COTTON RESEARCH COUNCIL

RESTORATION OF SOIL STRUCTURE IN CRACKING CLAYS

FINAL REPORT

DEPARTMENT OF AGRICULTURE, NEW SOUTH WALES

DECEMBER, 1987

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FINAL REPORT

Project number:	DAN 13L
Project title:	RESTORATION OF SOIL STRUCTURE IN CRACKING CLAYS
Field of research:	Soil Structure **Field code:** 2.1
Organisation:	Department of Agriculture, New South Wales
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Objectives:

This project was aimed at providing a rational approach to restoring soil structure after it becomes degraded under intensive irrigated cotton production.

The specific aims were:

1. to compare deep tillage and deep drying as methods for restoring soil structure in cracking clays;
2. to study the effects of wheat and safflower on the structure of degraded clay soils;
3. to define the soil moisture conditions needed for effective deep tillage.

RESTORATION OF SOIL STRUCTURE IN CRACKING CLAYS

SUMMARY

Introduction

This project was aimed at providing a rational approach to restoring soil structure after it becomes degraded under intensive irrigated cotton production. The project investigated mechanical loosening (deep tillage) and crop rotation ('biological tillage').

Four experiments were done:

1. a comparison of deep tillage and deep drying over a range of soil structural conditions - good, intermediate and poor;

2. the effects of wheat and safflower on soil structure (at Warren);

3. the effects of wheat and safflower on soil structure (at Narrabri);

4. deep tillage at different soil moisture contents.

Soil structure was assessed by SARAN coating intact soil clods to measure their shrinkage. In one experiment Rhodamine dye was used to trace large pores. Where cotton was grown, lint yields were measured as an indication of soil structural condition.

Results

1. Previous tillage effects can persist under bare fallow.

2. Deep tillage should be approached with caution. A cracking clay which is not dried to permanent wilting point to depth should not be deep tilled.

3. A vigorous rotation crop, grown under conditions which force the crop to dry the soil thoroughly, can promote good structure in cracking clays and obviate the need for deep tillage.

4. Although rotation crops promote good structure, they also deplete the soil of nutrients. Adequate fertiliser should be applied for a subsequent cotton crop to reach its yield potential.

Difficulties encountered

1. The establishment of different soil moisture profiles in the field is subject to the weather.

2. Time is needed for a crop to bring the soil to a particular moisture content. The longer it takes, the more the crop grows and the more organic matter is produced on that treatment. Different amounts of organic matter interact with the nutrition of a subsequent test crop. Earlier prepared treatments spend more time in a prepared condition and may benefit from the action of weather in mellowing the seed bed.

Recommendations for future research

1. Considerable knowledge of cotton soil management has been accumulated. Future efforts should aim at presenting this knowledge in a form that is accessible to cotton growers. One way of doing this is through a computer-based decision-support system for soil management. A proposal for such a system ('Compuclod') will be put to the Cotton Research Council for funding in 1988/89.

2. Under continuous cotton, there seems to be little opportunity to grow a non-irrigated crop between successive irrigated cotton crops. There is a need to find ways of deep drying the soil profile in a continuous cotton system.

3. The assessment of soil structure by the SARAN technique is time consuming. Quicker methods are needed.

4. The interaction of tillage system and nitrogen nutrition is being investigated in project DAN 25L (Effect of tillage practice on nitrogen fertiliser strategy and soil structure).

5. Project DAN 3L (Waterlogging of cotton in a cracking clay) is addressing the plant growth and yield aspects of poor soil aeration. More work is needed to define the critical levels of soil aeration and soil strength for unimpeded root growth in cracking clays.

Applications to industry

1. Non-irrigated rotation crops are recommended for improving soil structure in cracking clays used for cotton.

2. The nitrogen nutrition of cotton following a rotation crop needs careful attention. Assistance is available through NRATE, a decision-support program on the SIRATAC package.

3. Deep tillage is not recommended as a routine operation. However, when it is carried out, the soil should be previously dried to permanent wilting point to the depth of tillage.

Approved allocations

	Salary $	Travel $	Operating $	Capital $	Total $
1984/85	12,500	1,200	2,600	2,000	18,300
1985/86	13,494	1,200	2,600	1,500	18,794
1986/87	15,739	-	2,600	-	18,339
GRAND TOTAL					55,433

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Publications arising from the project

Abbott, T.S. and Daniells, I.G. (1987). Measurement of clod shrinkage using SARAN resin. National Workshop on the Effects of Management Practices on Soil Physical Properties, Toowoomba, September 1987.

Abbott, T.S., McKenzie, D.C., Hulme, P.J. and MacLeod, D.A. (1987). Effect of deep rooting rotation crops on a sodic grey clay. Australian Society of Soil Science Conference, Riverina Branch, Deniliquin, May 1987.

Daniells, I.G. (1986). Land preparation: deciding how best to keep costs down. Australian Cotton Conference, Surfer's Paradise, August 1986.

Daniells, I.G. (1986). Land preparation: how to keep costs down. Australian Cotton Grower, 7, 3.

Daniells, I.G. (in prep.). Degradation and restoration of soil structure in a cracking grey clay used for cotton production. For Australian Journal of Soil Research.

Daniells, I.G., Abbott, T.S., McKenzie, D.C. and Hulme, P.J. (in prep.). Rotation crops improve clay soil structure. For Australian Cotton Grower.

Hulme, P.J., McKenzie, D.C., Abbott, T.S. and MacLeod, D.A. (in prep.). Vertisol structure dynamics following an irrigation of cotton, as influenced by prior rotation crops. For Australian Journal of Soil Research.

RESTORATION OF SOIL STRUCTURE IN CRACKING CLAYS

DETAILED RESULTS

Study 1: Comparison of Deep Tillage and Deep Drying

1.1 Introduction

Deep tillage is often used to ameliorate soil which has become degraded through a number of years of cotton growing. However, there is evidence that cracking clay soils can be restored to good structure by the cracking effects of thorough drying. Thus, both deep tillage and deep drying are considered as ameliorative tools in cotton growing. Both have their disadvantages: deep tillage is expensive in equipment, fuel and time; deep drying can mean that a paddock is out of cotton production for a season. This study attempts to assess the benefits in increased yield due to deep tillage and deep drying - tested separately and in combination - as remedies for soil degradation.

1.2 Methods

An established experiment at Narrabri was used to test the remedies over a range of soil structural conditions: good, intermediate and poor soil structure. This range of soil conditions had been produced in 1983 by preparing land for cotton when the soil moisture content was either low, intermediate or high.

Superimposed over the range of soil conditions, a set of restorative treatments was applied in 1985. The treatments were:

(A) no treatment (fallow);
(B) deep tillage alone;
(C) deep drying by wheat;
(D) deep drying by wheat followed by deep tillage.

This suite of treatments allowed results to be analysed for the effects of:

(i) the land preparation treatments imposed previously;
(ii) deep tillage compared to no deep tillage;
(iii) wheat compared to bare fallow.

Treatment A was maintained in bare fallow. Treatment B was deep tilled to 0.5 m in two directions ten days after harvesting the previous cotton crop. The soil water profile at that time is shown as the dashed line in Fig. 1.

Treatments C and D (wheat) were cultivated by a triple-disc ridge cultivator, maintaining the existing ridges. Wheat was sown on 18.vi.84 by disc drill (180 mm between drills) at 70 kg ha^{-1} with 70 kg ha^{-1} N in the form of urea. The wheat was germinated by furrow irrigation.

When the wheat was harvested (21.ix.84) the soil profile was considered too wet for land preparation without damaging the soil. However, by 4.i.85, weed growth on treatments C and D (wheat) had dried the soil to the water content shown as the solid line in Fig. 1. Treatment D was deep tilled to 0.5 m in two directions. Treatments C and D (wheat) were disc ploughed to incorporate the wheat stubble.

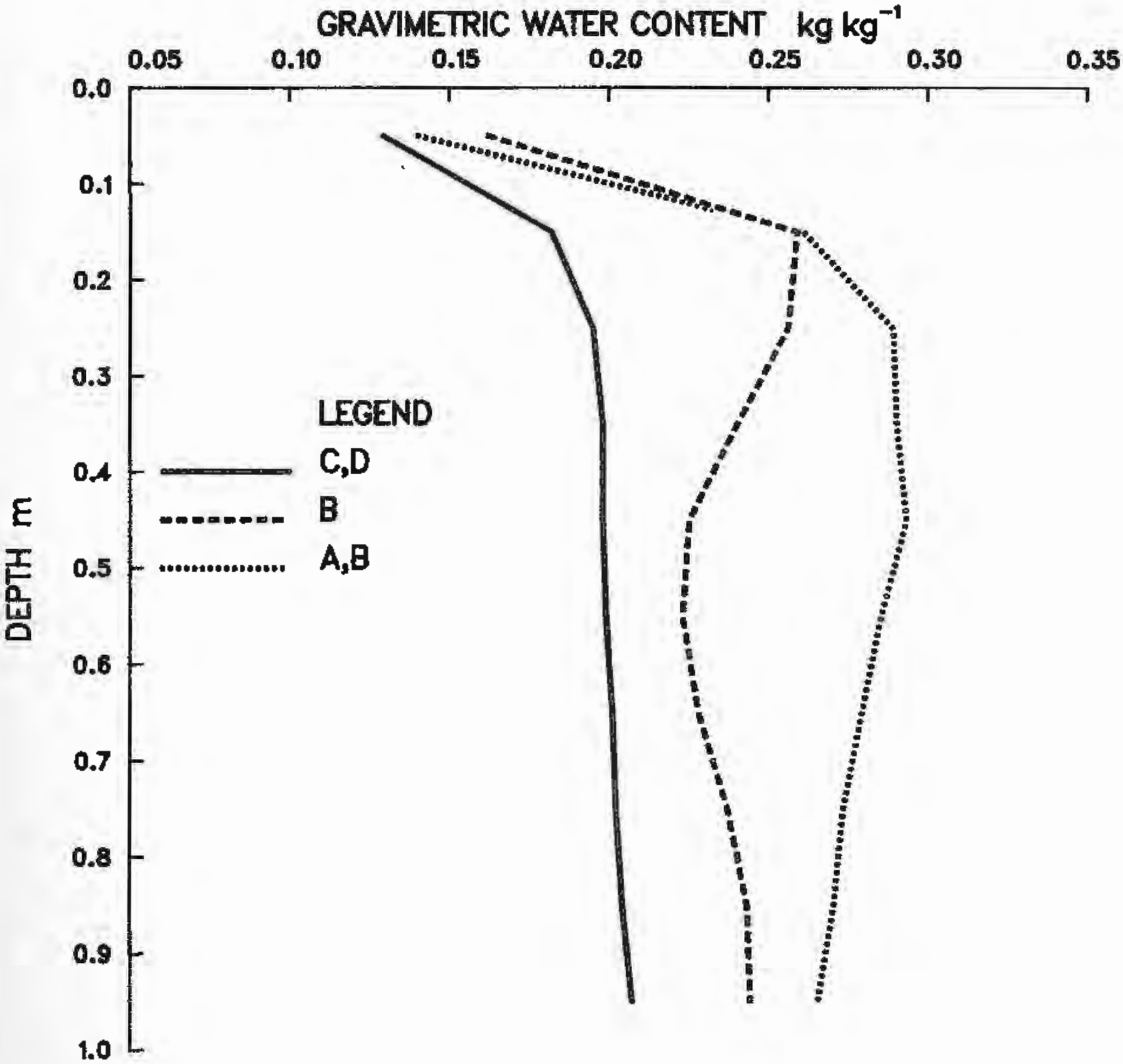

Fig. 1. Soil water profiles during restoration treatments.

Solid line: following wheat (treatments C and D prepared).

Dashed line: following cotton (treatment B deep tilled).

Dotted line: following fallow (treatments A and B prepared).

The whole experiment was chisel ploughed to 0.2 m and furrows were formed on 30.i.85. The soil water contents of treatments A and B (bare fallow) at that time are shown as the dotted line in Fig. 1. The experiment was left in this prepared condition until sowing (261 days later). The experiment was furrow irrigated on 30.ix.85 and sown on 18.x.85 with cotton cv. Deltapine 90. During the cotton season all plots were treated identically with standard agronomy for irrigated cotton.

Plant samples were analysed for nitrogen uptake, lint yields were measured and intact soil clods were collected to measure specific volume at a standard water content.

1.3 Results and discussion

Cotton lint yields are shown in Table 1. Wheat was expected to increase lint yields through restoration of soil structure but instead it depressed lint yield (1869 kg ha^{-1} after fallow, 1735 kg ha^{-1} after wheat). This effect can be explained by a decreased availability of soil nitrogen following wheat: nitrogen uptake by cotton plants was 129 kg ha^{-1} after fallow and 105 kg ha^{-1} after wheat.

Deep tillage depressed yield (1836 kg ha^{-1} after no deep tillage, 1769 kg ha^{-1} after deep tillage). This effect was not significant on the fallow areas but was significant ($P<0.05$) where wheat had been grown. The previously wet-tilled plots (and to a lesser extent the moist-tilled plots) yielded less than the dry-tilled plots when deep tillage was imposed. Thus the effects of the previous tillage treatments persisted where deep tillage was used as a restoration treatment.

Table 1. Lint yields (kg ha^{-1}) after the restoration treatments.

Condition		Tillage		Crop	
Good	1838 y	Deep till	1769 y	Wheat	1735 y
Intermediate	1822 yz	No deep till	1836 z	None	1869 z
Poor	1746 z				

Values in the same column followed by the same letter are not significantly different ($P>0.05$).

The specific volumes of intact soil clods are shown in Tables 2 and 3. Higher values represent less compaction (better soil structure).

At the 0.25 m depth (Table 2) none of the main treatments (averaged over all other treatments) had any effect on clod specific volume. However, there were significant interactions between treatments.

When averaged over all previous tillage treatments, deep tillage alone decreased clod specific volume, whereas deep tillage after wheat increased clod specific volume.

After wheat, the previous tillage treatments had no effect on clod specific volume at 0.25 m depth. However, after fallow, the previous tillage treatments were still apparent, with or without deep tillage. After fallow, the prior wet tillage treatment had significantly ($P<0.05$) poorer structure than the prior dry tillage treatment.

Table 2. Specific volume ($m^3\ Mg^{-1}$) of intact clods at a standard water content of 0.2 $m^3\ Mg^{-1}$. Depth of sampling : 0.25 m

Condition		Tillage		Crop	
Good	0.640 z	Deep till	0.633 z	Wheat	0.639 z
Intermediate	0.633 z	No deep till	0.632 z	None	0.626 z
Poor	0.624 z				

Values in the same column followed by the same letter are not significantly different ($P>0.05$).

Clod specific volume at 0.35 m depth (Table 3) was increased by wheat (0.625 $m^3\ Mg^{-1}$ after fallow, 0.638 $m^3\ Mg^{-1}$ after wheat). Deep tillage had no main effect (averaged over all other treatments) but interacted with wheat. Similarly to the 0.25 m depth, clod specific volume at 0.35 m depth was decreased by deep tillage alone but was increased by deep tillage after wheat. The previous tillage treatments showed an effect on clod specific volume at 0.35 m depth (Table 3). The prior wet and moist tillage treatments had significantly ($P<0.05$) poorer structure than the prior dry tillage treatment.

Table 3. Specific volume ($m^3\ Mg^{-1}$) of intact clods at a standard water content of 0.2 $m^3\ Mg^{-1}$. Depth of sampling : 0.35 m

Condition		Tillage		Crop	
Good	0.639 y	Deep till	0.630 z	Wheat	0.638 y
Intermediate	0.629 z	No deep till	0.633 z	None	0.625 z
Poor	0.627 z				

Values in the same column followed by the same letter are not significantly different ($P>0.05$).

It should be noted that the two deep tillage treatments were done at quite different soil water contents (Fig. 1). After cotton (treatment B: deep tillage, fallow) the soil was moist (about the lower plastic limit at 0.2 m depth) when deep tilled. Some smearing could be expected. After wheat and weed growth (treatment D) the soil was at permanent wilting point to depth when deep tilled. Deep tillage under these conditions should have had a good shattering effect.

The increase in clod specific volume due to deep tillage after wheat was not accompanied by increased yield (Table 1). Instead, yield was depressed, particularly on those areas which previously had intermediate or poor soil structural condition. This throws considerable doubt on the use of deep tillage to ameliorate degraded soil.

1.4 Conclusions

For cracking clay soils, the main conclusions to be drawn from these results are:

1. Previous tillage effects can persist under bare fallow;

2. Wheat can ameliorate previous tillage effects but will not promote cotton yield unless sufficient nitrogen fertiliser is applied;

3. Deep tillage should be approached with caution.
   There is no guarantee that deep tillage will ameliorate degradation caused by previous wet tillage treatments.

Study 2: Effects of wheat and safflower on soil structure

2.1 Introduction

Deep tillage is frequently used by cotton growers to loosen compacted clay subsoils but may do more harm than good if the soil is too wet at the time of the operation. In rotation with irrigated cotton, deep rooting crops such as wheat and safflower are sometimes grown under dryland conditions with the aim of drying and cracking the subsoil. These crops are often followed by deep tillage.

The aims of this work were:

i) to quantify the extent of drying of clay soils by wheat and safflower; and

ii) to determine whether or not wheat and safflower effect any improvement in degraded clay subsoil structure and, if so, to investigate the effects on the growth and yield of a subsequent cotton crop.

Two experiments were done: one at Warren and one at Narrabri. The two experiments are reported separately.

2.2 Warren experiment

2.21 Methods

A field experiment was established in June, 1984 in Field 34, Auscott Ltd, Warren in the lower Macquarie Valley of New South Wales. The soil is a self-mulching grey clay with a sodic subsoil. Soil texture is light medium clay to a depth of 1.25 m. Some properties of the soil are shown in Table 4.

Table 4. Mean values of pH (1:2, w/v, soil:0.01 M $CaCl_2$), electrical conductivity (1:2, w/v, soil:water), exchangeable cation percentages and organic matter content of the Field 34 grey clay (n=12).

Depth (m)	pH	EC (1:2) (dS/m)	Exchangeable cations (%) Ca	Mg	K	Na	Organic matter content (dag/kg)
0.15	7.3	0.25	68	26	3.8	2.3	0.99
0.35	7.6	0.35	63	30	2.2	4.9	0.60
0.55	7.8	0.46	56	33	1.9	9.6	0.54
0.85	7.9	0.76	44	35	2.1	19	0.44
1.25	7.9	1.2	40	35	2.3	23	0.30

There were three treatments, replicated four times on 2.1 ha plots, in a completely randomised design. The treatments, identical to those often used commercially, were:

i) Cultivated (disc ploughed) fallow (control);

ii) Wheat (Triticum aestivum cv Banks); and

iii) Safflower (Catharmus tinctorius cv Gila).

The wheat and safflower were sown directly into hills and furrows 1 m apart that had been used for irrigated cotton production in 1983/84. To encourage deep cracking,the wheat and safflower were not irrigated. Subsequently irrigated cotton was grown in 1985/86.

The soil was comprehensively sampled twice in conjunction with Mr. D. C. McKenzie, Senior Chemist (Soils), Agricultural Research Centre, Trangie. The first was in August, 1984 before the treatments could have had any effect on the soil ('Before' sampling); the second was in July 1985 ('After' sampling). The purpose of the Before sampling was to establish the soil structural conditions and water content profiles prior to the treatment application. The After sampling was needed to compare soil structural conditions and water content profiles with the Before sampling, as well as measuring treatment effects.

In each sampling, disturbed soil was collected at depths of 0.15, 0.35, 0.55, 0.85 and 1.25 m, and undisturbed cores and clods were taken in duplicate at the same depths except 0.15 m, using three backhoe pits dug in each of the 12 plots. The disturbed soil was used for the determination of texture and for chemical analysis. Gravimetric water content, bulk density and air-filled porosity were measured using the cores and clods.

The clods were also used to determine shrinkage curves (Fig. 2) by the SARAN resin procedure (Appendix) to provide a further measure of structural condition.

In February, 1986 the soil was sampled a third time in conjunction with Mr McKenzie and Mr P. J. Hulme, Postgraduate student, University of New England. The purpose was to investigate soil structure intensively in the top 0.35 m over the fourth irrigation cycle for the cotton crop. Core samples were taken in duplicate 2, 4, 7 and 12 days after irrigation, 0.25 m below the centre of the cotton beds to determine gravimetric water content and air-filled porosity. On day 4, pairs of core samples for the same purpose and clod samples for shrinkage curve measurements were collected at 0.05, 0.15, 0.25 and 0.35 m depths. Soil strength as measured by penetration resistance was monitored with a recording penetrometer at 15 mm intervals to 0.36 m on days 8 and 12.

In addition to the above samples and measurements, a dye infiltration technique was employed to provide a field index of macropore (large pore) frequency and continuity under moist conditions. Shortly before irrigation two 0.7 m long strips of cotton plants in each plot were cut at ground level and removed. The bare areas were covered with plastic until 4-6 days after irrigation when the hills were levelled to accommodate 0.30 m diameter infiltration rings. Rhodamine WT dye solution was added to the rings, then the soil beneath was trimmed at 0.05 m intervals to 0.25 m below the levelled surface. Each section was photographed vertically. With the aid of an overlay having 20 equally spaced parallel grid lines placed over the images, the length of dyed soil per unit length of grid line (L_L) was determined. L_L

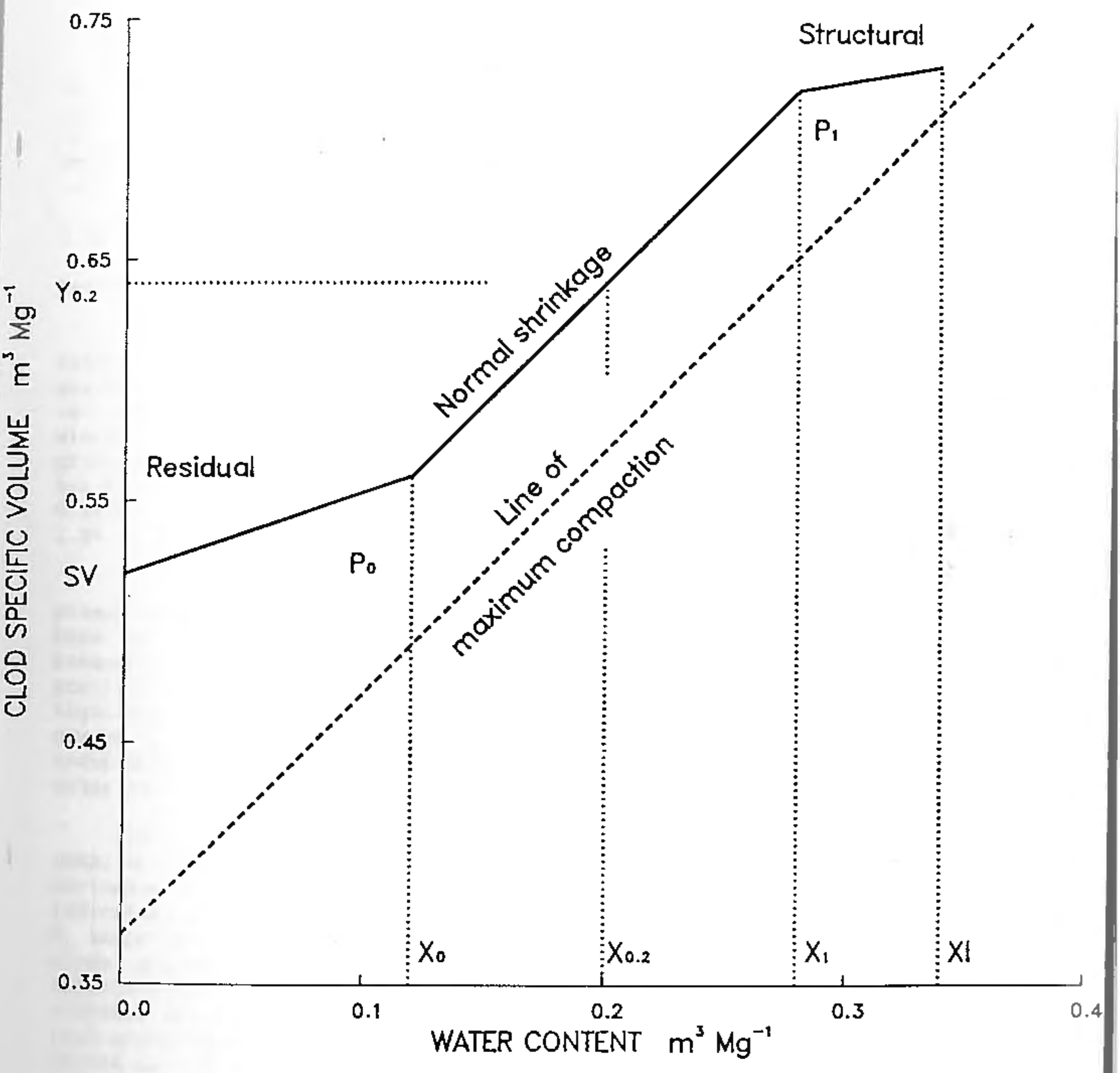

Fig. 2. The shrinkage curve, showing the three main zones of shrinkage and parameters derived from the curve.

was used as an index of the volume of macropores that are connected to the surface.

Profiles of volumetric water content were determined over the fourth irrigation cycle using a neutron moisture meter. Measurements were made at depths of 0.20, 0.25, 0.40, 0.60, 0.80, 1.00 and 1.20 m on days 1, 2, 3, 4, 6, 8, 10 and 12. Samples of soil from 0 and 0.10 m were collected at the same time to measure gravimetric water content by oven-drying at 105°C which was converted to volumetric water content.

Cotton growth and yield measurements were made by Mr McKenzie. Plant density, height and fruiting density were monitored at 3-weekly intervals throughout the season by measuring six 0.5 m lengths of row per plot. Similarly whole plants were harvested in mid-February to determine nitrogen uptake, and in May to measure cotton lint yield. Temperatures were not limiting to cotton growth during February.

2.22 Results and discussion

Before and After soil samplings

Results of gravimetric water content as a function of depth for the Before and After samplings are shown in Fig. 3. Before treatment application, gravimetric water content profiles were similar in all plots and so the data have been combined. They show a uniformly moist profile following the wet winter of 1984. After treatment application, almost one year later, gravimetric water content had decreased only marginally in the fallow plots but markedly in the wheat and safflower plots, particularly at 0.35 and 0.55 m. Safflower dried the soil profile more than wheat, particularly at 1.25 m.

Air-filled porosity values at the Before and After samplings are presented in Fig. 4; the Before values, being similar for all plots, have been combined. Also shown is the critical level of air-filled porosity for adequate oxygen diffusion in these soils (0.14 $m^3\ m^{-3}$) . Air-filled porosity levels were low before treatment application but increased significantly in the wheat and safflower plots. These results suggest that oxygen diffusion was adequate after treatment application to about 0.7 m under safflower and 0.5 m under wheat, but was inadequate at and below 0.35 m under fallow.

Two clod shrinkage parameters: the slope of the normal shrinkage line (NSS) and the specific volume of air-filled pores at the end of structural shrinkage (P_1) (see Fig. 2) were found to be the most sensitive shrinkage indicators of structural condition in this soil. Increased values of NSS and P_1 imply greater air-filled volume throughout, and at the wet end of, the normal shrinkage zone and thus improved structural condition. Wheat and safflower, in particular, increased NSS values to 0.85 m compared to the combined Before data, also compared to the fallow treatment but to a lesser (non-significant) extent (Fig. 5). Safflower substantially increased P_1 values to 1.25 m compared to the combined Before data, but wheat increased P_1 only at 0.35 m (Fig. 6). These results show that safflower and, to a lesser extent, wheat have improved the structure of this clay soil.

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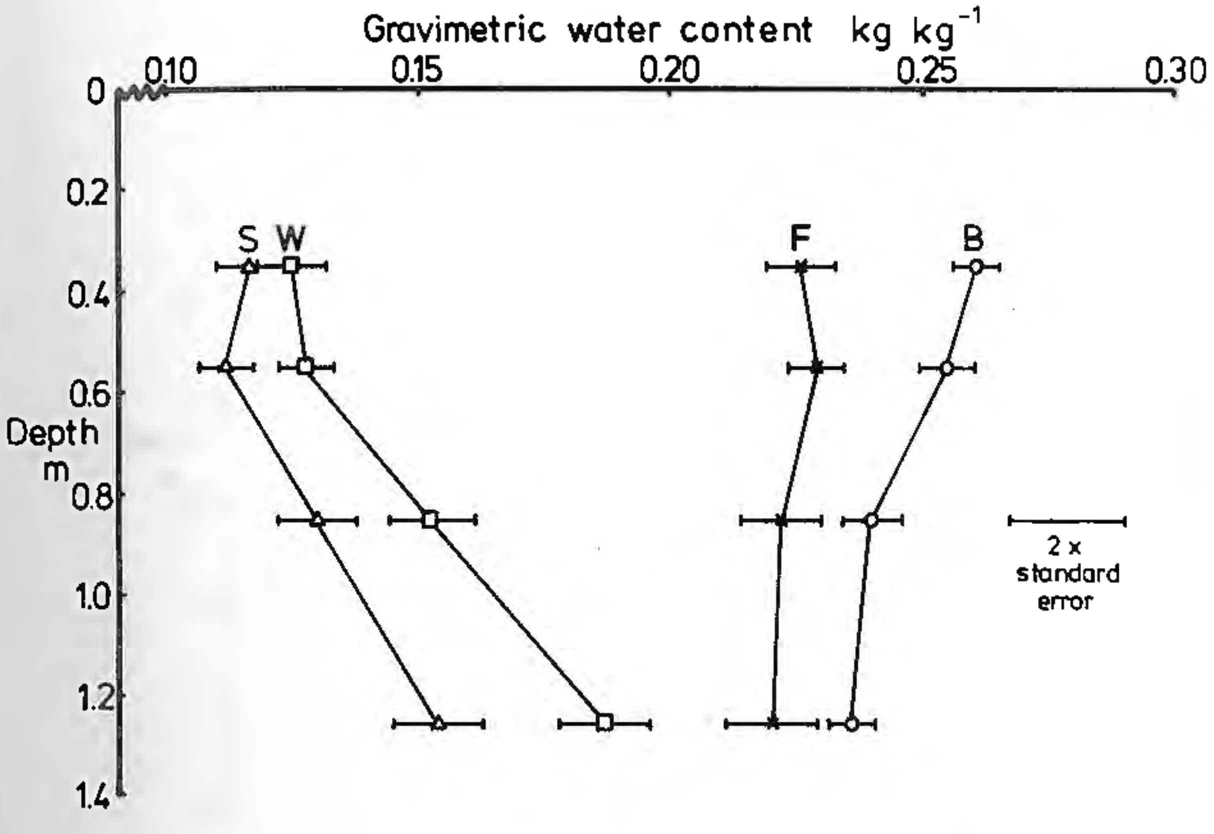

Fig. 3. Profiles of mean gravimetric water content (kg kg^{-1}) for the Before (n = 72) and After (n = 24) samplings. B = Before (all treatments combined); F = fallow, S = safflower and W = wheat (After sampling).

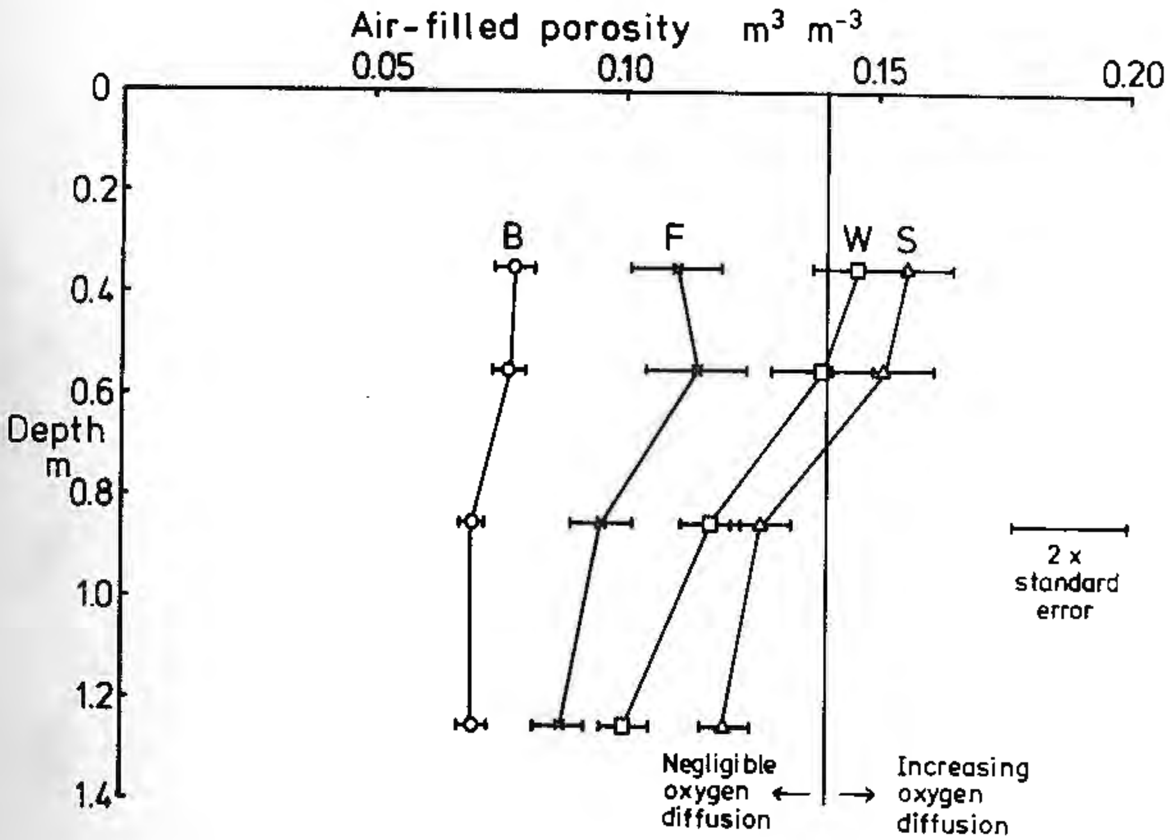

Fig. 4. Profiles of mean air-filled porosity ($m^3\ m^{-3}$) for the Before ($n = 72$) and After ($n = 24$) samplings. B = Before (all treatments combined); F = fallow, S = safflower and W = wheat (After sampling).

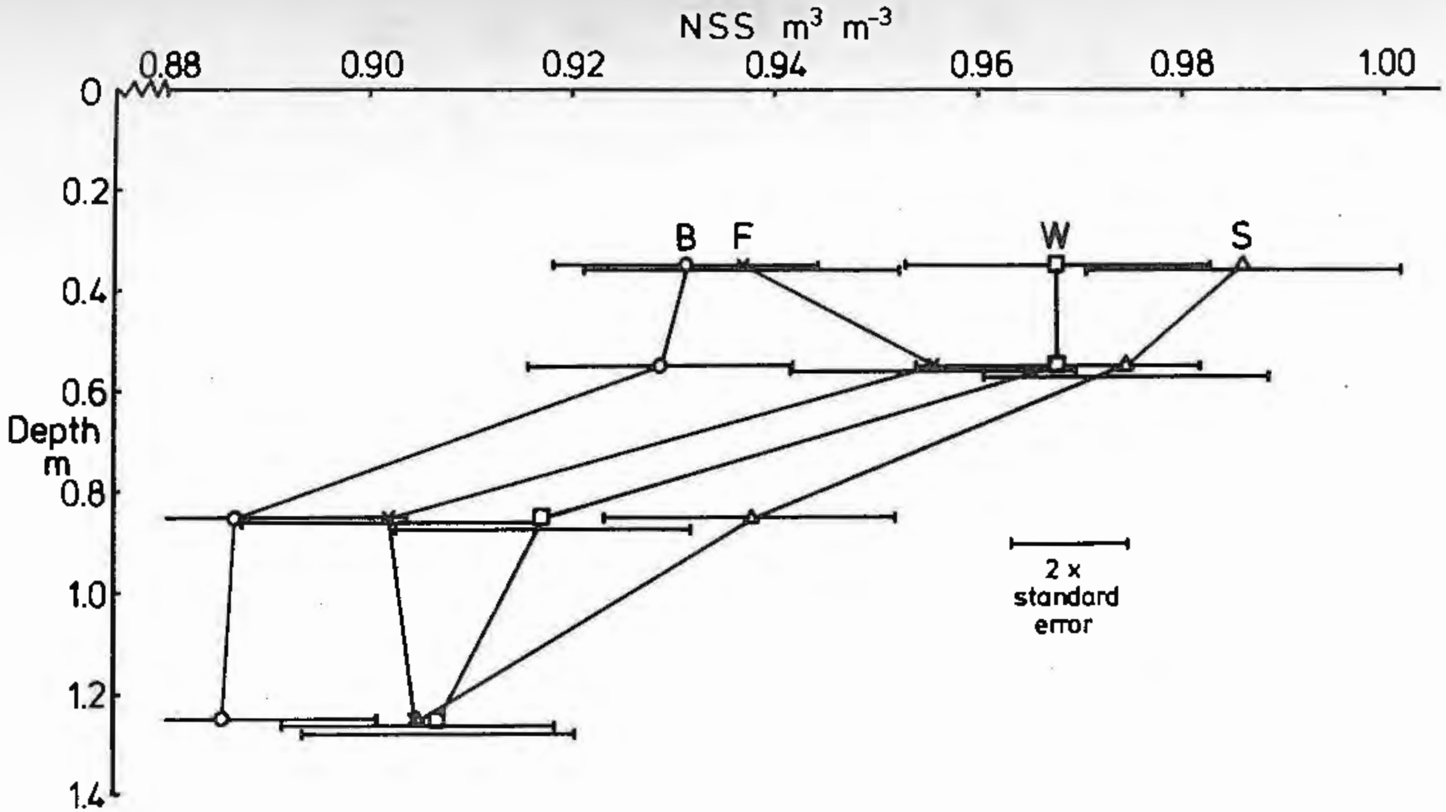

Fig. 5. Profiles of mean slope of the normal shrinkage line (NSS) ($m^3\ m^{-3}$) for the Before (n=72) and After (n = 24) samplings. B = Before (all treatments combined); F = fallow, S = safflower and W = wheat (After sampling).

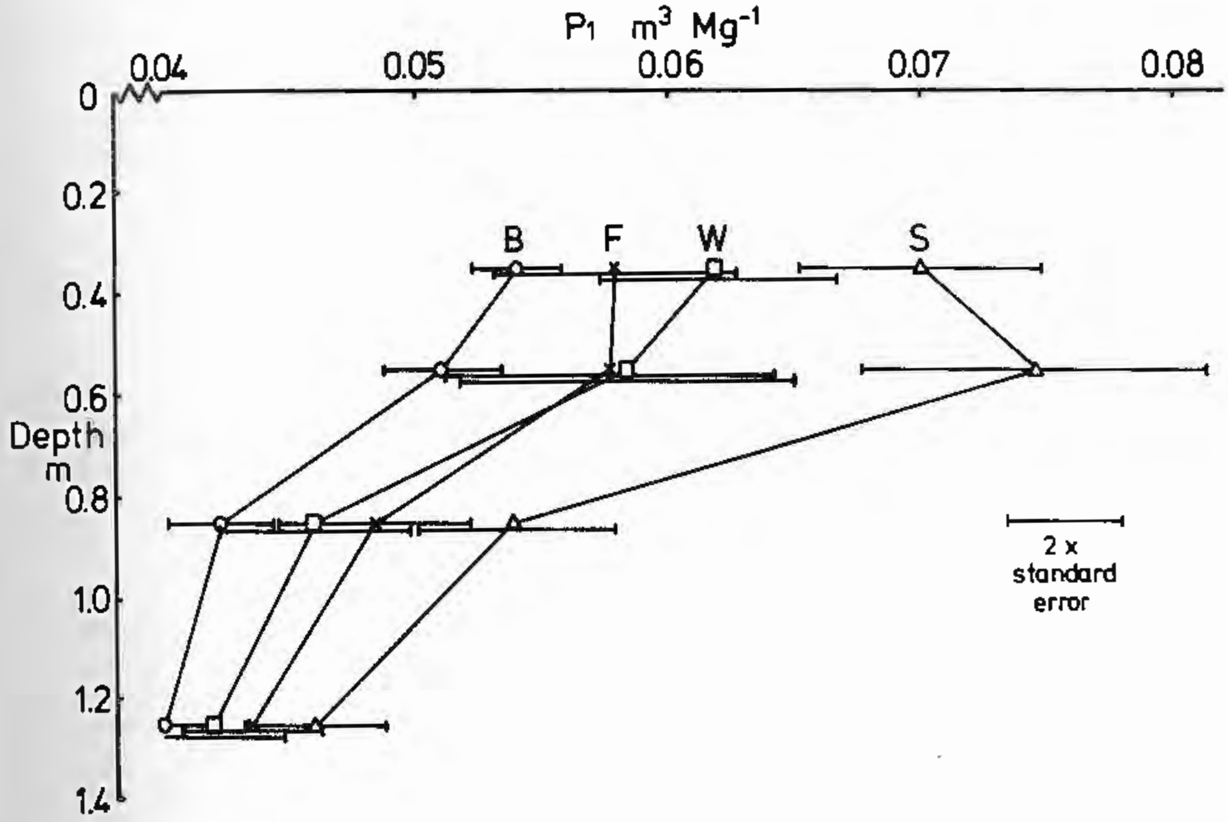

Fig. 6. Profiles of mean specific volume of air-filled pores at the end of structural shrinkage (P1) ($m^3\ Mg^{-1}$) for the Before (n = 72) and After (n = 24) samplings. B = Before (all treatments combined); F = fallow, S = safflower and W = wheat (After sampling).

Third soil sampling

Results of soil aeration measurements taken after irrigation in February, 1986 are shown in Table 5 and Fig. 7. Air-filled porosity at 0.25 m depth did not reach 0.14 $m^3 m^{-3}$, the critical level for adequate oxygen diffusion, until approximately 12 days after irrigation (Table 5). Wheat and safflower increased air-filled porosity levels from approximately day 7, but the differences were only significant at day 7. Air-filled porosity profiles on day 4 (Fig. 7) suggest that cotton roots below approximately 0.09 m in all treatments were subjected to poor aeration.

Table 5. Mean values of air-filled porosity ($m^3 m^{-3}$) measured at 0.25 m depth on four occasions following irrigation in February, 1986 (n=16).

Time after irrigation (days)	Treatment		
	Fallow	Wheat	Safflower
2	0.063 a	0.066 a	0.068 a
4	0.070 a	0.070 a	0.069 a
7	0.087 a	0.130 b	0.119 b
12	0.134 a	0.163 a	0.150 a

Values in the same row followed by the same letter are not significantly different (P>0.05).

Tables 6 and 7 show profiles of the clod shrinkage parameters NSS and P_1 measured 4 days after irrigation. The results show significantly worsening structure in the fallow treatment below 0.05 m to 0.25 m. Although the differences are not significant, both parameters increase between 0.25 and 0.35 m under fallow suggesting the possibility of a degraded layer at around 0.25 m. Increases in the parameter values in the wheat and safflower treatments at 0.15 m and 0.25 m suggest that wheat and safflower have ameliorated this layer to some extent, although only P_1 was significantly increased by safflower at 0.15 m and by wheat at 0.25 m.

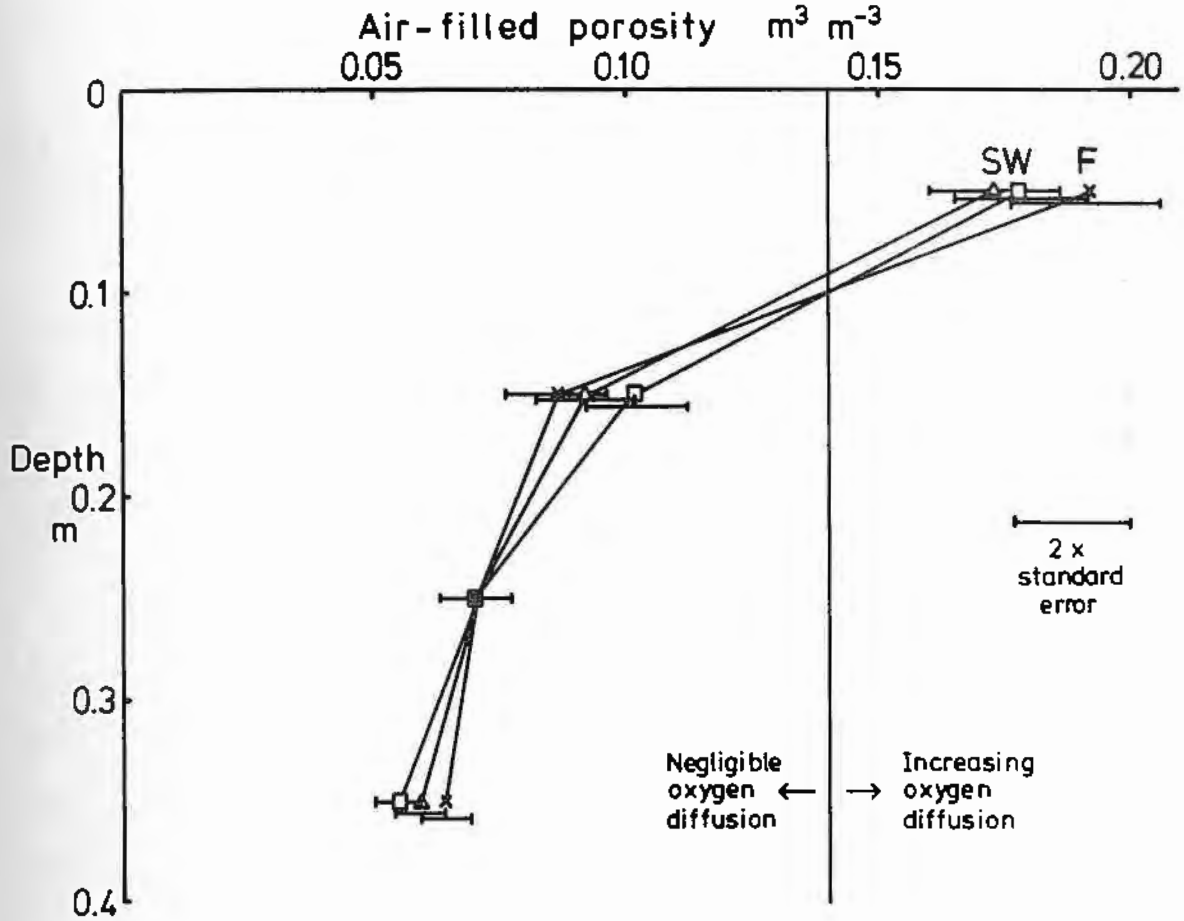

Fig. 7. Profiles of mean air-filled porosity (m^3 m^{-3}) measured 4 days after irrigation in February, 1986 (n = 16). F = fallow, S = safflower and W = wheat.

Table 6. Mean values of the clod shrinkage parameter NSS (m^3 m^{-3}) of soil clods taken 4 days after irrigation (n=16).

Depth (m)	Treatment		
	Fallow	Wheat	Safflower
0.05	0.9606 a,x	0.9633 a,x	0.9695 a,x
0.15	0.9426 a,x	0.9524 a,x	0.9574 a,x
0.25	0.9206 a,x	0.9482 a,x	0.9606 a,x
0.35	0.9376 a,x	0.9526 a,x	0.9547 a,x

Values in the same row followed by the same letter a, and values in the same column followed by the same letter x are not significantly different (P>0.05).

Table 7. Mean values of the clod shrinkage parameter P_1 (m^3 Mg^{-1}) of soil clods taken 4 days after irrigation (n=16).

Depth (m)	Treatment		
	Fallow	Wheat	Safflower
0.05	0.1255 a,x	0.1171 a,x	0.1057 a,x
0.15	0.0600 a,y	0.0745 ab,y	0.0795 b,x
0.25	0.0429 a,y	0.0626 b,yz	0.0526 ab,y
0.35	0.0458 a,y	0.0450 a,z	0.0587 a,y

Values in the same row followed by the same letter a or b, and values in the same column followed by the same letter x,y or z are not significantly different (P>0.05).

Profiles of soil strength as measured by penetrometer cone index, determined 8 and 12 days after irrigation, are shown in relation to critical limits for cotton root growth in Figs. 8 and 9. According to these limits soil strength below a depth of 0.05 m was sufficiently high to retard root growth 8 and 12 days after irrigation in all treatments, and was high enough

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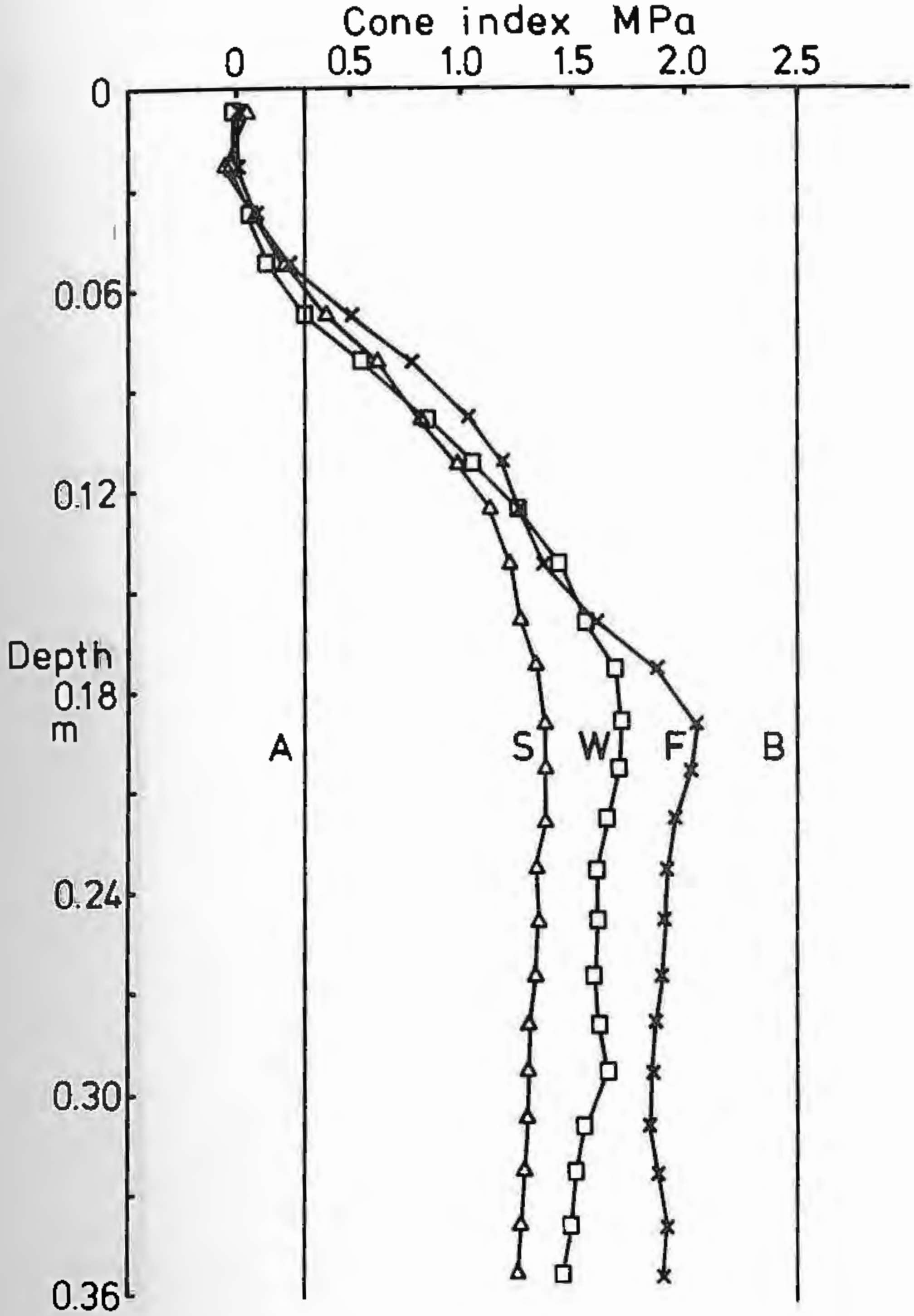

Fig. 8. Profiles of mean soil strength as penetrometer cone index (MPa) measured 8 days after irrigation in February, 1986 (n = 36). F = fallow, S = safflower and W = wheat. Cotton root growth is unimpeded at soil strengths less than 0.3 MPa (line A) but is stopped at soil strengths greater than 2.5 MPa (line B).

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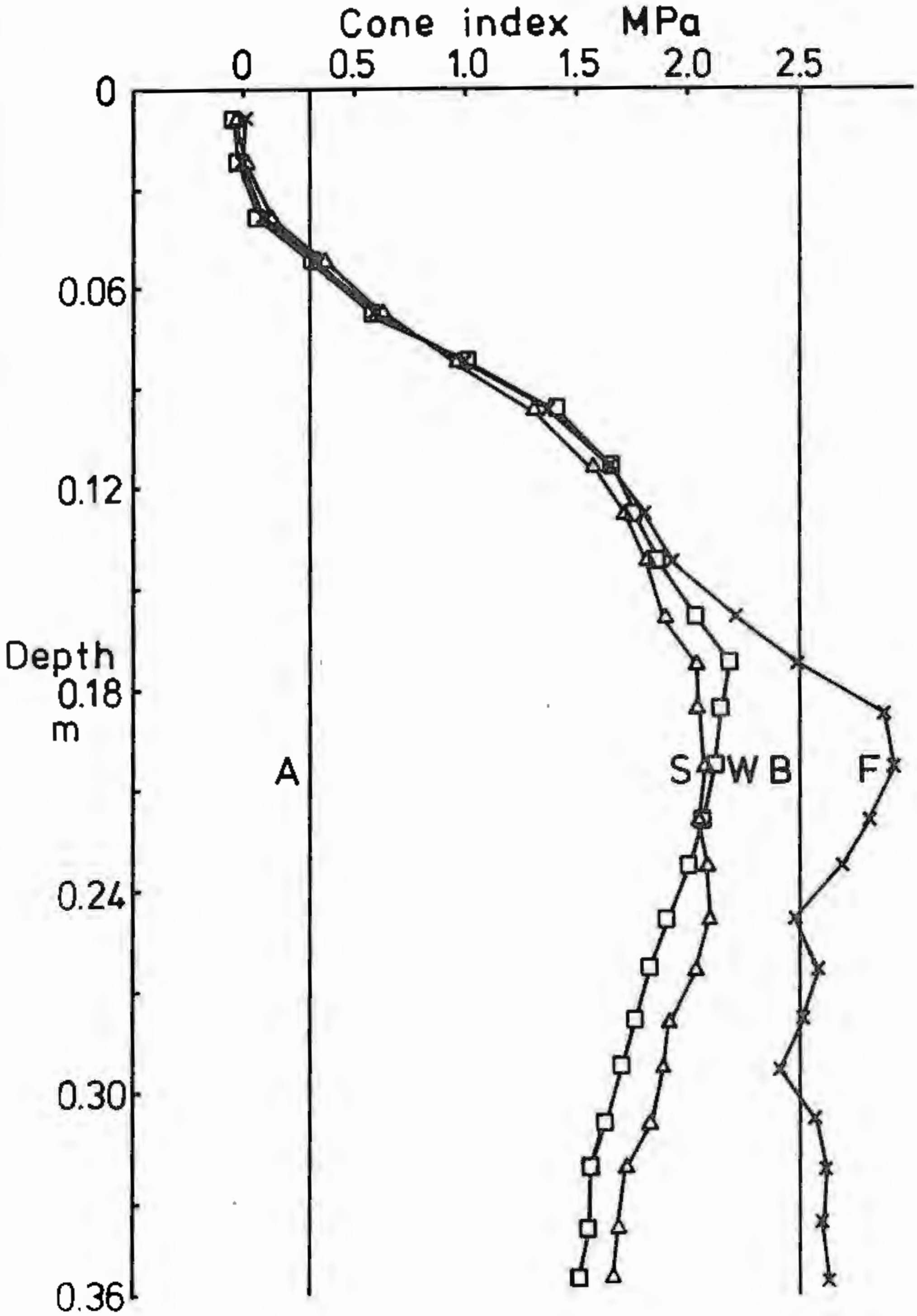

Fig. 9. Profiles of mean soil strength as penetrometer cone index (MPa) measured 12 days after irrigation in February, 1986 (n = 36). F = fallow, S = safflower and W = wheat. Cotton root growth is unimpeded at soil strengths less than 0.3 MPa (line A) but is stopped at soil strengths greater than 2.5 MPa (line B).

to stop root growth between 0.17 and 0.24 m 12 days after irrigation in the fallow treatment. This 0.07 m thick high strength layer coincides with the maximum depth of working of the disc plough in the fallow plots and may thus be described as a "ploughpan".

The volume of continuous macropores, as indicated by the parameter L_L, is shown as a function of depth in Fig. 10. To a depth of about 0.17 m, macropore volume was greatest in the fallow plots where disturbance by disc ploughing had occurred. However, this trend was reversed below 0.17 m, coincident with the existence of a ploughpan below that depth and consistent with the penetrometer and clod shrinkage results. Not shown in Fig. 10 is that the patterns of dye infiltration were influenced by the presence of cotton stems which, at 0.10 m depth, had a higher concentration of dye within 5 mm of the stem than the bulk soil. Macropores beside cotton stems may be important for the diffusion of oxygen to roots under waterlogged conditions.

Volumetric water content profiles (Fig. 11) show that the safflower, and to a lesser extent wheat, plots had drier deep subsoils than the fallow plots. Irrigation water was unable to penetrate below approximately 0.8 m because of low water infiltration into the swollen sodic subsoil and rapid extraction by cotton roots above 0.8 m. Consequently, cotton grown after safflower or wheat may require more frequent irrigation. Water extraction throughout the fourth irrigation cycle was unimpaired, despite air-filled porosity and strength data suggesting that root function should have been impeded.

Plant sampling

The results of cotton growth and yield measurements are presented in Table 8.

Cotton seedling growth was retarded in the fallow plots, probably due to restricted root growth near the ploughpan below 0.17 m. However, lint yields in the wheat and safflower plots were slightly decreased, apparently due to reduced nitrogen availability to the cotton plants. This was probably due to a combination of factors such as greater loss of anhydrous ammonia immediately following application in the cropped plots due to drier soil conditions, greater loss of nitrogen in the cropped plots through stubble breakdown and extra nitrogen uptake by the rotation crops.

This result illustrates the important principle that crop yields are restricted by the most limiting factor, in this case, soil nitrogen.

Table 8. Mean values of cotton growth and yield measurements in 1985/86 (n = 24).

Plant measurement	Treatment		
	Fallow	Wheat	Safflower
Early season growth (10.xii.85)			
Height (m)	0.19	0.24	0.24
No. of squares (m^{-2})	9	15	16
Lint yield (kg ha^{-1})	1550	1475	1440
Total nitrogen uptake (kg ha^{-1})	109	95	94

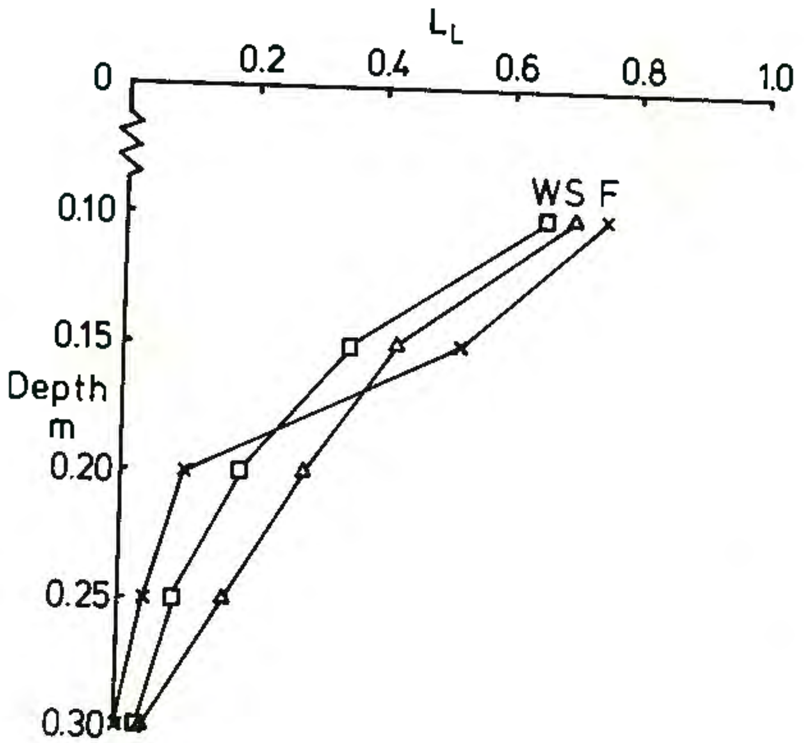

Fig. 10. Profiles of mean length of dyed soil per unit length of grid line (L_L) measured 4-6 days after irrigation in February, 1986 (n = 8). F = fallow, S = safflower and W = wheat.

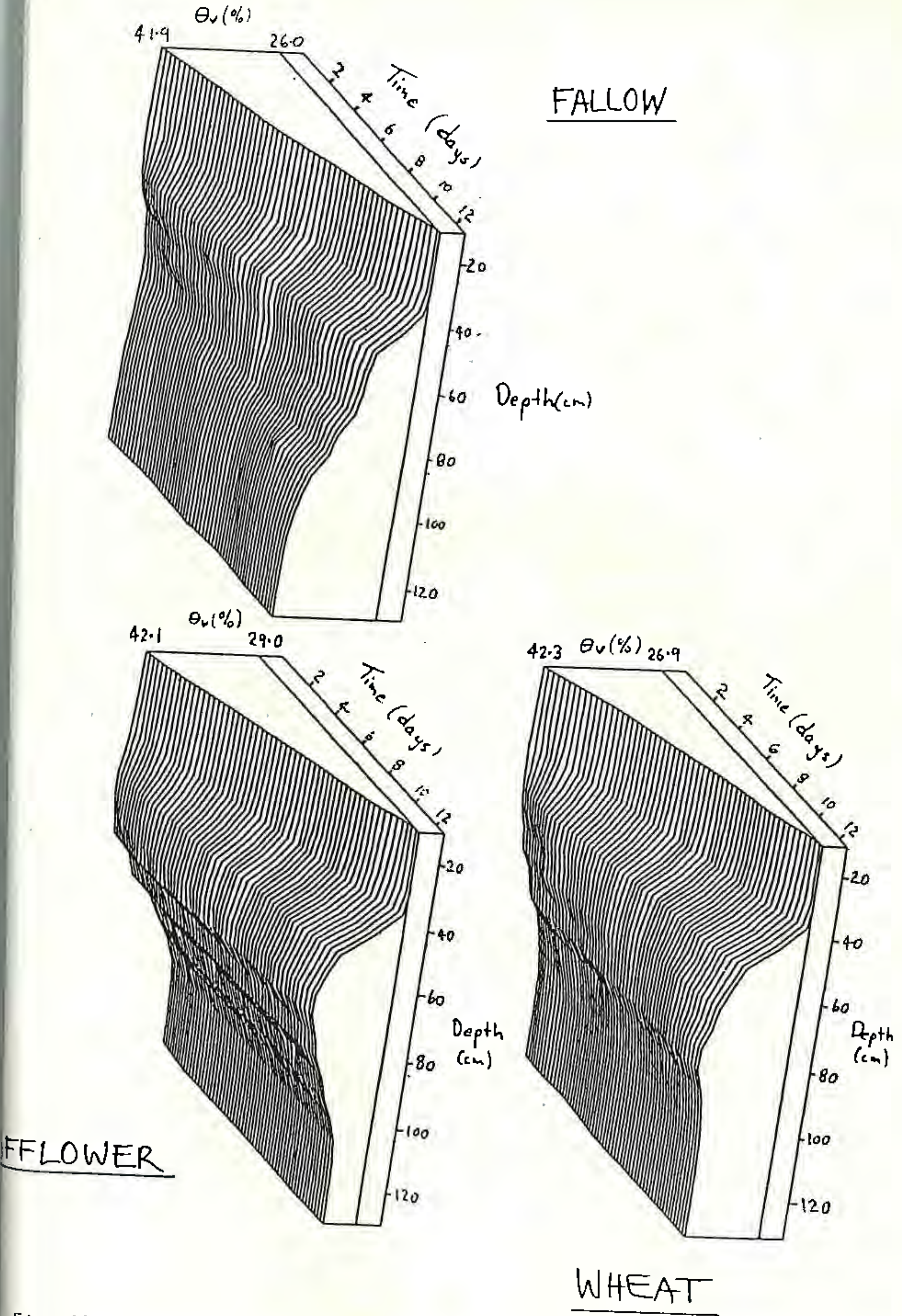

Fig. 11. Profiles of mean volumetric water content (Θ_v)(%) as a function of time following irrigation in February, 1986 (n = 12).

2.23 Conclusions

Wheat and safflower were very effective in drying the Field 34 clay soil, particularly in the top 0.6 m. As a consequence aeration was improved to give adequate oxygen diffusion to roots in the top 0.6 m. Safflower dried the soil profile more than wheat, to at least 1.25 m.

As well as drying the soil, wheat and in particular, safflower improved the structure of the clay soil in this experiment. These improved structural conditions persisted following several irrigation cycles for a cotton crop. They correlated with improved early cotton growth in the absence of other limiting factors.

An intensive investigation of soil structural conditions in the top 0.35 m during the fourth irrigation cycle revealed the presence of a ploughpan in the fallow (disc ploughed) plots, centred at about 0.2 m. Despite waterlogged conditions in the soil between cotton plants for up to 12 days following irrigation and the development of sufficient strength to retard root growth after only 8 days following irrigation, water extraction by roots was unimpeded in this period. Dye infiltration studies suggested that macropores beside cotton stems may allow sufficient diffusion of oxygen for root respiration. Also, established critical levels of soil strength for the restriction of cotton root development may not apply to these clay soils or perhaps sufficient roots had already penetrated the ploughpan through cracks by the fourth irrigation cycle when the strength measurements were made. Further research is required to define critical levels of aeration and strength for unrestricted root development in clay soils.

The rotation crops wheat and safflower effectively dry clay soils and favour the development of improved soil structure. However, they do deplete nutrient levels, particularly nitrogen, which must be replaced. Also, there may be difficulties in replenishing the store of deep subsoil water in time for the following cotton crop which could necessitate more frequent irrigation.

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2.3 Narrabri experiment

2.31 Methods

In 1984, a randomised-block design with eight replicates and three treatments was established on a cracking grey clay after cotton. The treatments were similar to those on the Warren experiment: bare fallow, wheat and safflower. The area was furrow irrigated and left for 8 weeks. The existing plant ridges were cultivated with a triple-disc ridge cultivator and sown with wheat (70 kg ha^{-1}) or safflower (15 kg ha^{-1}) or left in bare fallow. Urea fertiliser was applied to provide 70 kg ha^{-1} of N.

In February 1985, after the crops had matured, the area was furrow irrigated and pits were dug to enable intact clods to be collected. From each plot, two intact soil clods were sampled from 0.25, 0.35 and 0.45 m below the tops of the ridges. Shrinkage curves for the clods were obtained by the SARAN technique (Appendix). Plotting specific volume on water content gives a graph of three joined straight lines for each clod (Fig. 2). This enables specific volume to be reported at a standard water content and clods from different treatments can be compared.

2.32 Results and discussion

Table 9 shows clod specific volumes at a standard water content of 0.2 m^3 Mg^{-1}. Higher values of specific volume represent better structure.

The a,b notation in Table 9 (comparisons between treatments) indicates that soil structure at 0.25 m depth was significantly ($P<0.05$) better after wheat than after fallow or safflower.

The y,z notation in Table 9 (comparisons between depths) indicates that after fallow or safflower the soil structure at 0.25 m was significantly ($P<0.05$) worse than at 0.45 m. This suggests the presence of a dense plough pan at 0.25 m which was not ameliorated by fallow or safflower. After wheat, the 0.25 m and 0.35 m depths were as good as the 0.45 m depth, indicating an improvement in soil structure by ameliorating the (postulated) plough pan.

Table 9. Specific volume (m^3 Mg^{-1}) of intact clods at a standard water content of 0.2 m^3 Mg^{-1}.

Depth (m)	Treatment		
	Fallow	Wheat	Safflower
0.25	0.606 a,z	0.622 b,z	0.610 a,z
0.35	0.612 a,yz	0.622 b,z	0.618 ab,yz
0.45	0.620 a,y	0.623 a,z	0.626 a,y

Values in the same row followed by the same letter a or b, and values in the same column followed by the same letter y or z are not significantly different ($P>0.05$).

Table 10. Soil water content (kg kg^{-1}) to 1.2 m in the three treatments on 16.i.85.

Depth (m)	Treatment		
	Fallow	Wheat	Safflower
0.0 - 0.1	0.13	0.12	0.12
0.1 - 0.2	0.22	0.18	0.17
0.2 - 0.3	0.26	0.20	0.19
0.3 - 0.4	0.27	0.21	0.20
0.4 - 0.5	0.28	0.21	0.20
0.5 - 0.6	0.29	0.21	0.20
0.6 - 0.7	0.29	0.22	0.20
0.7 - 0.8	0.29	0.22	0.20
0.8 - 0.9	0.30	0.22	0.19
0.9 - 1.0	0.30	0.22	0.19
1.0 - 1.1	0.30	0.22	0.19
1.1 - 1.2	0.30	0.23	0.19

Table 10 shows the soil water profiles in the three treatments after the crops had matured. Both wheat and safflower dried the soil profile to 1.2 m. Safflower was more effective than wheat in drying the soil profile, yet was less effective in restoring soil structure at 0.25 m depth. No explanation can be offered for this.

2.33 Conclusions

Both wheat and safflower dried the soil profile to 1.2 m. Safflower dried the profile more effectively than wheat.

Wheat improved soil structure at 0.25 m and 0.35 m depths, as measured by increased specific volume of intact soil clods. Safflower had a small effect which was not statistically significant.

2.4 General comments on the wheat/safflower study

The Warren experiment showed wheat and safflower to be effective in improving soil structure. Safflower was found to be more effective than wheat.

The Narrabri experiment showed wheat to be effective in improving soil structure. Safflower showed no significant improvement.

Taken together, the two experiments have shown improvement in soil structure by dryland rotation crops.

The presence of a degraded layer between 0.2 m and 0.4 m depths is commonly reported in cracking clays used for cotton growing. Normal tillage does not reach this deep. The use of a vigorous rotation crop, grown under conditions which force the crop to dry the soil thoroughly, can obviate the need for deep tillage.

3.1 Introduction

Deep tillage is commonly practised by cotton growers as a means of loosening compacted soil. However, it is not effective in wet soil as the rippers merely slice through the soil without disrupting it very much. Growers need to know how dry their soil must be for successful tillage: they may be faced with the need to deep till when there is little chance of drying the soil completely.

3.2 Methods

A field experiment was done to measure the effect of deep tillage over a range of soil water content. The treatments were four different soil water profiles when deep tillage was done, plus a fifth treatment which was not deep tilled (control treatment). These five treatments in five replicates were arranged in a latin square design with space between the plots to allow the tractor to turn when deep tilling. Each plot was 16 m wide and 20 m long.

To establish the different soil water profiles, a crop of sorghum was grown in the 1985-86 summer. When the soil reached permanent wilting point, treatments A and E (see Fig. 12) were rotary hoed to chop up the sorghum. Treatment A was deep tilled to 0.45 m in two directions and both treatments A and E were ridged up for planting.

The sorghum on the remainder of the experiment was mown and the area was furrow irrigated. As the ratoon sorghum progressively dried the soil, each of treatments D, C and B (in that order, see Fig. 12) was rotary hoed, deep tilled two ways and ridged up.

When all plots were ridged up, the ridges were extended to link across the spaces between plots, leaving the area ready for cotton planting. Cotton was sown on 15.x.86 and all plots were treated identically with standard agronomy for irrigated cotton.

3.3 Results and discussion

Lint yields are shown in Table 11.

Table 11. Lint yields of cotton grown after deep tillage treatments.

Soil moisture content when deep tilled	Lint (kg ha^{-1})	Lint (% of control)
A: permanent wilting point	1749 z	112
B: moist	1088 y	70
C: moister	1273 y	82
D: wet (just trafficable)	1119 y	72
E: control (not ripped)	1556 z	100

Values followed by the same letter are not significantly different (P>0.05).

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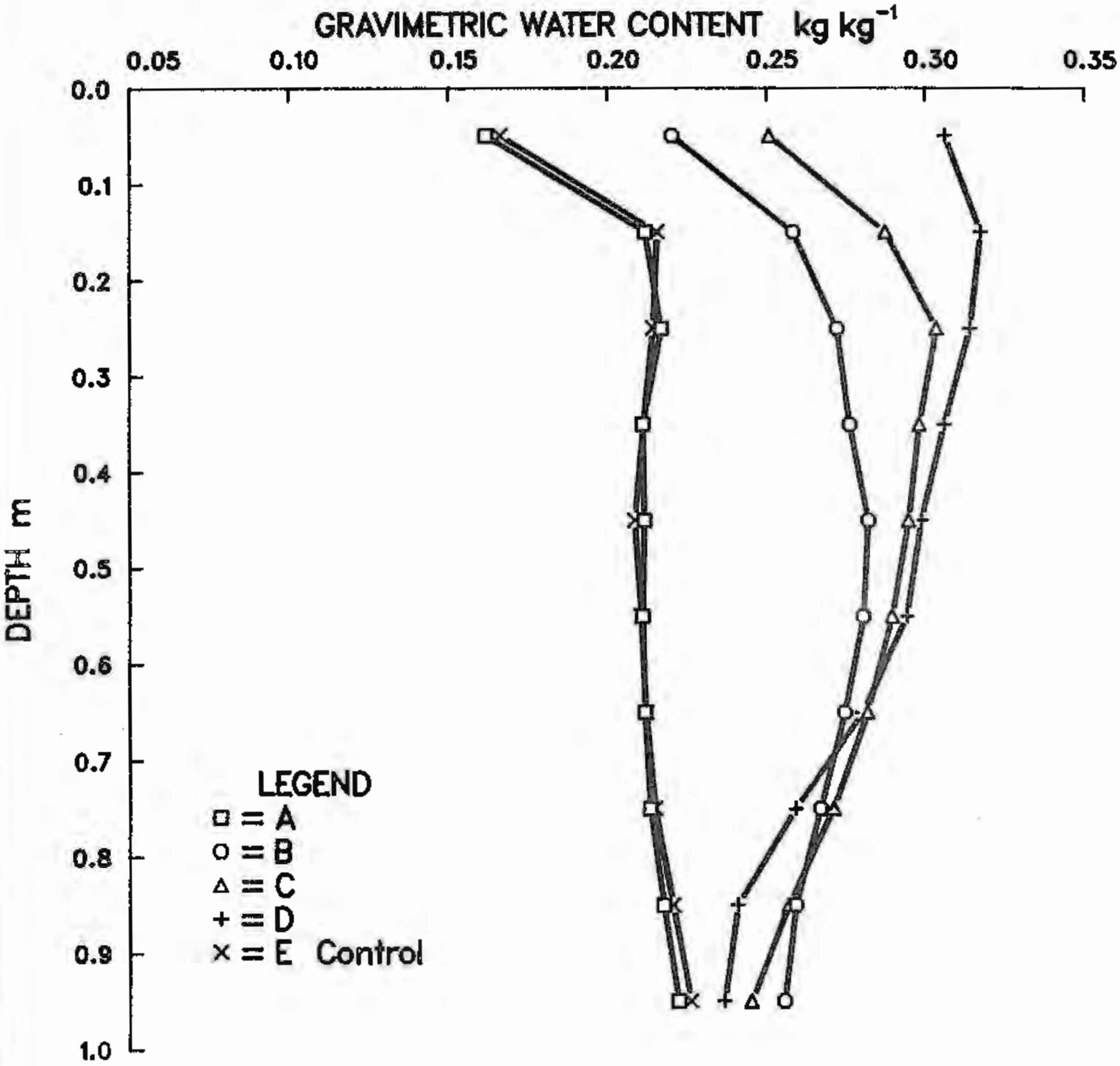

Fig. 12. Soil water profiles during deep tillage.

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Relative to the control treatment (Treatment E in Fig. 12 and Table 11), cotton yielded 12% more when grown after deep ripping soil which was dry to depth (Treatment A). This result was not statistically significant ($P>0.05$). On areas which were deep tilled when the soil was not dry (Treatments B, C and D in Fig. 12 and Table 11) cotton yielded 18% to 30% less than the control treatment ($P<0.05$). There was no significant difference ($P>0.05$) between treatments B, C and D: deep tillage of moist soil, no matter how moist, decreased yield.

These results indicate a 12% increase (not significant, $P>0.05$) in lint yield if deep tillage is carried out at the correct soil water content (permanent wilting point to depth). Although this result is not significant ($P>0.05$) it does call for explanation, as it contradicts the findings of Study 1. In Study 1, deep tillage depressed yield even when done in dry soil (after wheat). However, in Study 1, the yield depression due to deep tillage was most marked on those plots which had intermediate or poor structural condition (the prior moist or wet tillage treatments). The plots in good structural condition (the prior dry tillage treatments) showed a small (not significant) yield increase due to deep tillage. Studies 1 and 3 can be reconciled if, prior to deep tillage in Study 3, the soil structural condition was also good. Unfortunately, there is no evidence of this.

3.4 Conclusions

A cracking clay soil which is not at permanent wilting point should not be deep tilled: such an operation would prove to be a costly way of reducing yield.

APPENDIX

Details of the SARAN technique

Immediately after collection the clods may be coated in paraffin wax to prevent drying and shrinkage. When ready to proceed, the wax coating is gently peeled off. Alternatively, clods may be stored packed in moist, loose soil in a cool room. Clods may be used at the field moisture content or (to ensure that the structural shrinkage phase is measured) equilibrated to a suction of 0.10 m water on a sand bath.

Intact soil clods are suspended from cotton threads in the laboratory and coated in SARAN resin. This resin is permeable to water vapour (allowing the clods to slowly dry in the atmosphere) but is practically impermeable to liquid water (allowing clod volume to be measured by immersion in water). The coat is pliable and shrinks with the clod as the clod dries. Thus by weighing the clods in air and in water at intervals, soil water content and specific volume (reciprocal bulk density) can be estimated as the clods dry. Finally they are oven-dried at 105°C and a last mass and volume measurement made.

A shrinkage curve for each clod is obtained by plotting specific volume (reciprocal bulk density) as a function of gravimetric water content and fitting three joined straight lines to the data using a GENSTAT computer programme. These lines represent the three main zones of shrinkage: termed structural, normal and residual (Fig. 2). In the initial structural shrinkage zone, air replaces water lost from the large pores as the soil dries. This is in contrast to the normal shrinkage zone where no further air entry occurs. The extent of structural and normal shrinkage can be used as a measure of structural condition. The parameters shown in Fig. 2 and also the slopes of the normal and structural shrinkage zones are derived for this purpose.