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RURAL INDUSTRY RESEARCH FUNDS
FINAL REPORT

Authorised Body:	COTTON RESEARCH COUNCIL
Project Number:	DAN 3L
Project Title:	WATERLOGGING OF COTTON IN A CRACKING CLAY
Field of Research:	SOIL SCIENCE Field Code: 2.1
Organisation:	Department of Agriculture, NSW
Address:	P.O. Box K220 Haymarket, NSW 2000
Project Supervisors:	Dr E C Wolfe, Regional Director of Research (067) 679300 Dr L J Cook, Director Plant Production Research (02) 2175063
Principal Researcher:	Dr A S Hodgson, M.Sc.Agr., Ph.D. (067) 931105
Address:	Agricultural Research Station PMB Myall Vale Mail Run Narrabri, NSW 2390
Administrative Contact:	Mr G M Mohr, Research Co-ordinator (02) 2175130
Commencement Date:	July 1981
Completion Date:	June 1987

OBJECTIVES

The overall objective is to develop soil and agronomic management techniques to improve the aeration of irrigated clays and hence their productivity for cotton.

Specific objectives:

* To quantify waterlogging influences on the growth and yield of cotton.

* To quantify waterlogging influences on the physical and chemical properties of the cracking grey clays.

* To develop management techniques to overcome or ameliorate the effects of waterlogging.

BUDGET SUMMARY

Source of Funds	Seasons	Amount ($)
A.C.G.R.A.	1981-82	2500
	1982-83	17525
C.R.C.	1983-84	13950
	1984-85	16385
	1985-86	9250
	1986-87	10405
TOTAL		70015

SUMMARY OF RESULTS AND BENEFITS TO INDUSTRY

Waterlogging damage to furrow-irrigated cotton is surprisingly high. Over 100,000 ha of cotton are irrigated each year in NSW, predominantly on fine-textured cracking clays. Each furrow irrigation waterlogs these soils for 2-3 days on average (reference[3,4,9]), and crops are irrigated up to six times per season (average approximately four). In the absence of rain, this gives 1 days of waterlogging per season on average, with yield loss per day averaging 30 kg lint/ha(9). Thus 300 kg lint/ha yield loss is average, which at $1.50-$2.00/kg is $450 to $600/ha per year. ***Over 100,000 ha, the total loss to the industry (in NSW) is $45m to $60m per year.*** More loss occurs in wet seasons, when the number of days of waterlogging can exceed 20. However, this does not double the loss since the yield response follows a decay function(1).

Approximately 10% of the yield loss ($4.5m to $6m p.a.) can be readily recovered by completing irrigations quickly and maintaining deep, clean furrows to remove excess water(2,3,9). Current work is evaluating the additional benefit of increasing field slope. Tactical applications of foliar nitrogen fertilizer can also recover a considerable proportion of lost yield under certain conditions, which have now been defined(4,7,9). Present experiments in a new CRC-funded project ('Improving Soil Aeration for Cotton') are addressing the remaining loss.

ACHIEVEMENT OF AIMS

This has been a major, long-running project, and all of the stated aims have been achieved. In addition, several ancillary projects which were necessary for the success of the major project have been completed. These include: quantifying the physical properties of these soils under irrigation (2); calibrating the neutron method of estimating soil water content (6) and the gamma and neutron methods of estimating soil bulk density (8); determining the critical limits of oxygen exchange in these soils (10); demonstrating that oxygen diffusion is a sensitive index of changes in the structure of these soils (11); ameliorating damaged soil structure by using wheat and safflower crops to deeply dry and crack the soil (5); and evaluating the relative tolerance of summer grain legumes to waterlogging and assessing their potential for irrigated cropping (12).

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DIFFICULTIES

The biggest difficulty was rain when it closely followed the imposition of waterlogging treatments. Nevertheless, no field experiment was writted off by this factor and the results from all experiments have or are being published. Field experiments offer the only realistic option for a project of this type because the behaviour of both cotton and cracking clays is almost impossible to reproduce under controlled laboratory or glasshouse conditions. The large, indeterminate, bushy cotton plant has a prodigious ability to compensate for variation in plant spacing; thus plant variability, pot spacing and buffering of outermost plants present logistic problems in glasshouse experiments. Cotton root growth and leaf canopies in field experiments are likely to be more uniform and more relevant to commercial applications. The non-random variability associated with cracks of these soils makes representative soil sampling difficult, particularly at depth, but problems associated with reproducing this variability in the glasshouse or laboratory are almost insuperable.

LIST OF PUBLICATIONS

Postgraduate Thesis

1. Hodgson, A.S. (1986). The effect of waterlogging on cotton during furrow irrigation of a cracking grey clay. Ph.D. thesis. Univ. of New England.

Research Papers

2. Chan, K.Y., and Hodgson, A.S. (1981). Moisture regimes of a cracking clay soil under furrow irrigated cotton. *Aust. J. Exp. Agric. Anim. Husb.* 21, 538-42.

3. Hodgson, A.S., and Chan, K.Y. (1982). The effect of short-term waterlogging during furrow irrigation of cotton in a cracking grey clay. *Aust. J. Agric. Res.* 33, 109-16.

4. Hodgson, A.S. (1982). The effects of duration, timing and chemical amelioration of short-term waterlogging during furrow irrigation of cotton in a cracking grey clay. *Aust. J. Agric. Res.* 33, 1019-28.

5. Hodgson, A.S., and Chan, K.Y. (1984). Deep moisture extraction and crack formation by wheat and safflower in a vertisol following irrigated cotton rotations. In 'The Properties and Utilization of Cracking Clay Soils' Ed. J.W. McGarity, E.H. Hoult and H.B. So pp. 299-304. (University of New England: Armidale, N.S.W.)

6. Hodgson, A.S., and Chan, K.Y. (1987). Field calibration of a neutron moisture meter in a cracking grey clay. *Irrig. Sci.* 8, 233-44.

7. Hodgson, A.S., and MacLeod D.A. (1987). Effects of foliar applied nitrogen fertilizer on cotton waterlogged in a cracking grey clay. *Aust. J. Agric. Res.* 38, 681-88.

8. Hodgson, A.S. (1988). Use of neutron and gamma radiation meters to estimate bulk density and correct for bias of sampling for water content in a swelling clay soil. *Aust. J. Soil Res.* (in press).

9. Hodgson, A.S., and MacLeod, D.A. (1988). Seasonal and soil fertility effects on the response of waterlogged cotton to foliar applied nitrogen fertilizer. *Agron. J.* 80 (in press).

10. Hodgson, A.S., and MacLeod, D.A. Use of oxygen flux density to estimate critical air-filled porosity for respiration in a Vertisol. For *Soil Sci. Soc. Amer. J.* (submitted to journal).

11. Hodgson, A.S., and MacLeod, D.A. Direct comparison of oxygen flux density, air-filled porosity and bulk density as indices of structural modification of a Vertisol. For *Soil Sci. Soc. Amer. J.* (submitted to journal).

12. Hodgson, A.S., Holland, J.F., and Rayner, P. Relative sensitivities of six grain legumes to waterlogging during furrow irrigation of a Vertisol. I. Seedling mortality, Growth and yield.*Field Crops Res.* (under internal review).

Conference Papers

13. Hodgson, A.S., and Chan, K.Y. (1981). The effects of waterlogging during irrigation of cotton in a cracking grey clay. Drainage of Agric. Lands Seminar, Int. Comm. Irrig. Drain., Aust Nat. Committee Melbourne, Vic.

May, 1981. pp. 23-34.

14. Chan, K.Y., and Hodgson, A.S. (1981). Moisture regimes of a furrow irrigated vertisol under cotton. Symp. on the Properties and Utilization of Cracking Clay Soils, Armidale, N.S.W. August, 1981.

15. Hodgson, A.S., and Chan, K.Y. (1981). Deep moisture extraction and crack formation by wheat and safflower in a vertisol following irrigated cotton rotations. Symp. on the Properties and Utilization of Cracking Clay Soils, Armidale, N.S.W. August, 1981.

16. Dubbelde, E.A., Hodgson, A.S., and Wright, G.C. (1982). The lower limit of extractable soil water for crops grown on a cracking clay soil. Agronomy Conf. July 11-14, 1982. Wagga Wagga, N.S.W. *Proc. Aust. Soc. Agron.* 2, 308.

17. Hodgson, A.S. (1982). The basis, use and accuracy of the neutron method of soil moisture estimation. Irrigation Scheduling Workshop, Moree, N.S.W. 25-26th August, 1982.

18. Hodgson, A.S. (1982). Effects of furrow irrigation on the aeration of a grey vertisol used for cotton production. Symp. on Rural Drainage in Northern Australia, Toowoomba, Qld. Sept 27-29, 1982. pp. 39-52.

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23. Hodgson, A.S. (1985). Soil physical properties of a cracking clay soil used for irrigated cotton growing. Soil Workshop for Agronomists, Horticulturists, and Soil Conservationists. Tamworth, N.S.W. July 9-11, 1985. pp. 4-1 to 4-6.

24. Hodgson, A.S., and MacLeod, D.A. (1986). Rate of oxygen supply in a cracking grey clay. Aust. Soc. Soil Sci. Conf., Canberra, A.C.T. May 12-14, 1986.

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August 20-21, 1986. pp. 37-43.

28. Hodgson, A.S., and MacLeod, D.A. (1987). Three indices of structural change in a furrow irrigated Vertisol. National Workshop on the Effects of Management Practices on Soil Physical Properties, Toowoomba, Qld. Sept. 7-10, 1987.

Advisory Communications

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32. Hodgson, A.S. (1983). The physics of soil waterlogging. *The Australian Cottongrower* 4(1), 18.

33. Hodgson, A.S. (1983). Furrow irrigation management to minimize waterlogging damage to cotton. *The Australian Cottongrower* 4(1), 19-20.

34. Hodgson, A.S. (1983). Waterlogging costs 'staggering'. *The Land* Northern Extra. February 10, 1983. p 5.

35. Hodgson, A.S. (1983). Can foliar fertilizers help waterlogged cotton? N.S.W. Dept. Agric. *Irrigator's Newsletter* No. 1. November, 1983. pp. 10-12.

36. Hodgson, A.S. (1984). Waterlogged cotton - can foliar fertilizers help? N.S.W. Dept. Agric. *Macquarie Irrigator*. January, 1984. pp. 2-3.

37. Hodgson, A.S. (1985). Irrigate, don't saturate. *Irrig. Assoc. Aust. J.* pp. 19-20.

38. Hodgson, A.S. (1986). Can you afford waterlogging? *The Australian Cottongrower*. 7(3), 4-5.

39. Hodgson, A.S. (1986). Waterlogging is drowning cotton dollars. *North Western Courier* Ann. Rev. December 18, 1986. p. 21.

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DETAILED REPORT

Project: Waterlogging of Cotton in a Cracking Clay.

This project was commenced with financial support from the Australian Extension Services Grant (1979-80 and 1980-81). Continuing support was provided by the ACGRA (1981-82 and 1982-83) and the CRC (1983-84 to 1986-87).

Cotton growers observed in the late 1970's that waterlogging after irrigation stalled cotton plant growth, caused yellowing and presumably reduced yields. The problem became worse after a series of high rainfall years, with less waterlogging and higher yields being produced in fields recently developed for irrigation compared with that in adjacent, older irrigated land. However, the cause and magnitude of waterlogging and possible soil structural problems, the extent of yield losses, and the most effective ways of overcoming the losses, were unknown.

Physical Properties of Furrow Irrigated Cracking Clay Soils

Initial investigations of soil/productivity problems were hampered by lack of information on physical properties of cracking clay soils, on which the Australian cotton industry is based. Consequently, a series of experiments was done to characterize the hydrology and aeration of a representative cracking clay soil under furrow irrigation. The major findings were:

The maximum available water capacity was 195 mm to 1.5 m depth, but only 109 mm was replenished by furrow irrigation because cracks were sealed rapidly by the soil swelling and slaking. Sealing of cracks limited the wetting front to a depth of 0.8 m despite ponding, because saturated hydraulic conductivity is low. Bulk density increased with soil depth and changed with soil water content due to swelling and shrinking. The air-filled porosity of the subsoil remained below 0.05 $m^3 m^{-3}$ for several days after irrigation because drainage and redistribution of water is slow and drying depends on transpiration. The wilting point was 0.187±0.009 Mg Mg^{-1} for sunflower and 0.192±0.008 Mg Mg^{-1} for cotton, and the water content at -1.5 MPa was 0.2 Mg Mg^{-1}. The soil was poorly drained and thus had no definable field capacity.

Characterization of these properties enabled more accurate scheduling of irrigations, demonstrated poor soil aeration after irrigation, assisted with the planning of field experiments and enabled a more complete understanding of the behaviour of cracking clays under irrigated cropping. The results have been published ([2]).

Calibration of a Neutron Moisture Meter to Estimate Soil Water Content

A reliable, rapid, accurate and nondestructive method was required to estimate soil water content in irrigated fields of swelling clay soils. Direct core sampling is destructive, laborious and subject to errors associated with small sample size, changes in bulk density, and nonrepresentative sampling of cracks in these soils. The neutron radiation method relates soil water content to the number of neutrons attenuated per unit time by collisions with hydrogen nuclei, which are predominantly in soil water molecules. The method samples a large volume of soil, and reduces error of changes in soil water by repeatedly sampling the same part of the soil.

A neutron moisture meter was calibrated using recommended procedures at 15 x 0.1 m depth increments to 1.5 m. Separate calibrations were determined for the 0-0.1 m and 0.1-0.2 m depths, but all depths below 0.2 m conformed to a single calibration. Correction for bias due to cracking and changes in bulk density slightly improved accuracy, mostly in dry soil. Accuracy was markedly improved relative to published calibrations. A precision of ± 0.01 $m^3 m^{-3}$ for volumetric water content required 3 samples per mean by the neutron method or 11 samples per mean by the core sampling method. Neutron escape through shrinkage cracks or through the soil surface did not cause problems at depths below 0.3 m at low water contents near the permanent wilting point of cotton. The neutron method is therefore appropriate for use in dryland hydrological studies in this soil.

The neutron calibrations have been published (6) and have been used for several seasons by other researchers and in a commercial computer management system (SIRATAC) for irrigation scheduling of cotton. Further improvements to the theory and practice of the technique in swelling soils are currently being made, as discussed below.

Use of Radiation Meters to Estimate Bulk Density

A major problem with studies of swelling soil is the estimation of bulk density, which is a dynamic property that changes with depth, water content and soil structure. Estimates of bulk density using cores are subject to similar errors and problems to those cited above for estimates of water content. Gamma radiation backscattering is used to nondestructively sample relatively large soil volumes to estimate wet bulk density, which is a function of dry bulk density and volumetric water content. However, dry bulk density and water content are negatively correlated in swelling soil, which restricts values of wet bulk density to a relatively narrow range.

Consequently, gamma ray backscattering was poorly correlated with wet bulk density and the technique is therefore not recommended for use in this soil. Nevertheless, a high correlation between neutron counts and gravimetric water content in this soil provided a basis for predicting bulk density corrected for bias in sampling of shrinkage cracks using a published theoretical model of soil shrinkage. High correlation between neutron counts and corrected bulk density was found at all soil depths between 0.1 m and 1.5 m. A precision of ± 0.01 Mg m^{-3} for bulk density required 3 to 6 samples per mean, depending on soil depth. The mean relative difference between predictions of bulk density from neutron counts compared with independent estimates by the core method was ≤ 4.1% at depths below 0.3 m. The recommended procedure is therefore to predict bulk density from neutron counts in order to correct for sampling bias and bulk density effects on the neutron calibration.

The method eliminates the need for additional sampling for bulk density conjunction with the neutron moisture meter. These results have been submitted for publication (8).

Effects of Waterlogging on the Yield of Furrow Irrigated Cotton

When cracking clays are furrow irrigated, most of the root zone becomes poorly aerated. Frequent irrigations of long duration, especially on fields with little slope, increase the problem. Cotton is susceptible to waterlogging, but the extent of yield losses and the mechanism of damage were unknown. My research has quantified yield losses through waterlogging and related the losses to irrigation management, soil aeration and nitrogen uptake. Early experiments investigated the effects of running irrigation siphons for varying periods of time to vary waterlogging. Growth, fruiting, yield and N uptake of cotton were then related to the time siphons were run and to measurements of soil air-filled porosity (E).

Waterlogging events were equally damaging at different stages of crop growth and the effects were cumulative. The extent of yield loss varied with the severity of waterlogging and with the yield potential of the crop. When

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average yield was high, waterlogging decreased yield more rapidly than when yield was low. Within a waterlogging event, more yield was lost during the first few days of waterlogging than during extended waterlogging. As the total number of days of waterlogging per season increased from 5 to 25, the average loss of lint yield per day decreased from 38 to 19 kg ha^{-1}. However, total yield loss (days x loss day^{-1}) increased from 190 to 480 kg ha^{-1}. Waterlogging reduces yield by about 1 bale ha^{-1} (225 kg ha^{-1}) in dry seasons. More loss occurs in wet seasons, such as 1983-84, when an estimated $90m was lost. Results for these experiments have been published ([3,4,9]).

Amelioration of Waterlogging Damage with Foliar Applied Nitrogen Fertilizer

Waterlogged roots respire less than aerated roots and consequently absorb less water and nutrients from the soil, which produces deficiencies in the leaves. Waterlogged cotton does not usually wilt because the stomates close during waterlogging, which keeps the leaves turgid. However, nutrients become deficient and this reduces photosynthesis, plant growth and lint yield.

During the first 3-4 days of waterlogging after irrigation, most of the yield loss appeared to be due to less N being absorbed from the soil by the waterlogged roots. Sterilizing the soil with hydrogen bromide did not affect waterlogging damage, indicating that soil-borne disease was not associated with the plant responses. Much of the yield lost through temporary waterlogging could be recovered by bypassing the roots and supplying N directly to the leaves as a foliar spray of urea. As the severity of waterlogging increased, the response to foliar N increased up to a limit. Increasing the period of irrigation from 4 to 16 h $irrigation^{-1}$ increased the response to foliar N from 2.8 to 8.4 kg lint per kg of N, or from 168 to 506 kg lint ha^{-1} for the season. Response to 5 kg foliar N ha^{-1} in the 32 h irrigation treatment averaged 10.5 kg lint per kg of N, but higher rates were of no additional benefit because another factor then limited yield. The other factor is possibly another deficient nutrient, a toxic concentration of a reduced substance, or a hormonal imbalance. These factors are being investigated in current experiments. Results from this experiment have been published ([7]).

Farmers observed that waterlogged cotton does not always respond to foliar sprays of N, so experiments were done to explain the variability of response and to define more clearly the conditions under which foliar N should be applied. This work was done over a three year period, and climatic and soil fertilizer conditions included a cool, moist season with optimal soil fertilizer N; a hot, arid season with high soil fertilizer N; and a hot, arid season with a wide range of soil fertilizer N.

The results showed that increased waterlogging reduced N uptake and lint yield. There was no response to foliar N in the cool, moist season because factors other than N limited growth and yield whether or not N was supplied to the foliage. Lack of response to foliar N in the hot, arid season with high soil N was related to high uptake of N measured before irrigation, which compensated for reduced uptake by the roots during subsequent waterlogging. A three-factor interaction in the third season confirmed that more cotton yield was recovered by applying foliar N under more severe waterlogging when soil N levels were not high.

When N was applied to the soil, maximum lint yields of the 4 and 32 h waterlogging treatments were associated with respective N uptakes of 126 and 127 kg ha^{-1}. However, soil fertilizer rates of 120 and 180 kg N ha^{-1} were required for these respective uptakes. The difference was associated with reduced uptake during waterlogging. In addition, the N that *was* absorbed by waterlogged plants was inefficiently used. Recovery was higher for soil than for foliar applied N, but only at heavy rates. Heavy rates of foliar N were inefficient because only limited quantities could be absorbed by the foliage and leaf burn occurred. Application of heavy rates of foliar N to cotton is therefore not recommended. However, at low rates, foliar N tended to be more efficiently absorbed than soil N and is therefore more suitable for small, tactical sprays to overcome a short-term deficiency, such as during waterlogging or prior to delayed soil applications.

The results explained a mechanism of response of cotton to waterlogging, showed that foliar N can ameliorate the effects of waterlogging in cotton, defined the conditions under which responses to foliar N occur, and explained the variability in response to foliar N found under commercial conditions. These results have been submitted for publication (9). Current work is investigating the predictability of response to foliar N from petiole nitrate levels, measured before irrigation.

Use of Oxygen Diffusion to Characterize Soil Aeration

I modified Taylor's (1949) apparatus to measure quasi-steady-state diffusion of oxygen through intact soil cores sampled in the top 0.3 m of a cracking grey clay over a range of soil water content.

A two-stage linear model was fitted to the relationship between oxygen flux density (F) and air-filled porosity (E) at each depth position. The optimizing procedure did not converge for measurements taken in the 0.2-0.3 m depth because F and E values were restricted largely to the first (horizontal) stage of the model (see below). In every other case, the model fitted the data with high precision and the regression coefficients were not significantly different between depths and positions. Comparisons between depths averaged over all positions, and between positions averaged over both depths, showed no difference in every case. The model fitted to all depths and positions combined was therefore adopted to predict the diffusive exchange in the top 0.2 m of the ridges of this soil, namely:

$$F = 1517[(E-0.145)+SQRT(E-0.145)^2];\ n = 191,\ R^2 = 0.90,$$

and F can be predicted for various values of E. From published rates of oxygen consumption of cropped soil, the critical E of 0.150 ± 0.006 $m^3\ m^{-3}$ was determined for this soil.

The implication was that the soil remained waterlogged following furrow irrigation or heavy rainfall for longer than was previously thought, since soil takes longer to recover to a higher E. The large yield losses associated with extended irrigations in previous experiments can now be attributed to more da of stress. These results have been internally reviewed and are being submitted to a research journal (10).

Use of Oxygen Diffusion as an Index of Soil Structural Modification

Pore continuity is probably the most important aspect of soil structure for plant growth since it directly affects the movement of gases, liquids and roots through the soil. Gaseous diffusion (F) is extremely sensitive to the volume, tortuosity and continuity of air-filled pores, and therefore should be a sensitive index of changes in soil structure. I assessed the relative sensitivity of F, bulk density (BD) and air-filled porosity (E) in intact soil cores to detect differences in soil structure between soils cultivated when wet and when dry. Measurements were taken during the growth of a subsequent cotton crop.

Cultivating when the soil was wet reduced crop dry matter by 26% and yield by 35%; and usually increased soil water content (0_g) due to less crop water use, decreased E and F, and variously influenced BD relative to soil cultivated when dry. The sensitivity of F > E > BD for detecting differences in soil

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structure, particularly at the 0.2-0.3 m depth. The structural effects were highly correlated with the growth and yield of cotton.

The high sensitivity of F was attributed to its dependence on pore volume, continuity and tortuosity, all of which are disrupted by the smearing and remoulding action during cultivation of wet soil. The low sensitivity of BD as an index of structure was related to the lack of air in this soil when wet, which prevents compaction during wet cultivation. This explained why measures of bulk density by other workers showed little difference between treatments, even when corrected for field water content. The sensitivity of E to changes in 0_g is a good indication of structural stability. In a stable soil, the removal of water is accompanied by the influx of air since the soil pores remain intact (structural shrinkage). In a swelling soil with unstable structure, as water is removed the pores collapse and preclude the influx of air (normal shrinkage). Correspondingly, E increased more slowly with drying in soil with unstable structure than in soil with stable structure. Furthermore, E in unstable soil was usually less than the critical level for oxygen exchange, whereas E was usually above this level in stable soil.

These results help to explain the relatively poor growth and yield of cotton growing in the soil prepared when wet. They have been internally reviewed and are being submitted to a research journal ([11]).

Deep Drying by Crop Roots to Ameliorate Damaged Soil Structure

Some cracking grey clays used for irrigated cotton production were structurally degraded during wet seasons in the mid to late 1970's. Frequent cultivation with heavy machinery at relatively high soil water contents is thought to have been responsible. The formation of shrinkage cracks was considered important for structural regeneration of these soils. However, low soil water levels are avoided during irrigated cropping of cotton, and so other rotation crops are used to dry and crack the soil. The extent of deep drying and cracking of a grey clay by wheat and safflower was examined following four irrigated cotton rotations, which varied in intensity of cultivation. Structural conditions ranged from a well-structured subsoil in previously fallowed plots to a subsoil with an observable massive layer 0.2 to 0.4 m below the surface of soil which had been repeatedly cropped to cotton.

Wheat and safflower dried the profile to beyond the measured depth of vertical cracks (0.402±0.083 m), including the massive layer found in continuous cotton plots. Wheat extracted water to 0.85 m in all rotation treatments, whereas safflower extracted water to 1.45 m in fallowed plots, but to shallower depths after the more intensive cotton rotations. Safflower dried the soil deeper than wheat in every case. The dimensions of vertical cracks were not significantly different between wheat and safflower, regardless of the previous cotton rotations. The vertical crack volume was a minor proportion of total air-filled porosity, indicating that structural and angular planar voids were dominant.

Deep drying by these crops improves soil structure by forming continuous fracture planes and relatively stable root channels. The latter increase the transmission porosity of the soil and facilitate deep aeration, deep wetting, and root exploration by subsequent crops. These results have been published ([5]).

Responses of Grain Legumes to Waterlogging

Summer grain legumes often attract high prices, but as a group they are considered intolerant of waterlogging and therefore discouraged under flood irrigation. Soybeans are an exception, but little is known of the relative tolerance to waterlogging of other summer grain legumes. A project which began in 1986-87 compares the responses of six summer grain legume species to waterlogging as influenced by field slope and the duration of furrow irrigation. This project will benefit the cotton industry in two ways. Firstly, the majority of irrigation farmers in northern N.S.W. have little economic option other than to grow cotton. This project is showing that appropriate irrigation management enables waterlogging-sensitive species to survive, grow and produce appreciable quantities of high-value grain. Some of these crops may become important rotation crops for cotton, and are being evaluated in cotton rotations, especially in terms of nutrient carry-over from the legumes to succeeding cotton crops. Secondly, some of the grain legume species are more sensitive to waterlogging than cotton. This enables plant responses to be more easily studied and for more fundamental principles of factors such as nutrient uptake and hormone production to be assessed. The principles derived from such studies can then be used to improve and fine-tune the irrigation and nutrition management of cotton.

Waterlogging effects were exhibited more clearly by duration of irrigation treatments than by slope treatments due to the confounding influences of rain and soil removal on the latter. The growth of all species was reduced by increased waterlogging at the first irrigation, but the more tolerant species became less affected as they matured. Grain yields of soybean (2.41 t ha^{-1}), mung bean (1.74 t ha^{-1}) and cowpea (1.72 t ha^{-1}) were not significantly affected by waterlogging treatments, whereas yield losses of pigeon pea (12%), adzuki bean (15%) and navy bean (45%) occurred when the duration of irrigation increased from 4 or 16 h to 32 h. The last three species yielded 2.03, 1.10 and 1.18 t ha^{-1}, respectively, when field slope (1:1000) and the duration of irrigation (4 h) were optimum. Nitrogen uptake in the harvested grain of soybean (122 kg ha^{-1}) was two to five times that of the other species. Reductions in the concentration and uptake of nitrogen of affected species implied that nitrogen fixation or nutrient absorption were inhibited by waterlogging.

The study has already demonstrated that in a semi-arid, sub-tropical environment, a field designed and managed to ensure adequate drainage of excess irrigation water can constrain waterlogging to a period of one or two days per irrigation in the surface 0 to 0.2 m of cropped ridges, enabling sensitive species to survive, grow and produce appreciable quantities of grain. A research paper(12) and an advisory newsletter(40) have been written on these results. The paper is currently being internally refereed before submission to a journal. Current research addresses aspects of irrigation management, nitrogen fixation, nitrogen and phosphorus nutrition of the legumes, and the residual nitrogen in ex-legume plots that is available to succeeding cotton crops.