to be relatively small. The IF treatment had slightly higher air contents than the VF treatment and this was associated with slightly lower water contents.

Table 5 shows that soil air contents do increase with time but there were extended periods in both treatments when the air content was less than 0.1 $m^3 m^{-3}$. Since the sampling of VF treatment included a complete irrigation cycle, Table 5 suggests that at this soil depth the air content would be low throughout the season. It is also likely that a similar situation existed at other soil depths below 0.3 m. While the IF treatment had similar soil air contents, recovering to an adequate aeration status would be expected later in the irrigation cycle. The increase in soil air content was slower than reported at Narrabri (Hodgson and Chan, 1982). The implications of these low air contents are unclear since the treatments all produced high yields.

The results do raise the serious question of interpretation of such core data for cracking clay soils. Typically cracks are not representatively sampled and consequently the soil air content is underestimated. This may explain the relatively small detrimental effect that low air contents had on crop yield.

Conclusions.

These studies have shown that furrow irrigation management can be highly efficient in these soils. Controlled irrigation management which is appropriate to the soil and to other farm management inputs is essential. Adequate surface drainage is also necessary.

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IRRIGATION MANAGEMENT OF COTTON FOR EFFICIENT WATER USE.

B. CROP RESPONSE AND CROP WATER USE EFFICIENCY

G.D. Keefer
Dept. of Primary Industries, Emerald, Qld.

CROP RESPONSE

Cell expansion in plants is largely controlled by the "plant water potential" or water pressure within the cell. As a result cell expansion is the first plant process to slow down as plant water supply decreases. This slow down in cell expansion is reflected in a decrease in the rate of stem extension. In our irrigation management work we found the more frequently irrigated plants were consistently taller with more main stem nodes than the less frequently irrigated plants.

The rate of leaf expansion and the peak leaf area of each treatment were also closely related to irrigation frequency.

Figure 1A shows that in 1982-83 the leaf areas of the VF and F treatments reached the critical level of 3 m^2/m of row for near maximum radiant energy interception. The leaf areas of the VIF and Rain Grown treatments were well below this level.

Similarly in 1983-84 (Figure 1B) the leaf areas of the VF and F treatments exceeded the critical leaf area whereas the IF and VIF treatments had much smaller canopies which barely filled in the interrow spaces.

An ideal leaf canopy is one which intercepts total radiant energy before peak flower but which is open enough to allow penetration of radiation to the lower leaves supporting early bolls.

YIELDS AND CROP WATER USE EFFICIENCY.

The number of irrigations, lint yields, and water use efficiencies for 5 of the schedules used in the Emerald work are shown in Table 1. The IF and F-IF treatments were not tested in the 82-83 season. Yields were determined from the weight of seed cotton harvested with a commercial picker from the 4 centre rows of each irrigation block. Lint percentage was measured on samples fed through a small experimental gin.

In both seasons the VF irrigation schedule reduced yields by 7-9% compared with the consistently high yielding F treatment.

In 1982-83 the VIF treatment had 4 fewer irrigations than the F treatment and yields were reduced by 22%. The results from the VIF treatment were still very satisfactory by district and Australian standards.

In 1983-84 132 mm of early rain meant that no treatment received irrigation prior to flowering. Under these conditions the yield differences due to irrigation treatment were not as great. For example, in 83-84 the VIF treatment only reduced yields by 4% compared with the F treatment.

There are reports that W.U.E. can be improved by varying the irrigation deficit with crop development. Four additional variable deficit treatments were included in 1983-84 to test this hypothesis. The most promising was the F-IF which with 3 irrigations gave lint yields equal to those of treatment F.

The crop and irrigation responses can be summarised in terms of crop water use efficiency (W.U.E.) expressed as lint produced per mm of irrigation that infiltrated the crop root zone.

As might be expected crop W.U.E. increased with decreasing irrigation (C.F. 83/84 with 82/83). In both seasons the less frequently irrigated treatments (VIF, IF) had the highest W.U.E.

APPLICATION.

The absolute yields and W.U.E. will depend on the seasonal rainfall pattern but the data in Table 1 provide a basis for choosing irrigation management strategies appropriate to the resource limitations of any particular farm.

If land is the major limitation than maximum yields would be necessary and an irrigation strategy equivalent to F would be appropriate. If a larger planted area and more efficient use of limited irrigation water are selection criteria then the IF and VIF or the variable strategy F-IF should be considered.

A simple economic analysis can highlight the different results from two contrasting irrigation strategies. Two seasons results from the F and VIF irrigation strategies have been used to prepare the analysis in Table 2.

This analysis shows that the net returns per ha planted are higher with more frequent irrigation aimed at maximum yields (F). On the other hand the net returns per Ml of water supplied are higher with less frequent irrigation (VIF).

While the assumptions used in Table 2 would be altered to suit different farm situations the analysis demonstrates how the data collected in experiments can be used in guiding irrigation management decisions.

The programme being conducted by Steve Ockerby aims to obtain more information on the nitrogen requirements of various irrigation strategies. It will also examine other aspects of nitrogen management. Varietal performance under different irrigation management strategies is also being evaluated.

This information will also be useful in applying the results of the irrigation management programme.

CONCLUSIONS.

The primary justification for expenditure of public funds for research and development is the provision of improved technology for use by farmers and the groups servicing those farmers. The improved technology flowing from an irrigation management programme will have both short term and long term benefits.

Short Term Benefits.

Concurrently with the Emerald irrigation management programme David Hamilton has demonstrated in commercial crops:-

- the practicality of the crop factor/pan evaporation scheduling system.
- the benefits of appropriate irrigation scheduling.
- the costs of poor irrigation timing.

This scheduling system would enable cotton growers in all areas to predict when irrigation is needed.

It can be argued that many irrigators make a fair job of irrigation scheduling without the aid of instruments, calculators or computers. Emerald experience has clearly demonstrated that particularly in new areas the grower needs a system to guide management decisions. This system must be sensitive to seasonal differences.

Long Term Benefits.

The programme provides data which enable decisions to be made on the irrigation management best suited to a particular farm situation either existing or in course of development.

The long term benefits are closely allied with improving the efficiency of crop production. They will be measurable in terms of:-

- increased net returns.
- reduced labour inputs and costs
- increased agricultural production from our finite and limited resources (water and land).
- more robust evaluation of proposed irrigation developments.

ACKNOWLEDGEMENTS.

We wish to acknowledge the assistance of J.H. Ladewig and D.J. Nickson in the experimental work reported in these papers. The support of the Cotton Growers Research Committee is also gratefully acknowledged.

TABLE 1. NUMBER OF IRRIGATIONS, LINT YIELDS AND WATER USE EFFICIENCIES (W.U.E.) FOR A RANGE OF IRRIGATION TREATMENTS IN 1982/83 and 1983/84.

Irrigation Treatment		Number of Irrigations		Lint Yield bales/ha		W.U.E. kg lint/ha/mm	
		82/83	83/84	82/83	83/84	82/83	83/84
Very Frequent	VF	11	7	8.4	8.3	3.5	5.5
Frequent	F	7	5	9.0	9.1	4.2	5.9
Infrequent	IF	-	2	-	8.9	-	10.8
Very Infrequent	VIF	3	2	7.0	8.7	4.6	7.9
Variable	F-IF	-	3	-	9.3	-	7.9

TABLE 2. COMPARISON OF TWO CONTRASTING IRRIGATION STRATEGIES IN ECONOMIC TERMS ASSUMING A MAXIMUM WATER SUPPLY OF 800 Ml.

IRRIGATION STRATEGY	F	VIF
Average Number Irrigations	6	2.5
Irrig. Required by Crop Ml/ha	4.5	3.1
Irrig. Required at Pump or Dethridge Wheel[1] Ml/ha	5.6	3.9
Maximum Crop Area[2] ha	140	200
Yield bales/ha	9.1	7.9
Gross Production bales/farm	1274	1580
VARIABLE COSTS $\$ \times 10^3$ per farm		
Cultural operations, fertilizers chemicals[3]	112.0	160.0
Labour Irrigation[4]	2.4	1.4
Water Charge[5]	11.2	11.2
Cartage[6]	7.1	8.8
Total Variable Costs	132.7	181.4
GROSS RETURN $\$ \times 10^3$ per farm	509.6	632.0
NET RETURN[7]	376.9	450.6
NET RETURN /ha	2.692	2.253
NET RETURN/Ml	0.471	0.563

ASSUMPTIONS.

1. Field Application Efficiency 80%
2. Maximum water supply for season 800 Ml
3. $800 per ha to cover operation of machinery (Fuel, Oil, Repairs and Maintenance) seed, fertilizer, herbicide, insecticide, defoliant, aerial application costs, harvest (contract), insect scouting. Source D. Hamilton and M. Jorgensen Emerald Irrigator, May 1984 with 6.6% increase for inflation.
4. Labour in setting up and supervising furrow irrigation costed at 0.40 hours/ha/irrigation with labour charged at $7.00/hour
5. $14 per Ml
6. Cartage charged as $40.00/module plus $2.50/Km based on 14 bale modules and a distance of 15 Km from gin.
7. GROSS RETURN - Total Variable Costs.

It is assumed that Fixed Costs and Depreciation would be the same on both farms.

Figure 1A - Changes in leaf area of 4 irrigation treatments in 1982-83.

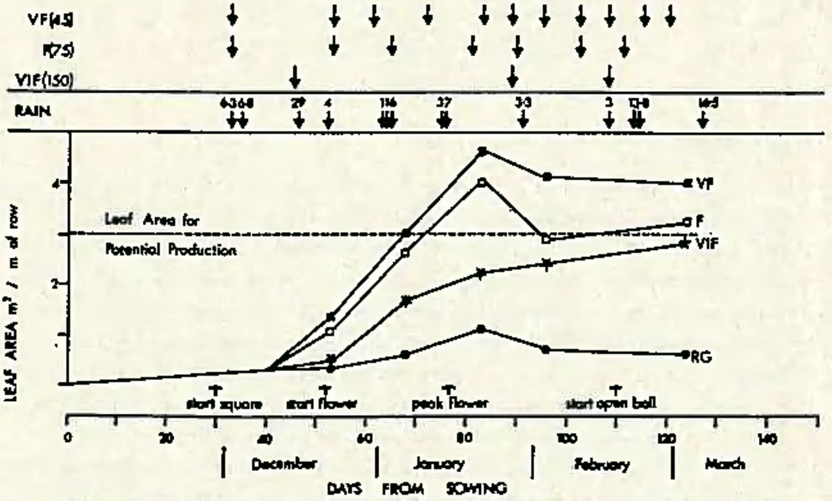
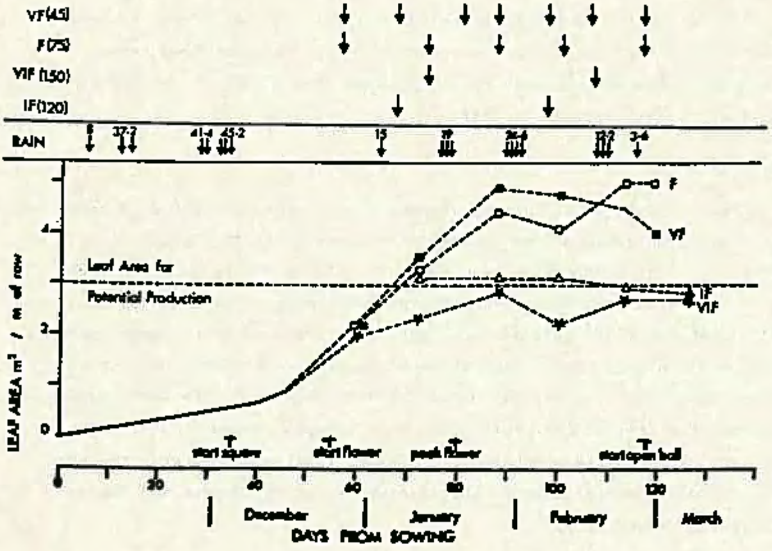


Figure 1B - Changes in leaf area of 4 irrigation treatments in 1983-84.



WATERLOGGING OF COTTON AND WAYS OF OVERCOMING ITS EFFECTS

Arthur S. Hodgson,
Senior Research Agronomist,
NSW Department of Agriculture,
Agricultural Research Station,
Narrabri.

Introduction

Furrow irrigation or heavy rain displaces most of the air from cracking clays, causing waterlogging. Small pockets of air may be trapped in waterlogged soil, but the oxygen in these is rapidly used up by roots and soil microorganisms. As the oxygen is removed, cotton roots respond dramatically. When the oxygen content of the soil air drops to 3-10%, root growth is temporarily delayed, at 1-2% root growth ceases, and when no oxygen is left, cotton root tips die within three hours (Huck, 1970).

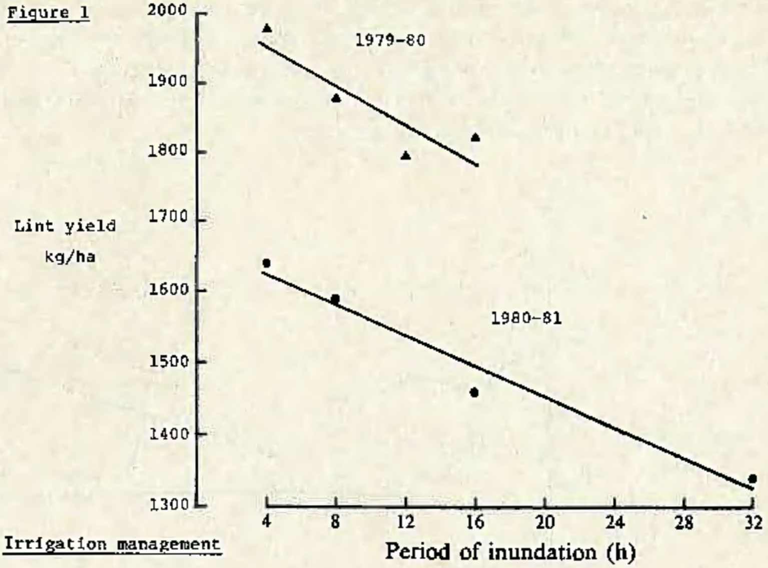
Soils recover from waterlogging by removing excess water, which allows fresh air to re-enter the profile and provides pathways for continued supplies of oxygen. Cracking clays drain by surface runoff, evaporation and transpiration. Some soils can drain excess water down through the subsoil, but deep cracking clays do not. Therefore, to minimize waterlogging in cracking clays, inundation periods should be brief, surface run-off should be rapid and transpiration by plants should be encouraged.

In a project supported originally by the Australian Cotton Growers Research Association and continued by the Cotton Research Committee, waterlogging damage to cotton has been assessed and ways of overcoming it are being investigated at Narrabri.

Yield losses

Figure 1 shows that running siphons for 16 hours instead of 4 hours per crop irrigation reduced lint yield by 159 kg/ha or 8% in 1979/80. In 1980/81, 32 hour irrigations reduced lint yield by 300 kg/ha or 18%. The period for which siphons ran was not the sole cause of yield loss. The faster draining field yielded more lint when irrigated at the same speed as the slower draining field. Thus when the siphons were turned off, other factors determined the rate at which the soil recovered from waterlogging and hence the lint yields. This means that the same speed of irrigation might not cause the same damage at different locations. However, the same principle would apply; namely, that faster furrow irrigation and faster drainage increase yields.

Figure 1



Irrigation management

Faster irrigation can be achieved by using more siphons per furrow, by using larger diameter siphons, by using more pressure head and by using shorter runs. The farmer should assess these options and weigh them against the possible yield advantages before adoption.

Field slope

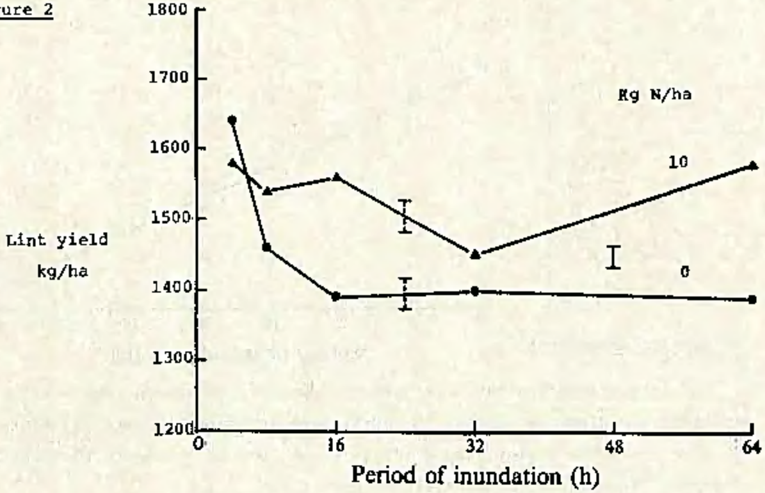
Slope influences the rate and degree of surface drainage, but we do not know by how much or to what extent this affects yield. Circumstantial evidence suggests that slope is important, but no valid comparisons have been made in cracking clays growing cotton. However, the Cotton Research Committee is supporting an experiment at Narrabri Agricultural Research Station which seeks to quantify the influence of slope on waterlogging damage to cotton. Land has been graded to 1:500, 1:1000, 1:1500 and 1:2000 in a randomized and replicated experiment, and speed of irrigation treatments can be superimposed on each of these slopes. Grading was completed in December, 1983 and cotton should be sown in October, 1985.

Foliar fertilizer

Waterlogged roots are less able to absorb water and nutrients from the soil. This often results in nutrient deficiency in the leaves, especially of mobile elements needed in large quantities, such as nitrogen (N). Waterlogged plants may lose some green colour due to N deficiency because N is removed from the chlorophyll of older leaves and sent to younger leaves, fruit and growing points. The older leaves will photosynthesise less carbohydrate, plant growth slows down and yields may suffer.

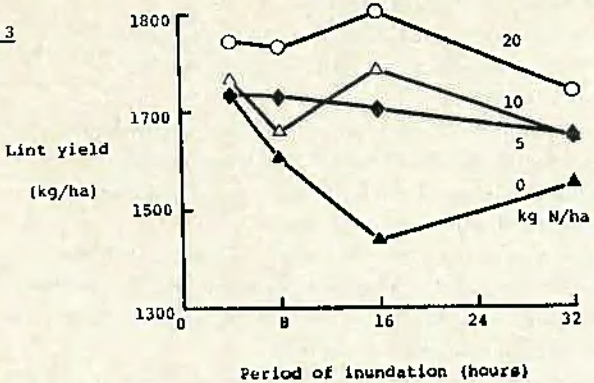
Fortunately, leaves can absorb nutrients through stomates and through cracks in their outer skin or cuticle. Thus a strategic spray of N fertilizer to the leaves just prior to waterlogging may overcome a shortage in supply from the roots and maintain crop growth.

Figure 2



In 1980/81, cotton waterlogged by irrigating for 4, 8, 16, 32 and 64 hours was sprayed with 0 or 10 kg N/ha as urea on the day before irrigation. All treatments were repeated at each of three crop irrigations. Results in Figure 2 show that lint yield was significantly increased by the foliar N, and that the response tended to be higher in the more waterlogged treatments. In 1982/83, cotton irrigated for 4, 8, 16 and 32 hours was foliar sprayed with urea at 0, 5, 10 and 20 kg N/ha. Again, all treatments were repeated at each of three crop irrigations. Results in Figure 3 showed that all foliar N sprays increased lint yield above the unsprayed control. The highest rate produced the highest yields, probably because post-irrigation storms extended the period of waterlogging on two occasions, and therefore increased the foliar N requirement. When no rains fall after irrigation, the rate of 10 kg N/ha would probably be adequate.

Figure 3



In 1983/84 there was no response to foliar N. This was probably the result of the cool, rainy season in which low temperatures and low solar radiation were also limiting yields. For yields to increase, all factors limiting yield need to be overcome. Because this could not be done for temperature and solar radiation, yields remained depressed despite the application of foliar N. It seems likely that waterlogging damage due to evening thunderstorms during otherwise hot, sunny weather may be more responsive to foliar N, since other factors are less likely to be limiting. However, the timing and intensity of such storms are difficult to predict beforehand. A period of about 24 hours is required for sufficient foliar N to be absorbed before waterlogging occurs.

Conclusions and recommendations

1. Fast irrigations decrease waterlogging and increase yields
    - use more siphons, larger siphons, more pressure head or shorter runs.
2. Fast irrigations do not cause fast drainage
    - use deep, clean furrows or increase field slope.
3. Foliar N can help alleviate waterlogging damage, providing other plant requirements are not limiting, eg., temperature and sunshine.
    - apply about 8-10 kg N/ha approximately one day before irrigating.
    - do not mix with insecticide as pH and droplet size of the mix are dramatically increased, probably to the

detriment of the insecticide.

- most N uptake is completed by the end of January, depending on season, so later foliar sprays may be less effective.
- urea is corrosive to metal and can burn cotton leaves. To minimize burning, spray at night or evening to allow uptake when temperatures are cool, humidity is high and stomates are fully open.
- urea is easily absorbed by leaves, but mixes with other forms of N such as ammonium nitrate and ammonium sulphate may cause less burning at high concentrations. This is being investigated at Narrabri.
- when N deficiency symptoms have appeared, it is too late to overcome the damage, but further damage may be arrested by foliar sprays.
- other nutrients such as zinc, sulphur, phosphorus and boron may possibly become deficient under prolonged waterlogging, but this has not been clearly demonstrated.
- there is a limit to the amount of N that can be stored in the crop canopy, so foliar sprays should not be regarded as a long-term application strategy.

Further reading

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THE GROWTH OF COTTON: TEMPERATURE, SOLAR RADIATION AND NITROGEN FERTILISER

G.A. Constable
Department of Agriculture N.S.W.
Narrabri

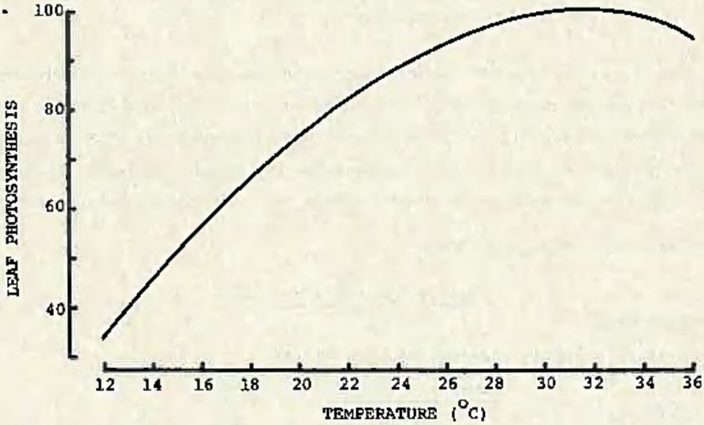
The 1983/84 season in N.S.W. and southern Queensland cotton growing areas was characterised by long periods of cool, wet and cloudy weather. Most areas had below average temperatures for each month. The season was especially notable when compared to the hot dry seasons in the preceding 3-4 years.

It is the aim of this contribution to present the primary relationships between cotton growth and temperature, solar radiation or nitrogen fertiliser. Temperature and solar radiation are not under our direct control: but the problems created by bad weather can be minimised. Suggestions will be made in this article on ways of cotton management to reduce problems associated with unfavourable weather.

Temperature

Two basic responses to temperature need emphasis when describing effects on cotton growth. The first response is that of leaf photosynthesis to temperature as shown in Figure 1.

1.



Photosynthesis is the key process of plant growth: it is the conversion of atmospheric carbon dioxide into plant dry matter. Leaf photosynthesis proceeds most rapidly at a temperature of about 30°C, but there is a fairly broad range of temperature where photosynthesis is satisfactory. At temperatures less than about 8°C and above about 45°C, photosynthesis is negligible. It must be emphasised that Figure 1 refers to photosynthesis at an instant during the day.

The second, and practically more important response is that between temperature and rate of development of cotton (Figure 2). These data are derived from field experiments and relate the days from sowing to squaring with average temperature experienced during that phase.

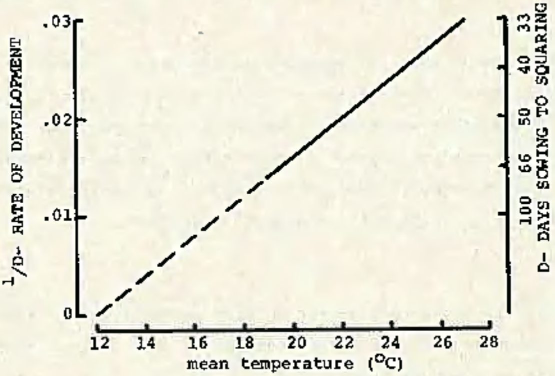


Figure 2. The relationship between mean temperature and rate of cotton development from sowing to squaring.

As can be seen, above 12°C development proceeds more rapidly at higher temperatures up to about 34°C. The point on this relationship where development ceases (12°C) is called the base temperature. This value is used in day degree (or heat unit) calculations. Day degrees essentially measure how long and how much above the base each day is suitable for cotton growth.

They are calculated as follows:

$$\text{DAYDEGREES} = \frac{(\text{Tmax} - 12) + (\text{Tmin} - 12)}{2}$$

for example if daily temperature were 30/18.

$$\text{DAYDEGREES} = \frac{(30-12) + (18-12)}{2} = \frac{18+6}{2} = 12$$

No negative terms are used for example if daily temperatures were 20/10:

$$\text{DAYDEGREES} = \frac{(20-12) + (10-12)}{2} = \frac{8+0}{2} = 4$$

The total daydegrees required in each developmental phase for Deltapine cotton are shown in the following table:

Phase	Daydegrees	Days at 28/20
Sowing to final emergence	80	7
Sowing to squaring	505	42
Sowing to flowering	777	65
Interval between branches	42	4
Flower to open boll	750	63
[illegible]	1527	

Note that 1527 (777+750) day degrees are required from sowing to the first open boll. Note also that the last useful flower will appear 750 day degrees before the first killing frost in autumn. Therefore a season with 2200 day degrees will have 673 (2200-1527) day degrees of useful flowering time, or about 11 (473/42) flowering branches per plant.

Solar radiation

The relationship between solar radiation and leaf photosynthesis is shown in Figure 3. About 60% of full sunlight is required for maximum photosynthesis. In the dark, there is a net loss of leaf weight - due to respiration. Figure 3 again relates to photosynthesis at one time of the day: not many leaves are exposed to full sunlight in the middle of the day, and none experience optimum temperatures all of the day. As a consequence, the pattern of leaf photosynthesis during the day is influenced strongly by light and temperature: at sunrise, the temperature is below optimum and light is also limiting. Therefore, photosynthesis of a typical leaf is rarely near potential rates (Figure 4).

The importance of the pattern shown in Figure 4 is emphasised when it is considered that cotton boll growth is mainly supported by the leaves near them: and generally leaves and bolls are below the top of the plant canopy. Thus the problems encountered by bolls during cloudy or cold weather can be appreciated. The rates of photosynthesis for lower leaves on a cloudy day are only 5% of leaves exposed to full light - reducing the ability of the crop to fill or hold bottom bolls. Because lower leaves are shaded and can be a drain on the plant, 14% of full sunlight is required to maintain plant weight; i.e. growth will not occur on a day with less than 14% of full sunlight.

The reaction of the plant to prolonged cloudy conditions depends on stage of growth. Up to early flowering, the general result is that lower squares and young bolls may shed: the growth of new leaves and young squares

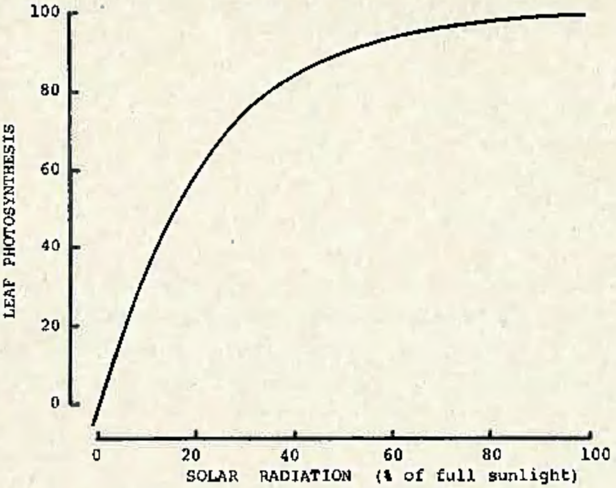


Figure 3. The relationship between solar radiation and cotton leaf photosynthesis.

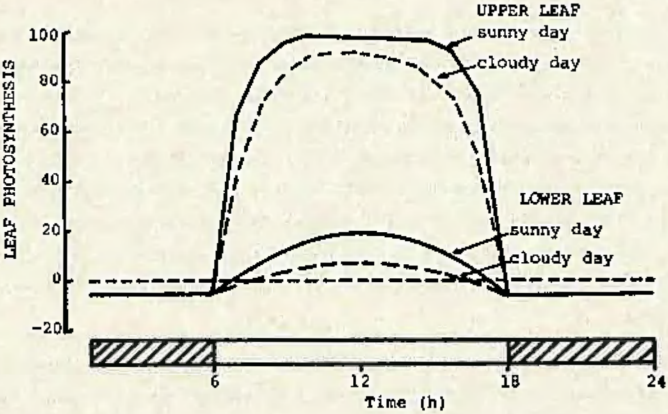


Figure 4. The pattern of photosynthesis for cotton leaves at the top or bottom of a cotton canopy on a sunny or cloudy day.

at the top of a plant may continue. During the boll filling stage, the result is usually smaller bolls, often reduced in micronaire as well: upper squares will probably shed at this stage.

Nitrogen fertiliser

Nitrogen is one of the most important elements in all crops and cotton is no exception. On average a cotton leaf contains about 20 milligrams of nitrogen and a cotton boll about 70 milligrams. Furthermore, the movement of nitrogen from the soil, through the plant and the conversion of this nitrogen into plant protein are all active processes that rely on photosynthesis.

Another very important characteristic of nitrogen nutrition is that approximately half of the nitrogen that ends up in a boll is derived, not directly from the soil, but indirectly from senescing leaves. Therefore there is a long delay between application of nitrogen and the ultimate destination of all this nitrogen into cotton bolls.

Given these characteristics and field data relating nitrogen uptake to yield, the desired pattern of daily nitrogen can be proposed (Figure 5).

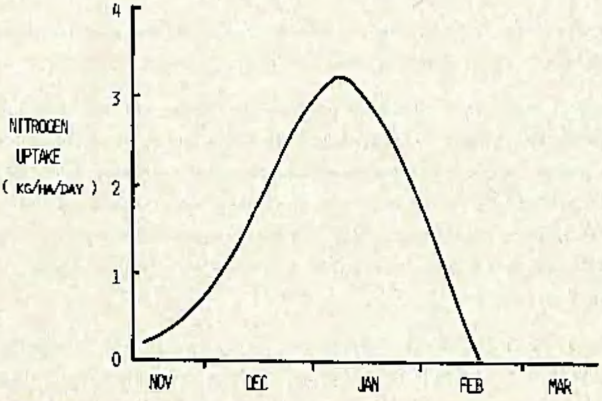


Figure 5. The desired pattern of daily nitrogen uptake for a cotton crop to have 120 kg N uptake/ha.

This pattern (i) allows for sufficient early vegetative growth, (ii) terminates nitrogen uptake on a realistic date so that crop maturity occurs before unfavourable weather, and (iii) ensures a total plant uptake of 120 kg N/ha.

The desired pattern can be used constructively when considering sidedressing (gas, solid or in irrigation water) or foliar application of nitrogen. Given that it takes three weeks to take up and fully utilise nitrogen, ideally all applications of nitrogen fertiliser should cease in mid January. Nitrogen applied on later dates could be poorly utilised.

Management to minimise problems during bad weather

Most cotton growing regions in Australia have seasons or times within a season when conditions are unfavourable for cotton growth. Although it should be obvious that temperature is not the only criterion for successful growth, it can be used as an indicator of climatic variability. For example at Narrabri the day degree sum from October to the end of April averages 2320, the extremes have ranged from 2150 to 2750 - i.e. the range is 26% of the average.

One obvious although not always practical method of minimising cool weather is to avoid it. For example, September plantings at Narrabri often do no better than early to mid October plantings. In other cooler areas, this option is not necessarily sensible because later plantings run the risk of lower yields.

The main points to consider for minimising problems during bad weather are nitrogen rate, plant spacing, and in future seasons, variety.

Nitrogen rate: There is a definite optimum nitrogen rate for any cotton field. Nitrogen deficiency decreases yield, but a point is reached with rates where there is no yield increase and further additions of nitrogen delay maturity. This delay in maturity can leave defoliation and harvest in cooler, unfavourable conditions. High nitrogen rates also produce bigger, leafier plants which are more seriously affected by problems during cloudy weather (see Figure 4).

Methods of soil and plant testing are being researched to enable more accurate decisions to be made on nitrogen application rates and dates.

Plant spacing: Again there is a definite optimum plant spacing for stable cotton yield. The spacing to aim for is about 10 plants/metre of row - say from 14 kg seed/hectare. With uniform spacing, half this number of plants are capable of maximum yield. Plant spacings in excess of 15/metre are to be avoided, particularly in wet seasons. Dense shading from thick stands exaggerate the problems illustrated in Figure 4.

Variety: The new okra leaf line (SIROKRA 401) which has now been released, has a more open leaf canopy which has shown particular superiority to Deltapine 61 in wet and short seasons.

Another point to consider under this subject is to have a range of management strategies on each farm. If some fields have inputs and management that is a little conservative, they will be the best fields in a problem season. Alternative more intensive strategies on other fields will be superior in better seasons. This approach helps to spread out irrigation and harvesting within each year.