INVOLVEMENT OF PHYTOTOXINS, PROBABLY HERBICIDES, IN THE GALATHERA SYNDROME

Final Report to The Cotton Research and Development Corporation

February 1993

NSW Agriculture

FINAL REPORT TO
COTTON RESEARCH AND DEVELOPMENT CORPORATION

Project Number: DAN 61C

Project Title: INVOLVEMENT OF PHYTOTOXINS, PROBABLY HERBICIDES, IN THE GALATHERA SYNDROME

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Commencement date: July 1991

Completion date: December 1992

Reporting date: February 1993

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ACKNOWLEDGMENTS

The authors accept responsibility for the content of this report, although the project was a collaborative effort that relied on the assistance and co-operation of many people, including the following:

- Mr. B.J. Loder, Managing Director, Mr. D. Anthony, Manager, Ms. S. Forsell, Agronomist and other staff members of Auscott Pty. Ltd., Narrabri, for access to their fields, assistance in examining the soils, monitoring soil moisture and for data on and the benefit of long experience with the Galathera syndrome.

- Mr. R. Martin, Dr. G. Constable, Dr. S. Allen, Mr. D. Larsen, Mr. I. Daniells, Mr. C. Graham and other staff of Narrabri Agricultural Research Station, for the use of machinery and equipment, access to the laboratory, access to past research, publications and assessments of the Galathera problem, guidance in field work and for clerical assistance.

- The glasshouse, laboratory and clerical staff of the Biological and Chemical Research Institute, Rydalmere who made the study and this report possible, in particular Ms. S. Sultana, Ms. H. Al Qalla, Ms. E. Marolt, Ms. Z. Bohm and Ms. A. Thompson.

- Mr. D. Nehl of the University of New England, Armidale, who kindly made the counts of mycorrhiza on cotton roots and provided helpful discussion.

- Dr. D. McLeod of the University of New England, Armidale, who offered assistance with clay mineralogy.

- Dr. P. Cull of Irricrop Technologies Pty. Ltd., Narrabri, for helpful discussion and advice.

- Dr. D. Nobbs, Faculty of Engineering, University of Sydney, for assistance with particle size measurements of soils.

- Mr. G. Upton, Scientific Officer, Parramatta Divisional Laboratory, NSW Roads and Traffic Authority, for allowing aggregate analysis to be conducted in his laboratory and supervising that work.

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EXECUTIVE SUMMARY

The Project

The Galathera syndrome affects cotton growing in the Namoi Valley, north–western New South Wales. Its symptoms include stunting and foliar discolouration of young seedlings, from which the plants may recover: but too late to reach their genetic potential for lint yield.

An earlier bioassay showed the presence of phytotoxin(s) in a Galathera–prone soil from the property of Auscott Pty. Ltd., Narrabri, N.S.W. (plate 1). This project sought to test that result and to find chemical and physical differences between Galathera and nearby non–Galathera soils which might account for differences, if any, in their phytotoxic properties.

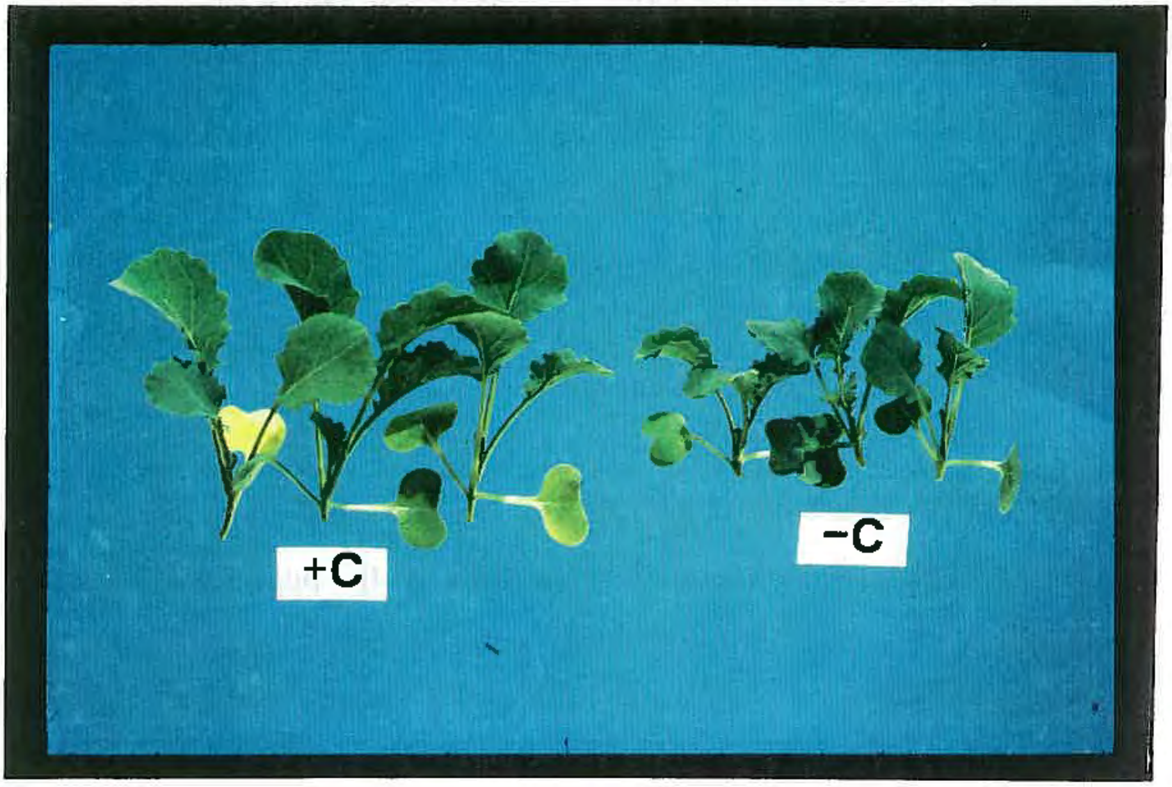

Plate 1. Tops of rape seedlings grown in Galathera soil. The plants on the left were grown in soil mixed with activated carbon.

The Studies

In the cotton fields in late 1991, 35 soil profiles were described and sampled for analysis on Auscott Pty. Ltd., Narrabri. Next, five pits were dug across adjoining cotton rows and wheel tracks – three in Galathera areas and two in non–Galathera areas. The soil in their walls was examined, rated structurally using *SOILpak* and tested for dispersion and shear strength. Undisturbed cores and clods, and disturbed soil close by, were sampled for analysis. Eight bulk soil samples were taken from near the pit sites for glasshouse experiments, i.e., from two Galathera fields (20 and 31) and two non–Galathera fields (11 and 18), at two depths on each site (0–10 and 10–20 cm).

In January 1992 cotton plants were measured and sampled for nutrient levels. For comparison, samples were taken from near the pit sites and elsewhere on Auscott's property. A second sampling in March 1992 measured lint yield and obtained root samples for study.

In the glasshouse the eight bulk samples were tested for the presence of phytotoxin(s) by growing cotton in them, with and without additions of a strong adsorbent (activated carbon). This trial also tested the effect of soil moisture status on the phytotoxic reaction.

A second pot trial studied the effect of water–logging on cotton, because observations on soil from the walls of the pits indicated that temporary poor aeration may contribute to the Galathera syndrome.

In the laboratory a program of measurement and analysis was undertaken – of soils, taken on survey and from the pits, of cotton plant tops taken in January 1992, of cotton roots and lint taken in March 1992 and of cotton plants and soils from the pot trials.

The Results

This report covers the pot work fully but, since the laboratory analysis and measurements on soils and cotton plant samples from the field are incomplete, only part of that work is presented.

In the field the appearance of soils from Galathera and non–Galathera areas was similar. Poor structure was more evident in the Galathera pits than in non–Galathera pits. The air–filled porosity of field moist cores from pit walls, taken in late November – early December 1991, was generally below the critical level and clearly lower in the Galathera pits. These observations suggested that poor aeration may contribute to the Galathera condition. A preliminary report was produced (Hawkins, 1992, see attached).

In the glasshouse the bioassay showed that phytotoxins were present in the surface 0–10 cm sample from field 20, the most Galathera–prone site, but not in the surface of field 31, the other Galathera site tested. No phytotoxin was detected in the subsurface (10–20 cm) at either of these sites. To our surprise both the surface and subsurface soils from the two non–Galathera sites (fields 11 and 18) contained traces of phytotoxin(s). These results, together with the fact that the fastest growth occurred on soil from field 20 in both the bioassay and the following experiment, lead us to conclude that phytotoxins are probably not the main cause of the Galathera syndrome.

We achieved poor aeration in the second glasshouse trial only after ponding water on the soil surface. These conditions depressed growth, caused foliar symptoms of nitrogen (N) deficiency, chlorotic and necrotic spotting on the younger leaves and reduced the concentration of phosphorus (P) and zinc (Zn). The soil from field 20, 10–20 cm, was the striking exception: growth increased; foliar levels of N, P and Zn were not depressed and no leaf symptoms developed.

The reduction in the foliar concentrations of a range of nutrients under water-logging in this trial resembles one aspect of the Galathera syndrome in the field; although, the leaf symptoms on the glasshouse plants (plates 2 and 3) were not the same as those found in the field. Seasonal variations in the occurrence of the syndrome also indicate that other factors, such as soil temperature, may be important.

The failure to achieve anoxia in the subsurface soil from field 20 and its slow onset in the subsoil from field 31, the other Galathera site, indicate low biological activity. This could result in different herbicide degradation rates and affect the production of microbial phytotoxins. In the field, reduced biological activity would slow down, but may not prevent, the development of anaerobic conditions.

Differences among the soils in pH, electrical conductivity, cations, lime content, organic carbon, C/N ratio, clay dispersion, clod shrinkage and particle size might account for the somewhat poorer structure, poor aeration and lowered biological activity in the Galathera areas and the generally sub-optimal air-filled porosity over all the pits, at high moisture content. But, not all these analyses are completed, so only tentative conclusions can be reached.

First, organic carbon has probably been halved in these soils since European settlement and C/N ratios are quite narrow. The Galathera areas appear to have higher carbon contents than the non-Galathera areas, but, despite this, their biological activity may be lower. Much depends upon the nature of the organic matter remaining.

Secondly, there appear to be differences in clay dispersion. In the laboratory, the two non–Galathera pits rated medium and two of the Galathera pits rated high, but the third Galathera pit (field 31) rated only medium. Dispersion measured in the field tends to be greater at all Galathera sites. Exchangeable sodium percentage, an important determinant of dispersion and other physical properties, does not seem to differ much between the two groups. However, lime, which counteracts the dispersive effect of sodium, is higher in the non–Galathera sites. Again site 31 is the exception.

Thirdly, soils from the Galathera sites had less favourable structure: when soil from the water–logging trial was dried, crushed using a known amount of work and put through a nest of sieves, the Galathera soils produced more coarse aggregates than the non–Galathera soils.

Thus, the Galathera condition, which is worse nearer the streams, is associated with poorer structure, lower air–filled porosity, greater dispersion and possibly lower lime in a set of soils containing 3 – 7% exchangeable sodium in the upper profile. The pattern of increasing lime as one moves laterally away from the stream is consistent with the lime in these soils having been transported by the streams, along with the sediments on which the soils were formed, in contrast with *in situ* formation of lime by weathering. This is analogous to the movement of more soluble salts in the prior stream landscape of the Riverine Plain of South–eastern Australia (Butler, 1950).

RECOMMENDATIONS FOR FURTHER RESEARCH

1. Complete the work on soil and plant samples, held at the Biological and Chemical Research Institute, Rydalmere and report on the data therefrom. This should reveal the fundamental physical and chemical properties of Galathera and non–Galathera soils and indicate the soil–related causes of the problem. Completion will require at least 18 months research, including:

    - soil analyses: exchangeable cations; soluble salts; lime content; dispersion; particle size; clod shrinkage; air–filled porosity; available zinc and copper and, clay mineralogy;
    - measurements on cotton roots;
    - processing and statistical treatment of all the data on soils and cotton plants and,
    - preparation of a report and scientific paper(s).

2. Map the distribution of the syndrome in the Auscott cotton fields more precisely. Low level, stereo, colour photography would probably be the best medium. It may be necessary to repeat the mapping because of year to year variation in the occurrence of the condition. Such maps would allow a comparison of soil properties with plant growth and spot estimates of lint yield on, for example a grid across Galathera and non–Galathera areas.

3. Investigate further the nature and extent of the phytotoxin(s). The initial study should determine the concentration of herbicide residues and their likely impact on cotton growth.

4. Expand the research on microbial activity: measure the soils' respiration rates and their biomass; examine the chemical nature of the organic matter and its availability as a substrate; find the cause of the narrow C/N ratio.

5. Examine whether low soil temperature early in the season and low P supply are restricting root growth.

6. There is evidence that some soil properties, such as lime content, vary considerably over both short and longer distances (i.e., 10's of cm and 100's of m) and, by inference, that dependent physical properties vary with them. Consequently, it would seem desirable to measure soil properties and cotton growth over both intervals. Extending the range of some of the soil properties by examining soils distant from the problem area may prove useful.

INTRODUCTION

The Galathera syndrome is named after the creek where it first appeared. Soon after seedlings emerge, characteristic symptoms develop including stunting, malformed and discoloured leaves and nutritional abnormalities. Rapid growth later in the season results in normal sized plants with delayed maturity and low yield (Allen *et al.*, 1992). Some 10,000 hectares in the Namoi Valley were first estimated to be affected; however, Allen *et al.*, more recently proposed that the Galathera Syndrome could be the acute expression of a more widespread, chronic problem in cotton production on the cracking clays.

The syndrome has developed a considerable folklore. First, it affects all of a wide range of cotton varieties, yet none of the other crops tried, including cereals, safflower, sunflower and Dolichos lablab. Secondly, despite studies over an extended period, its occurrence has not been correlated with any chemical or physical properties of the soil. This seems at odds with the conviction that soils of the syndrome areas have a more puggy consistency when wet and take longer to dry (B. Loder, pers. comm.). Perhaps then the soils are highly variable and/or the appropriate properties had not been measured, because differences in sand and clay content (Nehl and Brown, 1992a) and in zinc adsorption (Hulme, 1990) have recently been demonstrated. Thirdly, the condition cannot be prevented or cured by fertiliser treatments (Allen et al., loc. cit.), although some response to zinc has been obtained (Constable, 1990). Fourthly, other potential stress factors such as an insufficient phosphorus supply to the emerging seedlings caused by low soil temperature early in the season have been suggested as causes (M. Sumner, pers. comm., 1992). The latter is highly credible since soil temperatures at sowing are typically suboptimal for root development and function (Cooper, 1973), the plant symptoms are consistent with root malfunction and hearsay links seasonal variations in temperature with the intensity of the Galathera syndrome. Fifthly, Galathera-like symptoms have been induced in cotton on Narrabri Agricultural Research Station by soil sterilisation with methyl bromide, whereas similar sterilisation of a Galathera soil stimulated growth (Allen et al., *1992). These results indicate complex microbial involvement. Nehl and Brown (1992a) have shown a decline in vesicular arbuscular mycorrhiza (VAM) infection of cotton roots as Galathera Creek is approached and proposed renaming the disorder "mycorrhizal deficiency syndrome". Sixthly, Nehl has proposed the presence of either VAM antagonists or microbial phytotoxins (pers. comm., 1992). Finally, the syndrome never occurs in pots.*

Several persistent herbicides are used for weed control in cotton and an exploratory bioassay for phytotoxin(s) had proven positive (plate 1). Consequently we thought it desirable to investigate phytotoxin(s) as possible contributor(s) to the syndrome. For this purpose we conducted a bioassay, using cotton as the indicator plant. The physical and chemical properties of soils, from syndrome and nearby non–syndrome sites, were also studied to shed light on the fundamental causes of any phytotoxicity that might be observed during the bioassay.

A limited field survey of affected and unaffected soils around Galathera Creek was carried out in November–December 1991, on the property of Auscott Pty. Ltd., Narrabri. As part of the field survey five back–hoe pits were dug, three in syndrome and two in non–syndrome areas. The faces of the pits were examined, rated according to the *SOILpak* method (Daniells and Larsen, 1991) and sampled for physical and chemical analysis.

A bulk sample of soil was collected for glasshouse experiments from each of two depths at two affected and two unaffected sites. The depths chosen (0–10 and 10–20 cm) reflected estimates of root exploration by the crop at the time of onset of the syndrome.

Cotton plants were surveyed close to the areas from which the bulk soil samples had been drawn. This was done early in January 1992, to assess nutrient status and growth of the young plants and again in March, to assess mature root and stem growth and lint yield.

The eight bulk soil samples were bioassayed for phytotoxins using cotton as the test species. In a second experiment the effects of poor aeration were examined, following a suggestion that temporary poor aeration of the soil might be involved in the Galathera disorder (Hawkins, 1992 attached).

A description of all of these pieces of work follows, along with the results, a discussion and conclusions.

PART I

BIOASSAY FOR PHYTOTOXIN(S)

PART I. BIOASSAY FOR PHYTOTOXIN(S)

A. Summary

Treatments

For the bioassay, cotton was grown in the eight composite soils (map 1) in the glasshouse, with and without the addition of activated carbon, at two moisture levels. Activated carbon has been shown to reduce the effects of many organic phytotoxins through adsorption (Toth *et al.*, 1987) whereas its addition to soils without phytotoxin(s) never enhances plant growth and occasionally depresses it. Two watering regimes were used to test the possibility that the hypothetical toxin(s) may only be active or produced nnder a particular moisture regime. These treatments were intended to maintain ~60% and ~100% water saturation. Poor aeration was expected to depress growth at the latter moisture level (Toth, 1988). The treatments produced lower moisture levels than expected (appendix I C). These are referred to throughout the report as ~35% and ~45% saturation.

Responses

Activated carbon considerably enhanced the growth of cotton only for the 0–10 cm soil (table 1) from the most Galathera–prone site, field 20*, map 1 (Constable *et al.*, 1989). This clearly demonstrates the presence of phytotoxin(s). However, the occurrence of phytotoxins was not confined to Galathera sites, consequently we do not consider that they are the primary cause of the Galathera syndrome.

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* The field numbers are identifiers used by Auscott Pty. Ltd., Narrabri.

MAP 1. Property of Auscott Pty. Ltd., Narrabri.

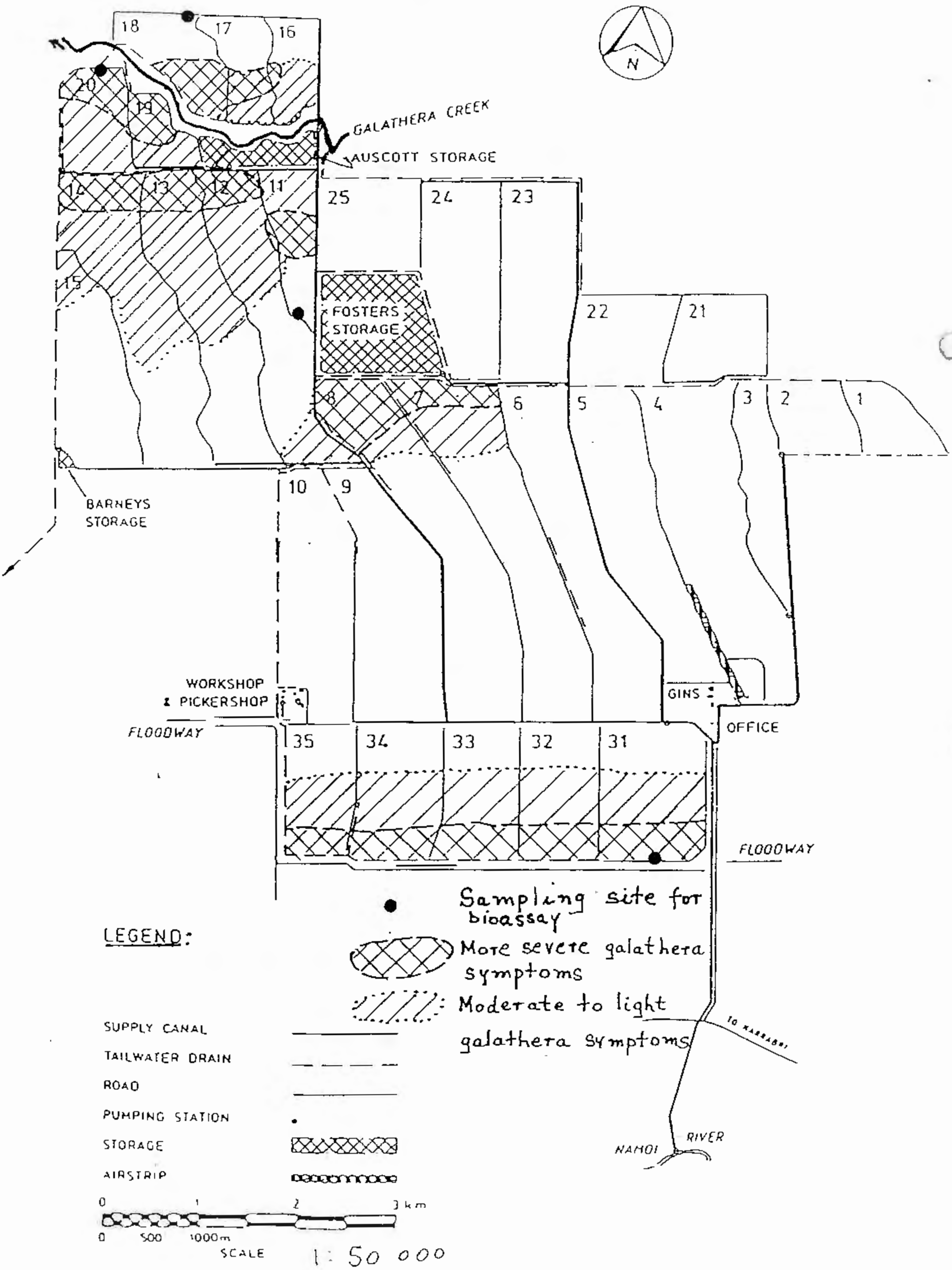

Table 1. **The statistical significance of the responses of cotton to the presence of activated carbon (meaned across water treatments) and varying soil moisture (meaned across carbon treatments) in the bioassay. Soils were from Galathera-prone fields (20 and 31) and non-Galathera fields (11 and 18).**

Treatment effect	Soil depth (cm)	Growth responses and their statistical significance					
		Dry weight†		Plant height†		Leaf area†	
		Field	Stat. sig.	Field	Stat. sig.	Field	Stat. sig.
Activated carbon addition	0–10	20 (+12) 31 (-0.7) 11 (+7) 18 (+4)	** ns ns ns	20 (+6) 31 (+2) 11 (0) 18 (+2)	* ns ns ns	20 (+9) 31 (+2) 11 (+12) 18 (+3)	* ns * ns
	10–20	20 (-17) 31 (-0.6) 11 (+10) 18 (+10)	** ns ns ns	20 (-11) 31 (-4) 11 (+0.1) 18 (+3)	*** ns ns ns	20 (-11) 31 (-0.8) 11 (+11) 18 (+16)	ns ns ns *
Increase in soil moisture from ~35% to ~45% saturation	0–10	20 (+18) 31 (+19) 11 (+18) 18 (+14)	*** *** *** *	20 (+14) 31 (+7) 11 (+9) 18 (+4)	*** ** * ns	20 (+32) 31 (+27) 11 (+32) 18 (+20)	*** ** *** **
	10–20	20 (+4) 31 (+8) 11 (+3) 18 (+13)	ns ns ns ns	20 (-1) 31 (+1) 11 (-6) 18 (+3)	ns ns ns ns	20 (+12) 31 (+11) 11 (+6) 18 (+23)	ns ns ns **

† In the field column: the first pair of digits is the field number allocated by Auscott Pty. Ltd., Narrabri; this number is followed by values in parentheses for the sign and the relative growth response caused by the treatment (+ = growth increase, – = growth decrease and 0 = no effect). In the statistical significance column: ns = non-significant, * = significant at 5% level, ** = significant at 1% level and *** = significant at 0.1% level

The higher level of moisture saturation caused faster growth for all soils. The treatments caused other, smaller effects. These and the major effects are presented and discussed in detail in section B. The phytotoxin(s) were not characterised; however, its (their) presence is convincing evidence of abnormal microbiology in Galathera soils and consequently of different chemical and/or physical properties.

B. Detail

Experimental

The four composite samples of soil were drawn from Galathera fields (20 and 31) and from non–Galathera fields (11 and 18) at 0–10 and 10–20 cm. The fields were all under cotton at the time of sampling. Each bulk soil sample was mixed thoroughly by coning and quartering and from it a sufficient volume was drawn for the pots. This was crushed in a jaw crusher, mixed and 180 g was weighed into each pot. The air–dry soil contained ~8 g water/100 g of oven–dry soil. One g of activated carbon (Norit SA5, Norit, N.V., Amersfoort, The Netherlands) was added where required and mixed through the soil. Three seeds of cotton (*Gossypium hirsutum* c.v. Sicala) were plauted (15 April '92), covered with a further 30 g of soil and the fertiliser added*. The watering wicks were inserted (fig. 1) and the pots watered to ~35% of saturation. Water movement up the wicks maintained this regime. Plants were thinned to two per pot soon after germination and the two moisture regimes were established by placing pots on stands so that the top edges of the pots were at either one of two heights above the bench level. Water was supplied via wicks from reservoirs with a free water surface ~40 mm above the bench level. The values for Z (fig. 1) used in this experiment were (200–40) mm and (90–40) mm for the lower and higher moisture treatments. These treatments had resulted in ~60% and ~100% of moisture saturation for a grey clay soil from Breeza (Toth *et al*., 1988); however, the levels achieved for the Auscott soils were only ~35% and ~45% of saturation respectively (appendix I C). The design consisted of with or

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* Fertiliser consisted of 7.5 mL of each of two solutions. One solution contained 21.7 g/L of diammonium phosphate and 11.1 g/L of potassium sulfate. The second solution contained 14.3 g/L of calcium nitrate tetrahydrate.

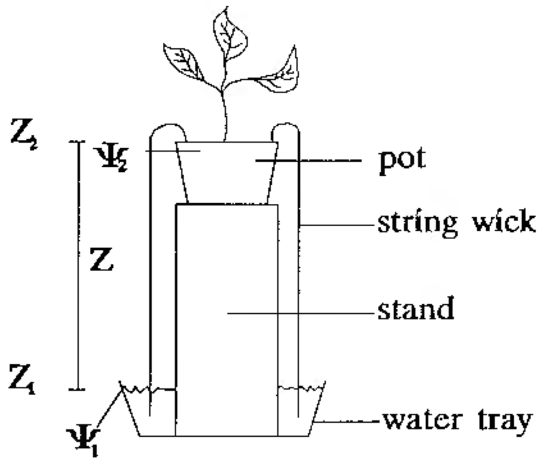


Figure 1. **Watering method for pots after Toth *et al.*, 1988**

without carbon in factorial combination with the two moisture regimes. Treatments were replicated 8 times. Pot locations were randomised completely and re–randomised weekly. Seedlings were harvested four weeks after germination. The dry weight, height and leaf area of each plant was recorded (fig. 2 and appendix I A). Results of statistical analysis are given in appendix I B.

Results and Inferences

Carbon and Water Interaction. The data do not support our idea that production or activity of phytotoxin(s) may have been a function of soil moisture. The only significant interaction between carbon and moisture (P 0.05) occurred for dry weight and leaf area on the 10–20 cm layer site 31 and that effect was small (fig. 1 and appendix I A).

Response to Activated Carbon. Activated carbon substantially increased cotton growth as assessed by all three measures of plant response (table 1 and fig. 2) for the surface soil from field 20, the most Galathera–prone of the four sites (Constable *et al.*, 1989). This clearly demonstrates the presence of phytotoxin(s). Predictably the greatest growth enhancement occurred under the growth regime that supported the fastest rate of growth, i.e., ~45% moisture saturation (table 1). Of the three plant properties measured, leaf area showed a more consistent response to carbon across all four sites in the surface layer than did dry weight or plant height (fig. 2).

Evidence for the occurrence of phytotoxin(s) in the surface soil of field 20 is of considerable interest because this field is one of the best documented Galathera sites, yielding ~22% below the farm average (Constable *et al.*, 1989). The early onset of the syndrome in the field would require that the toxin be present in the surface soil, probably in the 0–10 cm layer. Its (their) occurrence there verifies the result of a previous bioassay for phytotoxin(s) using rape (plate 1). That result had possibly failed to distinguish between residual concentrations of the herbicides used during cotton production and phytotoxin(s) of other origins, because rape is sensitive to substituted urea and triazine herbicides, e.g., Cotoran®, Diurex® and Gesagard®.

Seedlings growing in the surface layer of the site in field 11 showed a small positive response to carbon for dry weight and leaf area, but only that for leaf area is significant P 0.05 (table 1 and fig. 2). Likewise, the growth trends for the surface layer from the site in field 18 show small increases in dry weight, plant height and leaf area, but none is statistically significant.

In the 10–20 cm soil layer from field 20, activated carbon decreased plant growth, but the effect on leaf area is not significant P 0.05 (table 1 and fig. 2). Similar small negative responses occurred in other experiments when soils were treated with this batch of activated carbon (J. Toth pers. comm., 1992). Such growth inhibitions are perhaps due to interference with the availability of phosphorus. Whatever the cause, the effect indicates that the sample of subsurface soil from field 20 has different chemical and/or physical properties from the samples from the other three fields. It is noteworthy that field 31, the other Galathera–prone site sampled, also showed negative responses, but none was significant (P 0.05).

Cotton in the 10–20 cm layer from sites 11 and 18 consistently grew better with carbon additions: however, only the effect on leaf area in the soil sample from field 18 is significant P 0.05 (table 1 and fig. 2). Nevertheless, the consistency of the response strongly suggests that traces of phytotoxin(s) was (were) present in the 10–20 cm layers of both the non–Galathera fields sampled. This weakens the argument that phytotoxin(s) may cause the Galathera syndrome.

Characterisation of the phytotoxin(s) was not attempted, because it was outside the scope of the project. Furthermore, tying the phytotoxic effect to a specific compound or group of compounds may be a very complex task: residues of herbicides will almost certainly be present and Nehl and Brown (1992b) recently showed that steaming and fumigation appear to remove agents antagonistic to plant growth from Galathera soils, suggesting that the agent(s) is (are) of microbial origin. Whatever the source of the phytotoxin(s), the detection of greater levels in surface soil from field 20 than in any of the other soils tested is strong evidence for abnormal microbial activity in Galathera soils. Microbial activity may be abnormal at all Galathera sites, because Nehl and Brown (1992a) have shown low levels of endomycorrhizal infection in roots of cotton growing on such soils. The symptoms of the Galathera syndrome are consistent with poor root function and consequently with this finding.

Text continued following fig. 2.

Figure 2a. Mean dry weight per plant for the tops of cotton in the bioassay. Soils (0–10 cm) were from Galathera-prone fields (20 and 31) and non-Galathera fields (18 and 11) property of Auscott Pty. Ltd., Narrabri. Moisture regimes are indicated by the numbers 35 and 45 above pairs of columns. Within each pair, hatching indicates that activated carbon was mixed through the soil before sowing. The length of the bar below each field number represents the size of the standard error.

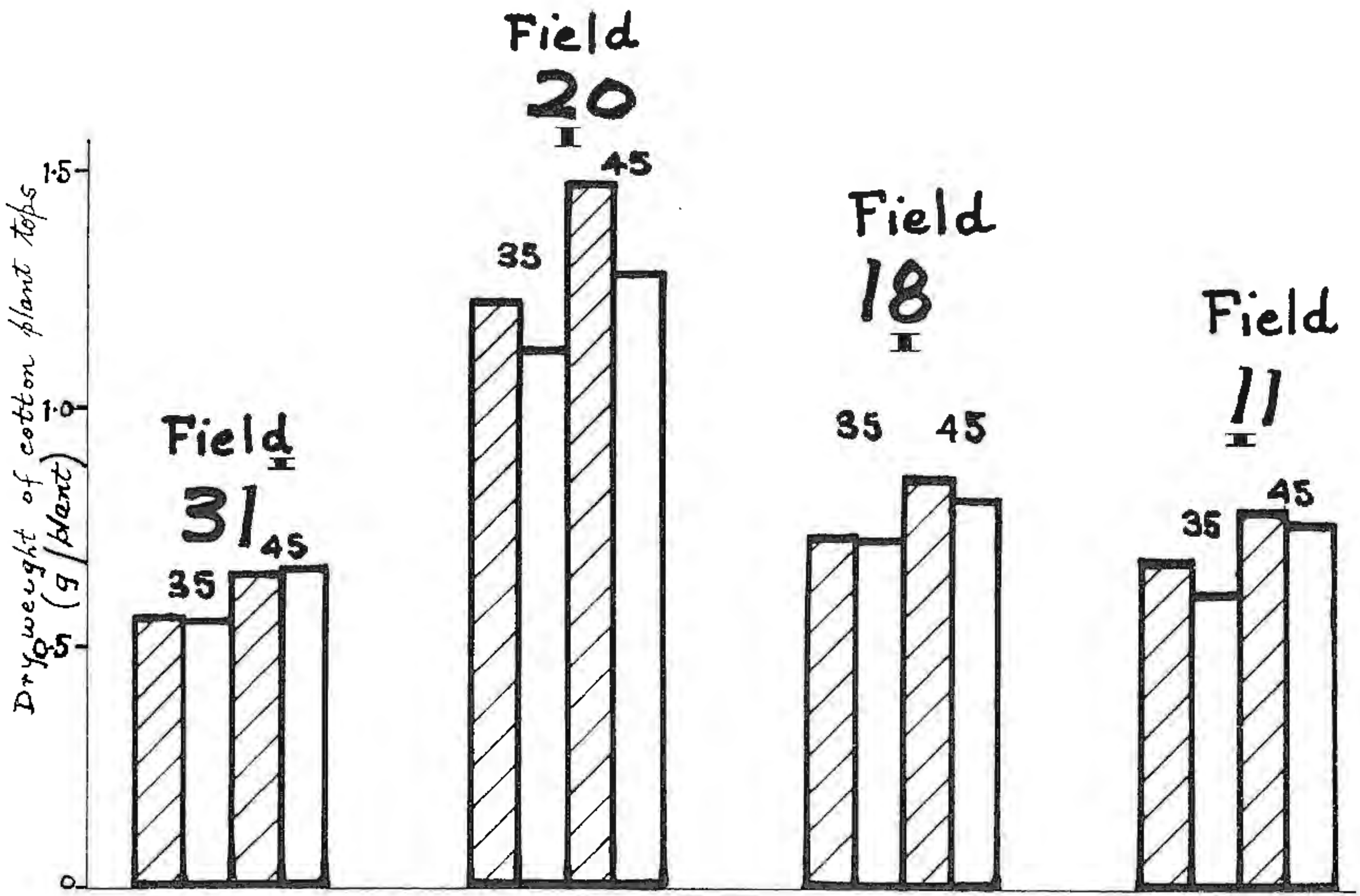


Figure 2b. Mean dry weight per plant for the tops of cotton in the bioassay. Soils (10–20 cm) were from Galathera–prone fields (20 and 31) and non–Galathera fields (18 and 11) property of Auscott Pty. Ltd., Narrabri. Moisture regimes are indicated by the numbers 35 and 45 above pairs of columns. Within each pair, hatching indicates that activated carbon was mixed through the soil before sowing. The length of the bar below each field number represents the size of the standard error.

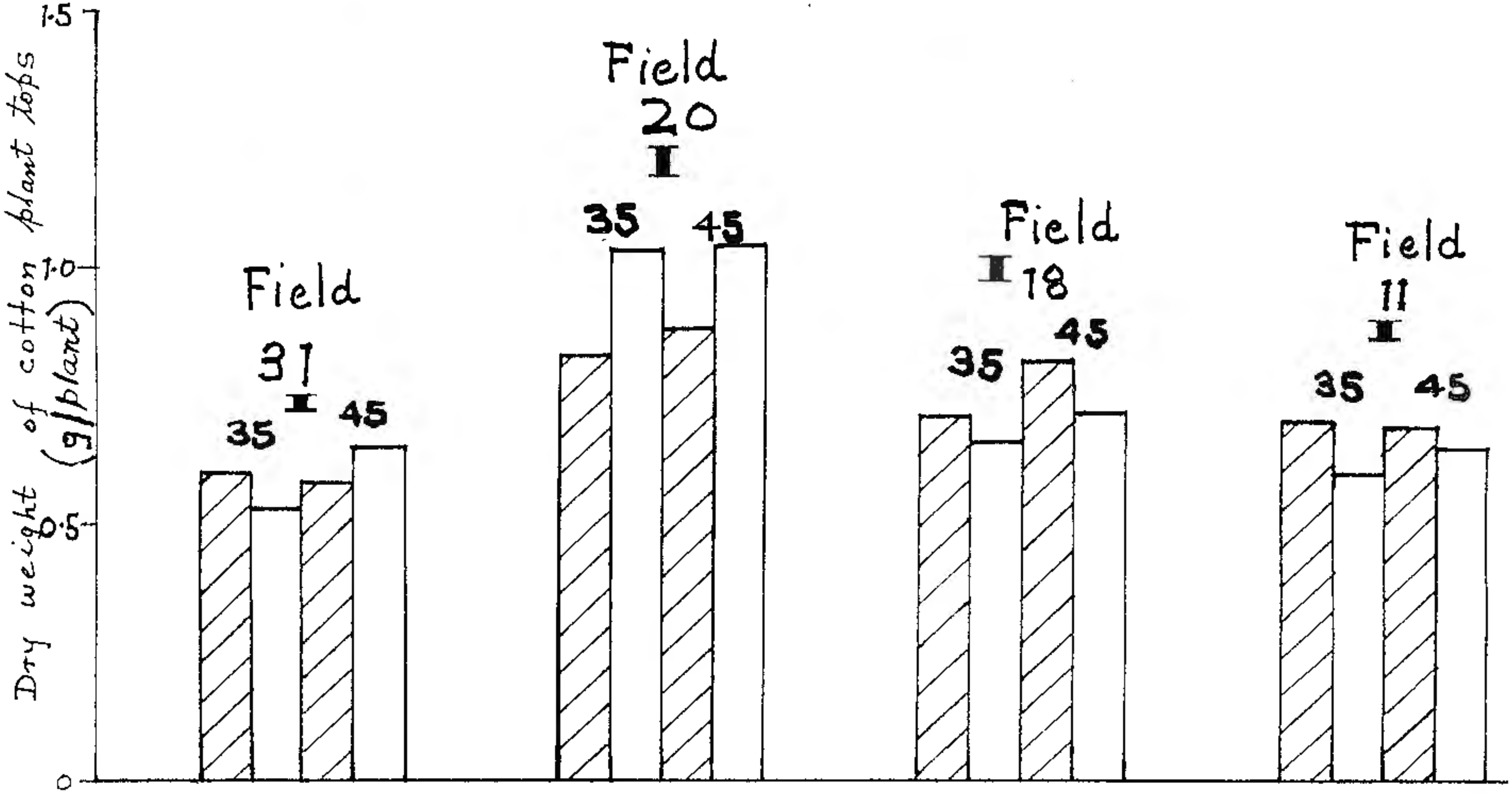


Figure 2c. Mean height of cotton plants in the bioassay. Soils (0–10 cm) were from Galathera–prone fields (20 and 31) and non–Galathera fields (18 and 11) property of Auscott Pty Ltd., Narrabri. Moisture regimes are indicated by the numbers 35 and 45 above pairs of columns. Within each pair, hatching indicates that activated carbon was mixed through the soil before sowing. The length of the bar below each field number represents the size of the standard error.

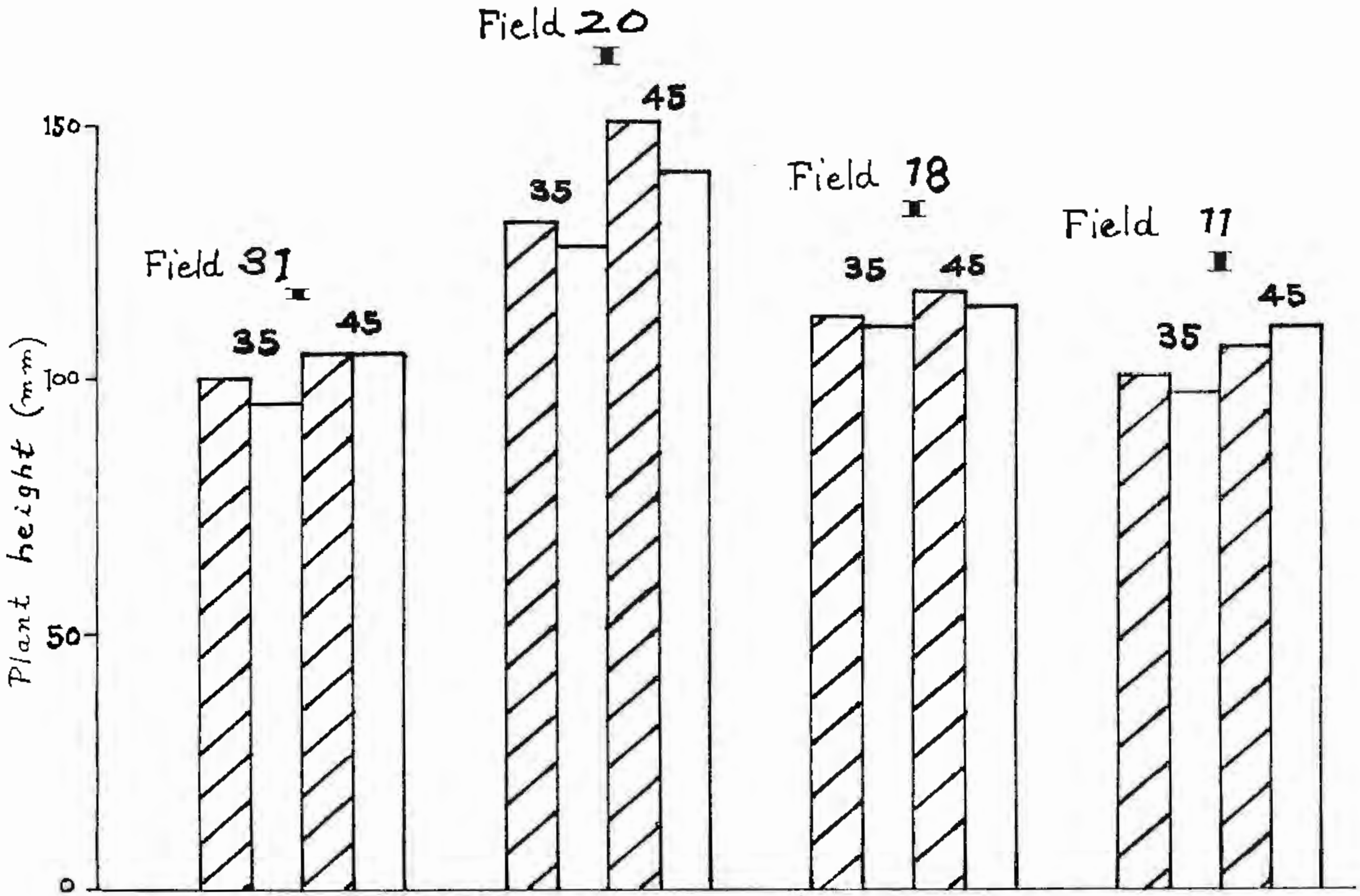


Figure 2d. Mean height of cotton plants in the bioassay. Soils (10–20 cm) were from Galathera-prone fields (20 and 31) and non-Galathera fields (18 and 11) property of Auscott Pty. Ltd., Narrabri. Moisture regimes are indicated by the numbers 35 and 45 above pairs of columns. Within each pair, hatching indicates that activated carbon was mixed through the soil before sowing. The length of the bar below each field number represents the size of the standard error.

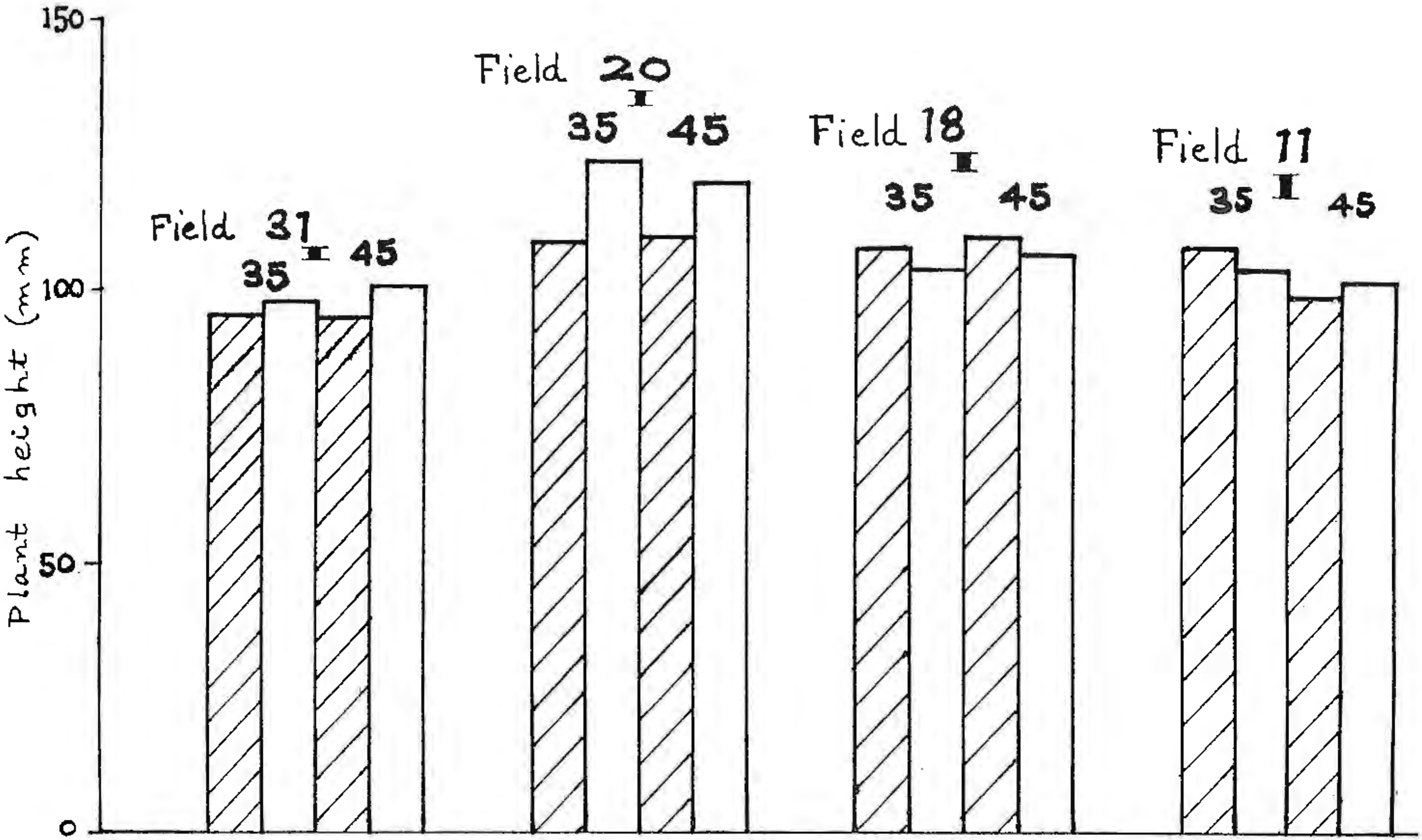


Figure 2e. Mean leaf area per plant for cotton in the bioassay. Soils (0–10 cm) were from Galathera-prone fields (20 and 31) and non-Galathera fields (18 and 11) property of Auscott Pty. Ltd., Narrabri. Moisture regimes are indicated by the numbers 35 and 45 above pairs of columns. Within each pair, hatching indicates that activated carbon was mixed through the soil before sowing. The length of the bar below each field number represents the size of the standard error.

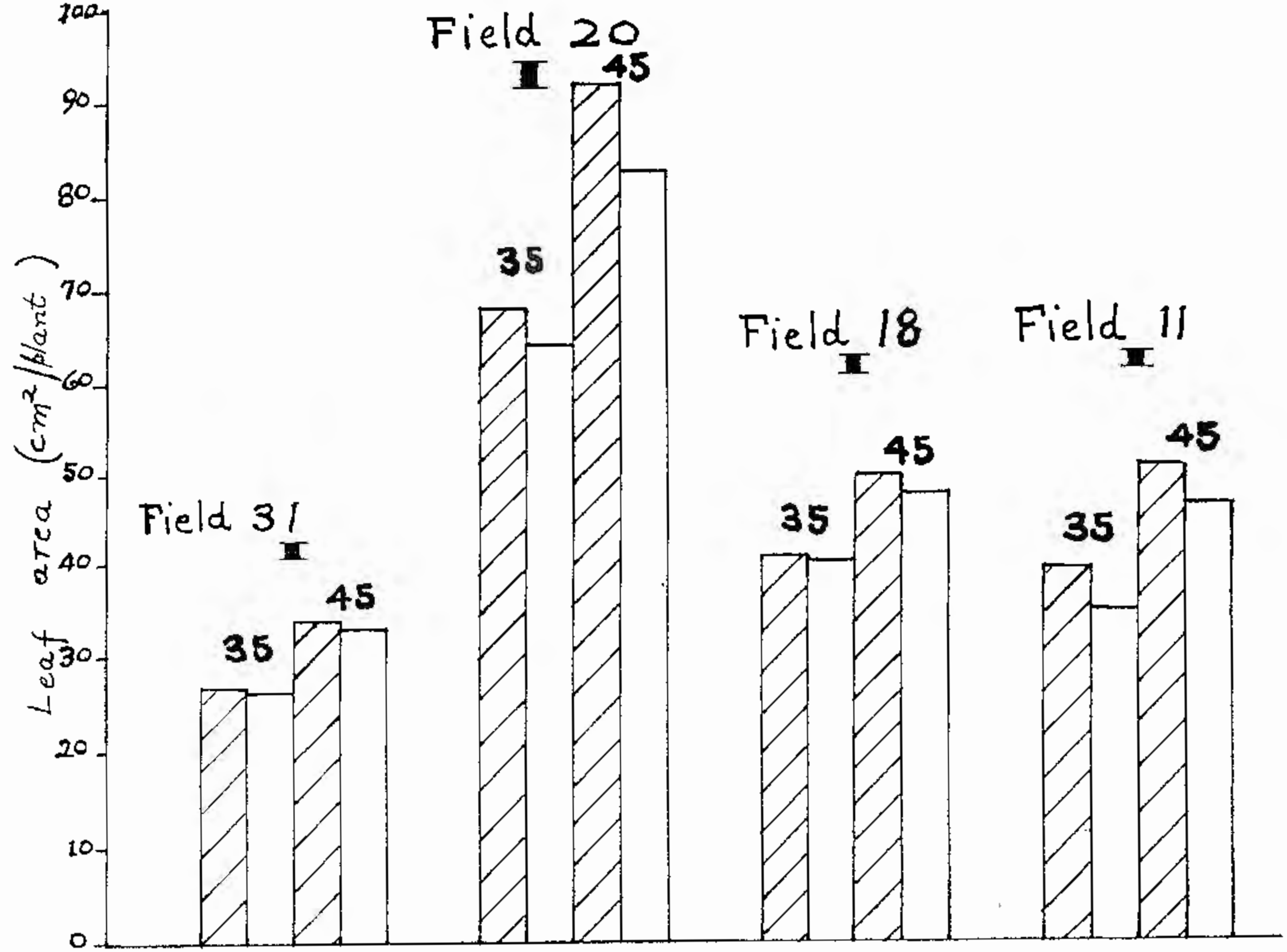
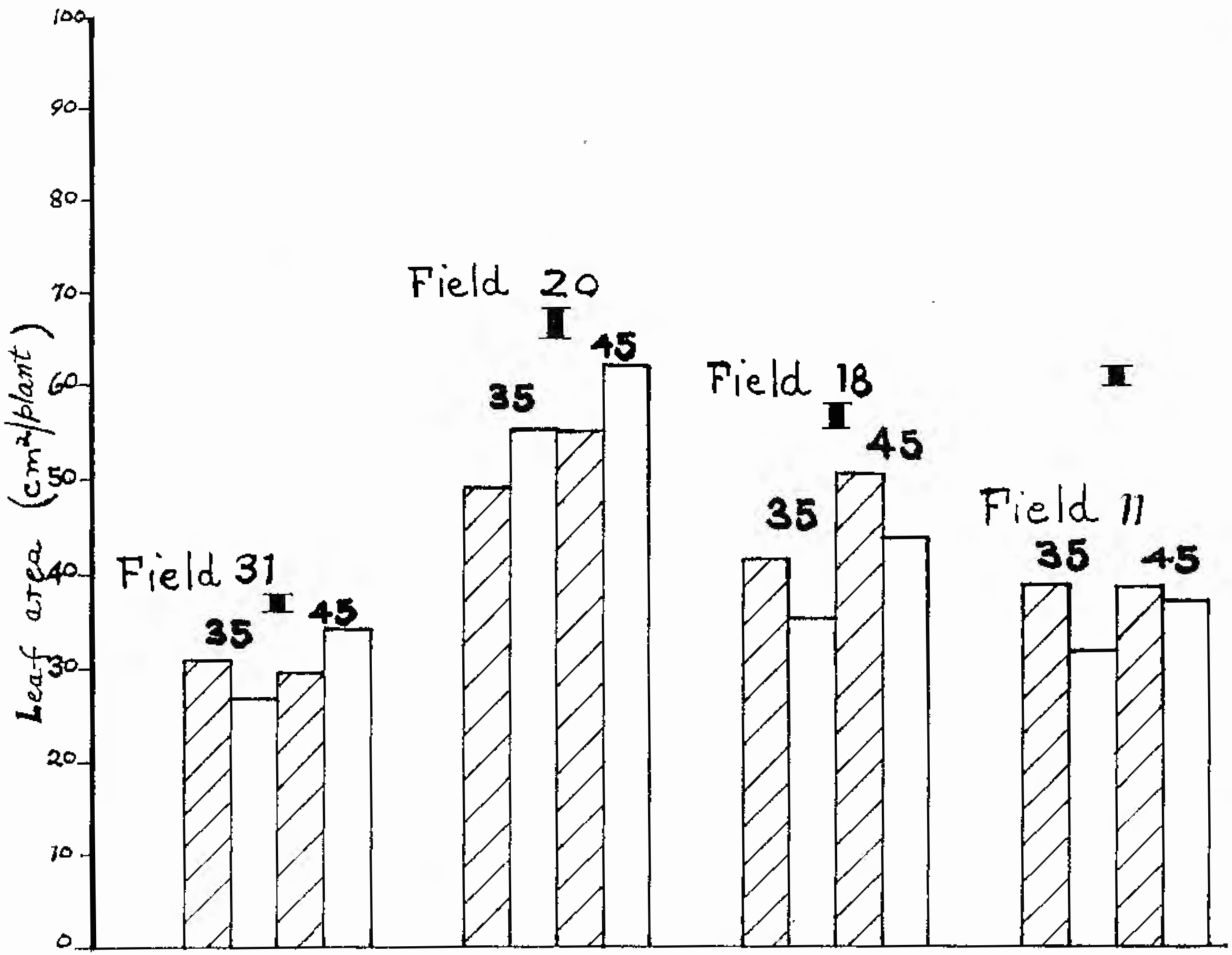


Figure 2f. Mean leaf area per plant for cotton in the bioassay. Soils (10–20 cm) were from Galathera–prone fields (20 and 31) and non–Galathera fields (18 and 11) property of Auscott Pty. Ltd., Narrabri. Moistnre regimes are indicated by the numbers 35 and 45 above pairs of columns. Within each pair, hatching indicates that activated carbon was mixed through the soil before sowing. The length of the bar below each field number represents the size of the standard error.



Response to moisture levels. For all surface samples significant positive growth responses were obtained to increased soil moisture (table 1 and fig. 2). Plants growing in the 10–20 cm layer also consistently grew faster at the higher moisture level, but only one of these differences reached significance (table 1 and fig. 2).

Better growth at the higher moisture level was not expected because this treatment had been designed to result in ~100% moisture saturation and to exceed the optimal water content for the crop (Toth *et al*., 1988). However, it soon became apparent that the plants in the higher treatment were growing better than those in the lower one (table 1 and fig. 2). A check on the moisture levels in the soils explained why. The lower and higher moisture regimes achieved only ~35% and ~45% moisture saturation (appendix I C). Results from the water–logging experiment (part 2) show that, even if 100% saturation had been achieved, the soils would probably not have become anaerobic.

The growth increase obtained at the higher water level shows that the seedlings growing in ~35% saturated soil were water–stressed, though they showed no symptoms and the water supply was maintained continuously (fig. 1). This result is not surprising given the high transpiration demands of the glasshouse environment and the small volume of soil in the pot. The matter of growth in relation to soil moisture levels is dealt with further in part II.

Conclusions

Phytotoxin(s) impaired the growth of cotton in the soil from the 0–10 cm layer of field 20 and perhaps the soils from other sites; however, we infer that phytotoxin(s) are not likely to be the principal cause of the Galathera syndrome. They may nevertheless be limiting production and consequently warrant further investigation.

The data clearly provide additional support for the argument that microbial processes may be abnormal in Galathera-prone soils. As a corollary, systematic differences must exist in the chemical and/or physical properties of the prone and non-prone soils. The unique negative effect on growth caused by the addition of activated carbon to the sample of subsoil from field 20 is an indication of one such difference. We feel strongly that such differences should be elucidated with a view to comprehending the fundamental cause of the syndrome. With this information it may be possible to devise a practical method of amelioration.

PART II

GLASSHOUSE TRIAL TO OBSERVE THE RESPONE OF COTTON TO WATER-LOGGING OF SOIL

PART II. GLASSHOUSE TRIAL TO OBSERVE THE RESPONSE OF COTTON TO WATER-LOGGING OF SOIL

A. Summary

Background

Until now, attempts to produce the Galathera syndrome in glasshouse cotton have failed (G. Constable, pers. comm., 1991). This could relate to aeration differences, at the same water content, in pots and in the field because maximal growth in pots is often obtained at soil moisture levels high enough to cause poor aeration in the field (J. Toth, pers. comm., 1991). Therefore, since Hawkins (1992, attached) had previously suggested that poor aeration might contribute to the Galathera condition, we conducted a second pot trial, to establish the nutritional and growth responses of cotton to poor aeration.

Treatments

This experiment used the same eight bulk soil samples as the bioassay. After seedling establishment, two watering regimes were imposed. Hereafter they are described as "60%" and "100%" saturated (table 2). From day 17 the latter treatment was raised to "110%" by ponding water on the soil surface.

Responses

Water–logging (ponding) depressed growth (table 3, plates 3–5 and fig. 3) on all soils, except the 10–20 cm layer from the most Galathera–prone of the sites sampled (Constable *et al.*, 1989). Its unique response is analysed in section B. Water–logging changed foliar nutrient levels (table 5) and, by the second harvest, chlorotic spots, reminiscent of manganese toxicity, had developed on the young foliage (plate 2).

Table 2. **Bulk density (BD), gravimetric moisture content (θg) and air–filled porosity (AFP) of the soils in the water–logged pot trial (means of four replications). Fields 20 and 31 are Galathera–prone, 11 and 18 are not. Field numbers are those used by Auscott Pty. Ltd., Narrabri.**

Field and depth (cm)	Nominal percentage moisture saturation						
	"60%"			"110%"†			"100%"*
	Measured soil properties						
	BD (kg/dm^3)	θ g (g/g)	AFP (m^3/m^3)	BD (kg/dm^3)	θ g (g/g)	AFP (m^3/m^3)	θ g g/g O.D. soil
20, 0–10	0.92	0.48	0.21	0.88	0.70	0.06	0.68
20, 10–20	0.96	0.42	0.24	0.90	0.66	0.06	0.62
31, 0–10	1.06	0.38	0.20	0.98	0.59	0.04	} 0.57
31, 10–20	1.07	0.36	0.21	0.97	0.59	0.07	
11, 0–10	0.94	0.44	0.24	0.89	0.70	0.04	0.61
11, 10–20	0.97	0.40	0.25	0.92	0.67	0.03	0.64
18, 0–10	0.97	0.43	0.22	0.92	0.68	0.05	0.65
18, 10–20	0.97	0.42	0.22	0.89	0.67	0.07	0.64

* The methods for determining both this value and θ g are described in appendix II A.

† The free water was poured from the pots just before measurement.

B. Detail

Experimental

Soil for this trial was taken from the eight bulk samples described in part I. Because plants in the "100%" treatment had not exhibited any visual symptoms of water–logging by day 17, this treatment was raised to "110%" on that day, i.e., free water

Table 3. **The statistical significance of the mean responses of cotton to water–logging ("110%" saturation) in the large–pot trial. Soils were from Galathera fields (20 and 31) and non–Galathera fields (11 and 18).**

Harvest	Soil depth (cm)	Growth responses and their statistical significance					
		Dry weight†		Plant height†		Leaf area†	
		Field	Stat. signif.	Field	Stat. signif.	Field	Stat. signif.
Harvest 1	0–10	20 (–15) 31 (–9) 11 (–5) 18 (–24)	ns ns ns *	20 (–12) 31 (–7) 11 (–13) 18 (–25)	ns ns * **	20 (–16) 31 (–21) 11 (–16) 18 (–49)	ns ** ns ***
	10–20	20 (+13) 31 (+6) 11 (–8) 18 (–12)	ns ns ns ns	20 (+11) 31 (0) 11 (–3) 18 (–8)	* ns ns ns	20 (+36) 31 (–14) 11 (–14) 18 (–27)	* * ns **
	Soil depth (cm)	Dry weight†		Plant height†		Number of internodes†	
Harvest 2	0–10	20 (–36) 31 (–38) 11 (–40) 18 (–70)	** ** *** ***	20 (–17) 31 (–13) 11 (–21) 18 (–37)	ns * ** ***	20 (–7) 31 (–4) 11 (–8) 18 (–16)	ns ns * *
	10–20	20 (+41) 31 (–37) 11 (–30) 18 (–37)	* *** * **	20 (+34) 31 (–10) 11 (–17) 18 (–16)	*** ns *** **	20 (+11) 31 (–5) 11 (–5) 18 (+0.1)	** ns ns ns

† In the field colnmn: the first pair of digits is the field number allocated by Auscott Pty. Ltd., Narrabri. This number is followed by values in parentheses for the sign and the percentage response cansed by the treatment (+ = growth increase, – = growth decrease and 0 = no effect). In the statistical significance colnmn: ns = non–significant, * = significant at 5% level, ** = significant at 1% level and *** = significant at 0.1% level.

was maintained above the soil surface. Details of the experimental and statistical methods used are set out in appendix II A and C. Plants were harvested on two occasions, namely 39 and 62 days after sowing, i.e., 22 and 45 days after ponding. Dry weight of tops, plant height and leaf area were determined for three plants at the first harvest. At the second, dry weight of tops, plant height and internode number were measured on the two remaining plants and the foliage was scored for the severity of the chlorotic symptoms induced by water–logging.

Results and inferences

Watering to 100% saturation would certainly have induced anaerobic conditions in the field, but in pots it had not by day 17. So oxygen must have continued to enter the soil, perhaps because of the combined effects of the large daily fluctuations in soil water content due to transpiration and the consequent additions of (aerated) water. Further, ponding depressed air–filled porosity from 5–12% to 3–7% (table 2). That difference may account for the observed differences in plant behaviour. It seems therefore that the critical air–filled porosity may be lower in pots than for the same soil in the field (Hodgson and MacLeod, 1989).

Ponding decreased growth, more so in the second harvest than in the first and more for the 0–10 cm than the 10–20 cm layer (table 3 and fig. 3). Data for both harvests are given in appendix II B and are discussed below.

Ponding of the 0–10 cm soils from all 4 sites, reduced growth at harvest 1 as assessed by all three measures used. Of the 12 responses obtained, seven were non–significant (P 0.05, table 3).

By the second harvest, the effects of water–logging were much worse (fig. 3 and appendix II B) and only three of the twelve responses were non–significant. By this time, most of the water–logged plants had developed a chlorotic foliar symptom that resembled manganese toxicity (plate 2 and table 4).

Table 4. Severity of a chlorotic condition (plate 2) of new leaves, scored at the second harvest (day 62) in the "110%" moisture treatment in the water–logging experiment. Score for the "60%" treatment was 0.

Soil sampling depth (cm)	Field†			
	11	18	20	31
	Leaf chlorosis score*			
0–10	2.3 (0.33)	3.3 (0.21)	0.3 (0.21)	3 (0)
10–20	2.8 (0.17)	3.3 (0.21)	0 (0)	3.2 (0.31)

† Field numbers used by Auscott Pty. Ltd., Narrabri.

* The severity of the symptoms is ranked from 0 (no symptoms) to 4 (burn plus severe spotting, plate 2). The scoring system is detailed in appendix II A. Data are means of 6 replicates and the values in parentheses are standard deviations.

It is interesting to explore why soil from the most Galathera–prone of the sites sampled (field 20) supported the fastest growth for both depths and both moisture regimes at both harvests, with one exception – the 60% water regime on the 10–20 cm layer at harvest two. There field 20 ranked last in productivity (fig. 3).

We suggest that these effects occurred because the soils from field 20 supplied more or less adequate amounts of zinc (Zn), nitrogen (N) and phosphorus (P) whether ponded or not and

Text continues following plates 2–5 and table 5

Plate 2: Chlorosis and necrotic spots on leaves of cotton grown under water-logged conditions in pots of soil from field 18, 0–10 cm layer (harvest 2).

Plate 3: Depression of growth and leaf symptoms produced in cotton growing in water-logged soil from field 18, 0–10 cm layer (harvest 2).

Plate 4: **Stimulation of cotton growth produced by 110% moisture regime in pots of soil from field 20, 10–20 cm layer (harvest 2).**

Plate 5: **Comparison of cotton growth, by harvest 2, in pots of soil from four sites, 10–20 cm layer.**

Table 5. Nutrient content of cotton leaves, harvest 1, water–logging trial in pots. Field numbers are those used by Auscott Pty. Ltd., Narrabri. (Table continues on the page following).

Site (field)	Water regime (% of saturation)	PLANT NUTRIENT CONTENT*									
		N	P	K	Cu	Mg	Na	Mn	Ca	Zn	S
		0–10 cm samples									
20	60	5.7	0.62	3.4	11.2	1.1	0.06	158	5.4	39	1.42
	"110"	4.6†	0.48	3.5	9.0	0.8	0.13	129	3.7	25	0.60
31	60	5.5	0.48	3.3	6.1	1.4	0.11	103	4.5	20	1.40
	"110"	4.2†	0.37**	3.2	8.3	1.1	0.16	79	3.9	12**	0.74
11	60	5.7	0.54	3.6	10.2	1.2	0.05	221	5.4	25	1.34
	"110"	4.2†	0.37**	3.6	7.2	0.9	0.06	178	4.1	12**	0.66
18	60	5.5	0.65	3.3	10.7	1.2	0.07	177	6.0	20	1.43
	"110"	3.5†	0.24**	2.5	11.2	0.8	0.09	128	3.6	9**	0.50

* Units are g/100g (%) except for copper, manganese and zinc which are mg/kg.

† These nitrogen levels are considered deficient (Reuter and Robinson, 1986).

** These levels are considered low (Reuter and Robinson, loc. cit).

Table 5. **Nutrient content of cotton leaves, harvest 1, water-logging trial in pots. Field numbers are those used by Auscott Pty. Ltd., Narrabri. (Table continued from the previous page).**

Site (field)	Water regime (% of saturation)	PLANT NUTRIENT CONTENT*									
		N	P	K	Cu	Mg	Na	Mn	Ca	Zn	S
		10-20 cm samples									
20	60	5.3	0.56	3.5	9.0	1.1	0.09	170	5.4	37	1.2
	"110"	5.5	0.68	3.6	7.5	1.0	0.14	170	5.0	36	1.1
31	60	5.5	0.55	3.3	8.2	1.3	0.08	110	5.1	21	1.4
	"110"	4.4†	0.41	3.3	6.7	1.1	0.17	80	4.1	11**	0.8
11	60	5.6	0.52	3.5	11.4	1.2	0.06	250	5.6	22	1.3
	"110"	4.7†	0.43	3.6	10.7	1.0	0.09	180	4.9	13**	0.9
18	60	5.7	0.49	3.3	9.9	1.2	0.07	220	5.8	24	1.2
	"110"	4.4†	0.33**	3.1**	9.2	0.9	0.08	140	4.3	11**	0.7

* Units are g/100g (%) except for copper, manganese and zinc which are mg/kg.
† These nitrogen levels are considered deficient (Reuter and Robinson, 1986).
** These levels are considered low (Reuter and Robinson, loc. cit).

that growth began to be restricted by moisture supply in the 10–20 cm layer, at 60% moisture, between harvests one and two. The evidence supporting this hypothesis is presented in two parts.

Text continues following fig. 3

Table 6. **Mycorrhizal counts on roots of cotton, grown as described for the bioassay, on soils from the 0–10 cm layer. Activated carbon was added (+) or not (–) before sowing. Mycorrhizal counts were carried out by David Nehl.***

Site †	Treatment		Percent arbuscular roots	
	Moisture saturation (%)	Carbon	Individual pots	Mean
	Plants 45 days old			
11	–35	–	3.3	
		+	0	
	–45	–	6.5	
		+	14.7	
20	–35	–	0.5	
		+	0	
	–45	–	1.0	
		+	3.7	
	Plants 70 days old			
11	–35	–	8,0,1,5,3,3	3.3
		+	0,0,0,1,2,0	0.5
	–45	–	1,0,0,0,2,2	0.8
		+	0,0,1,1,0,2	0.7
20	–35	–	0,1,0,0,0,0	0.2
		+	1,2,3,2,2,6	2.7
	–45	–	1,1,1,0,0,1	0.7
		+	0,0,0,1,0,0	0.2

† Sampling sites are identified by the field numbers used by Auscott Pty. Ltd., Narrabri.

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* University of New England, Armidale

Figure 3a. Dry weight of plant tops at harvest 1 in the water-logging experiment. Soil samples were taken from Galathera-prone fields (31 and 20) and non-prone fields (18 and 11) from a depth of either 0–10 or 10–20 cm, property of Auscott Pty. Ltd., Narrabri. Within each pair of columns the watering regimes ("60%" and "110%" saturation) are indicated by non-hatching and hatching respectively. Data are means of six replicates and the length of the bar represents the standard error.

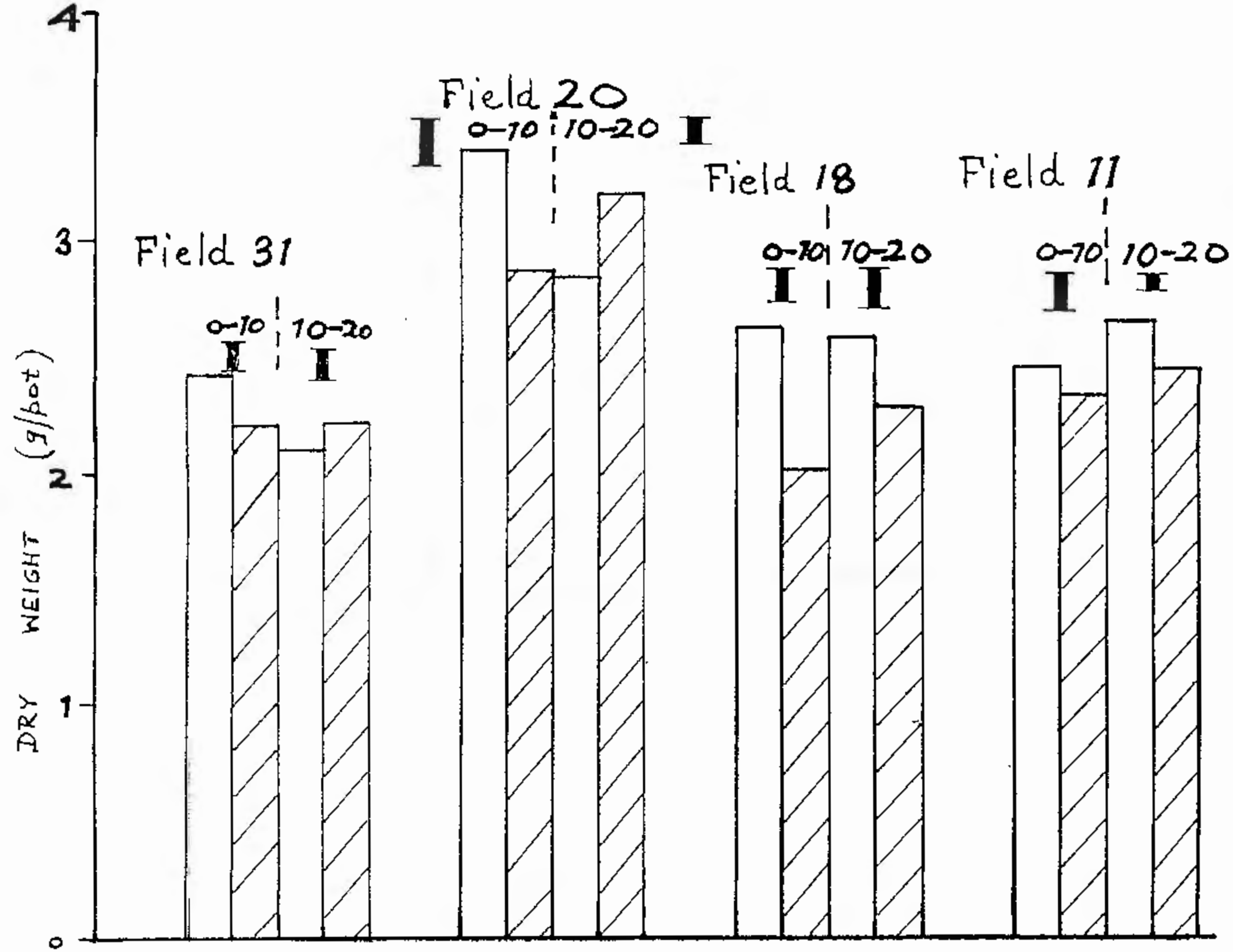


Figure 3b. Plant height at harvest 1 in the water-logging experiment. Soil samples were taken from Galathera-prone fields (31 and 20) and non-prone fields (18 and 11) from a depth of either 0-10 or 10-20 cm, property of Auscott Pty. Ltd., Narrabri. Within each pair of columns the watering regimes ("60%" and "110%" saturation) are indicated by non-hatching and hatching respectively. Data are means of six replicates and the length of the bar represents the standard error.

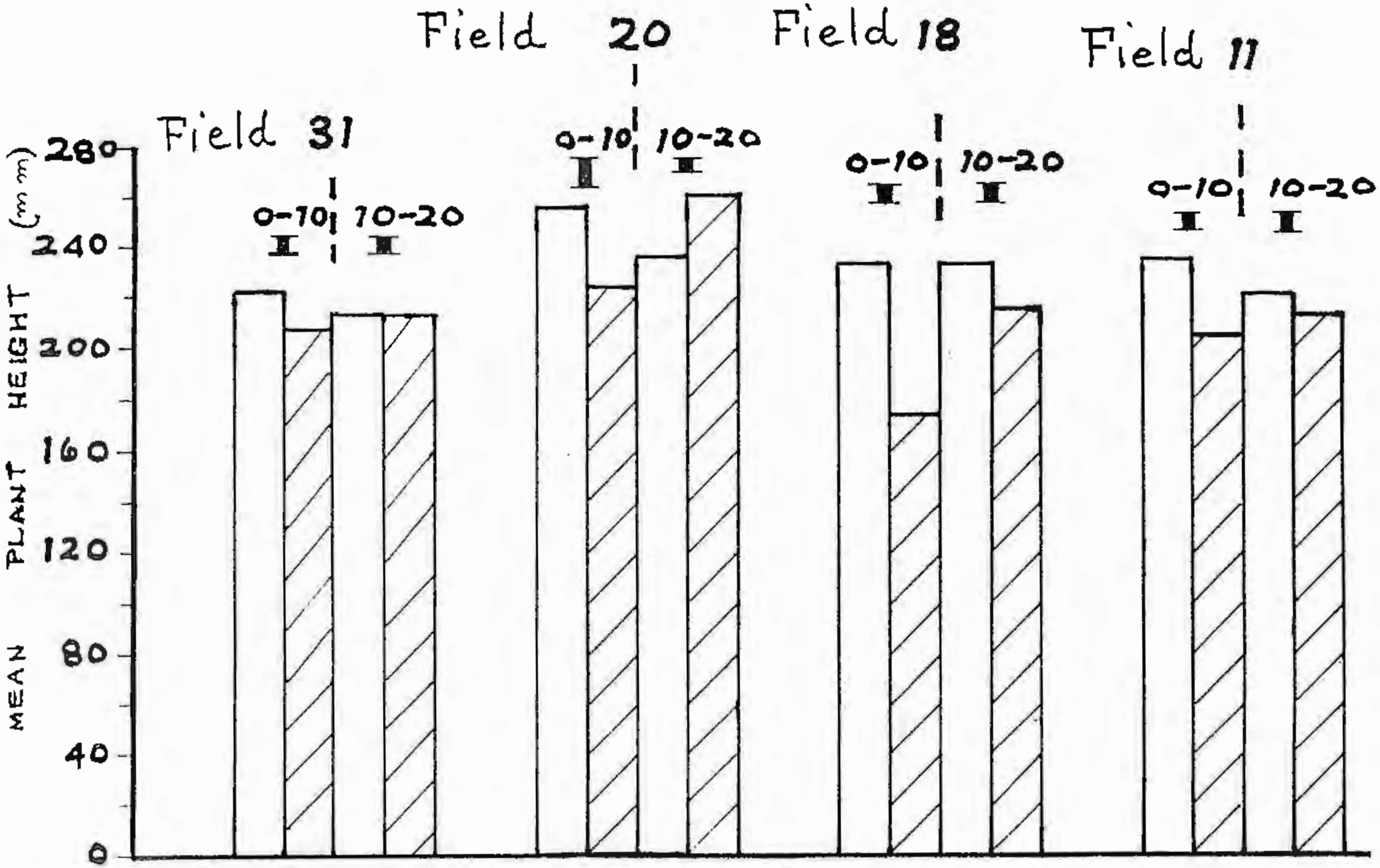


Figure 3c. Leaf area at harvest 1 in the water-logging experiment. Soil samples were taken from Galathera-prone fields (31 and 20) and non-prone fields (18 and 11) from a depth of either 0–10 or 10–20 cm, property of Auscott Pty. Ltd., Narrabri. Within each pair of columns the watering regimes ("60%" and "110%" saturation) are indicated by non-hatching and hatching respectively. Data are means of six replicates and the length of the bar represents the standard error.

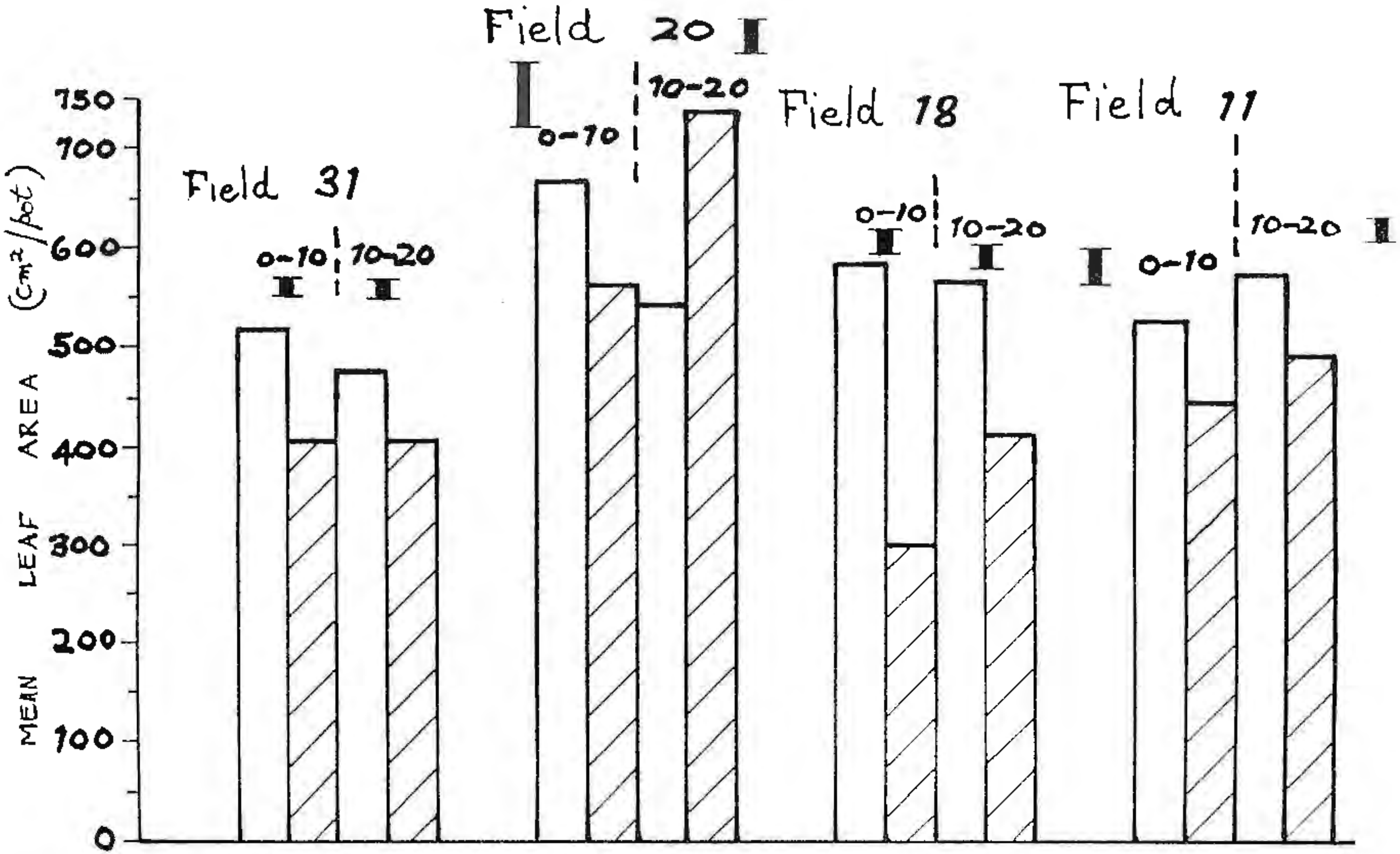


Figure 3d. Dry weight of a plant tops at harvest 2 in the water-logging experiment. Soil samples were taken from Galathera-prone fields (31 and 20) and non-prone fields (18 and 11) from a depth of either 0-10 or 10-20 cm, property of Auscott Pty. Ltd., Narrabri. Within each pair of columns the watering regimes ("60%" and "110%" saturation) are indicated by non-hatching and hatching respectively. Data are means of six replicates and the length of the bar represents the standard error.

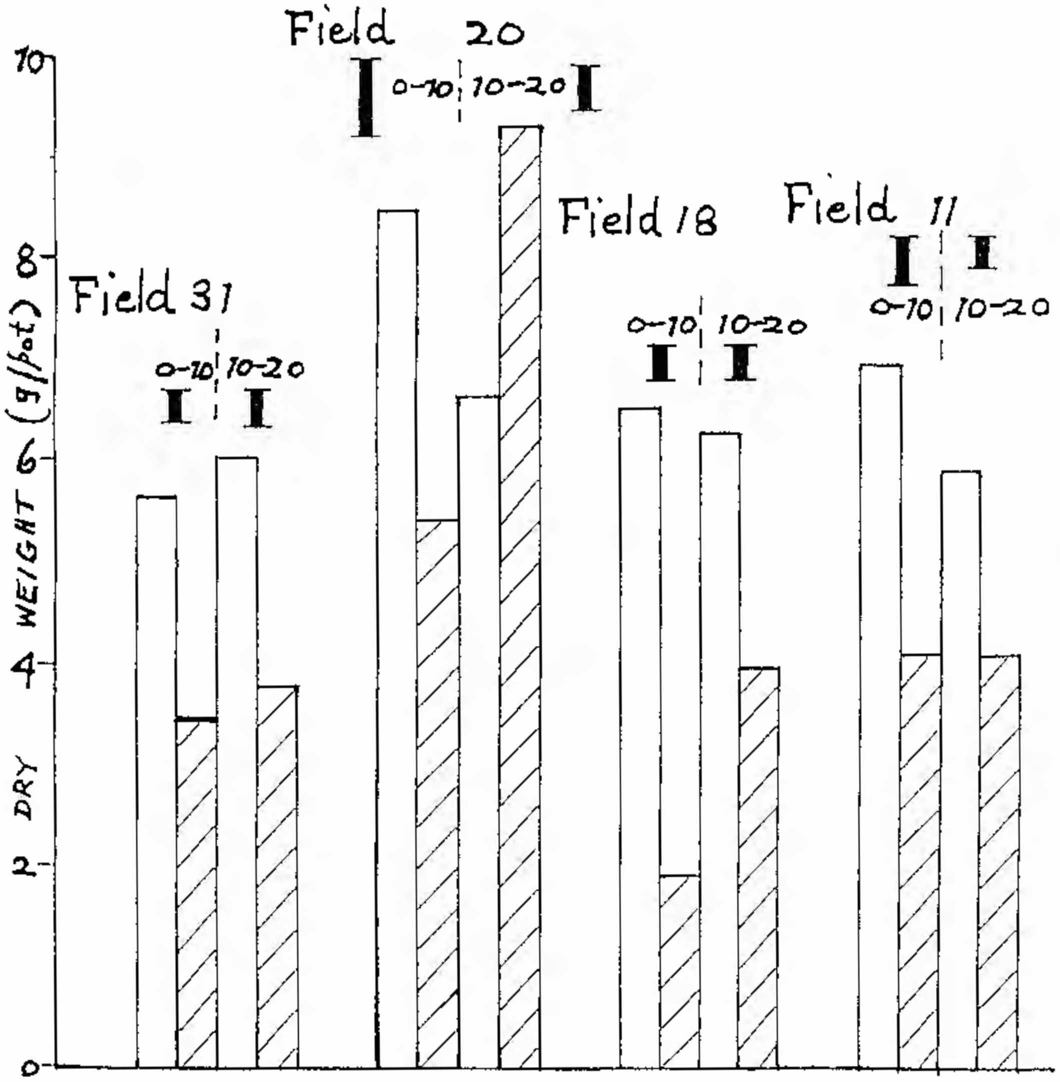


Figure 3e. Plant height at harvest 2 in the water-logging experiment. Soil samples were taken from Galathera-prone fields (31 and 20) and non-prone fields (18 and 11) from a depth of either 0-10 or 10-20 cm, property of Auscott Pty. Ltd., Narrabri. Within each pair of columns the watering regimes ("60%" and "110%" saturation) are indicated by non-hatching and hatching respectively. Data are means of six replicates and the length of the bar represents the standard error.

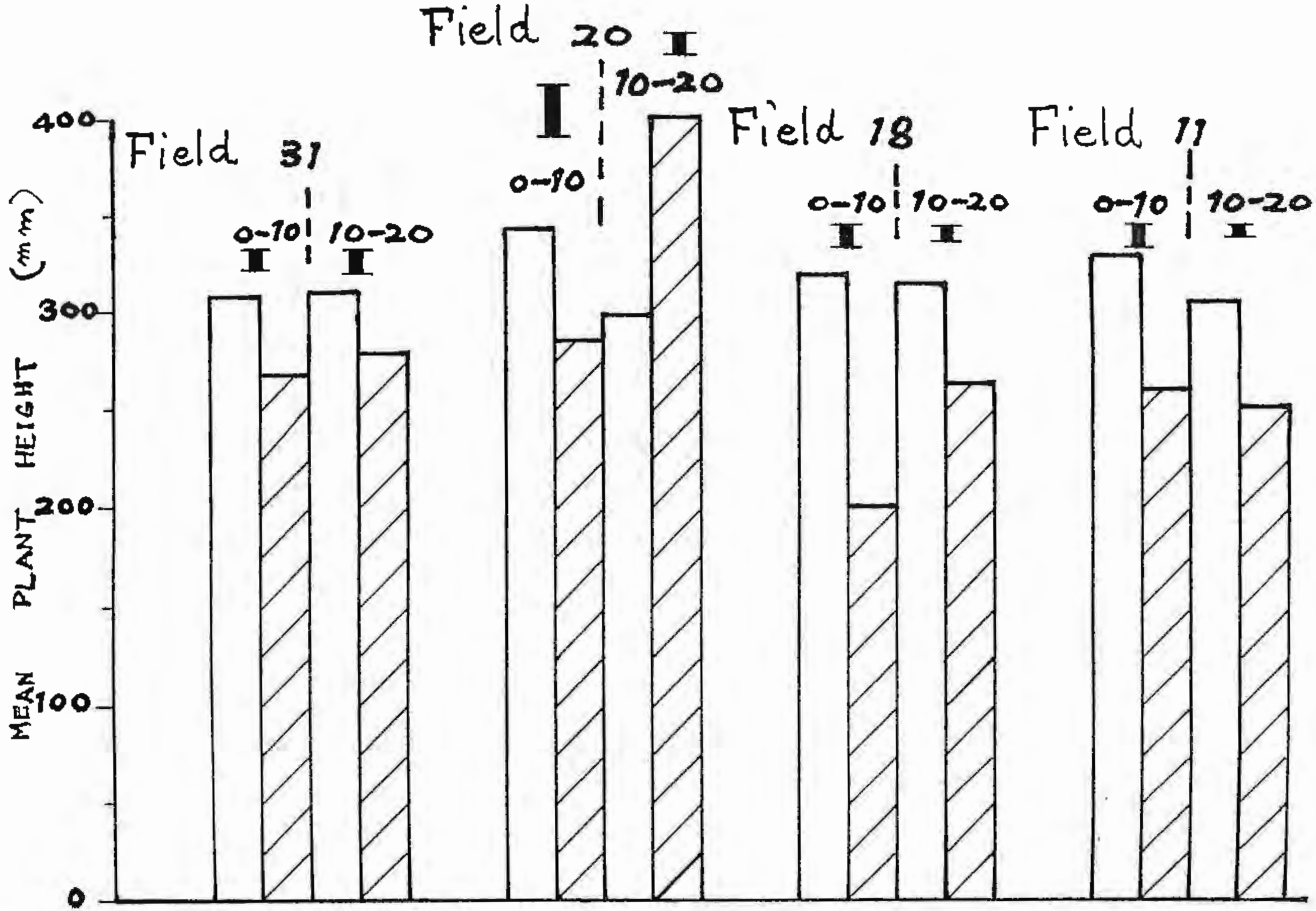
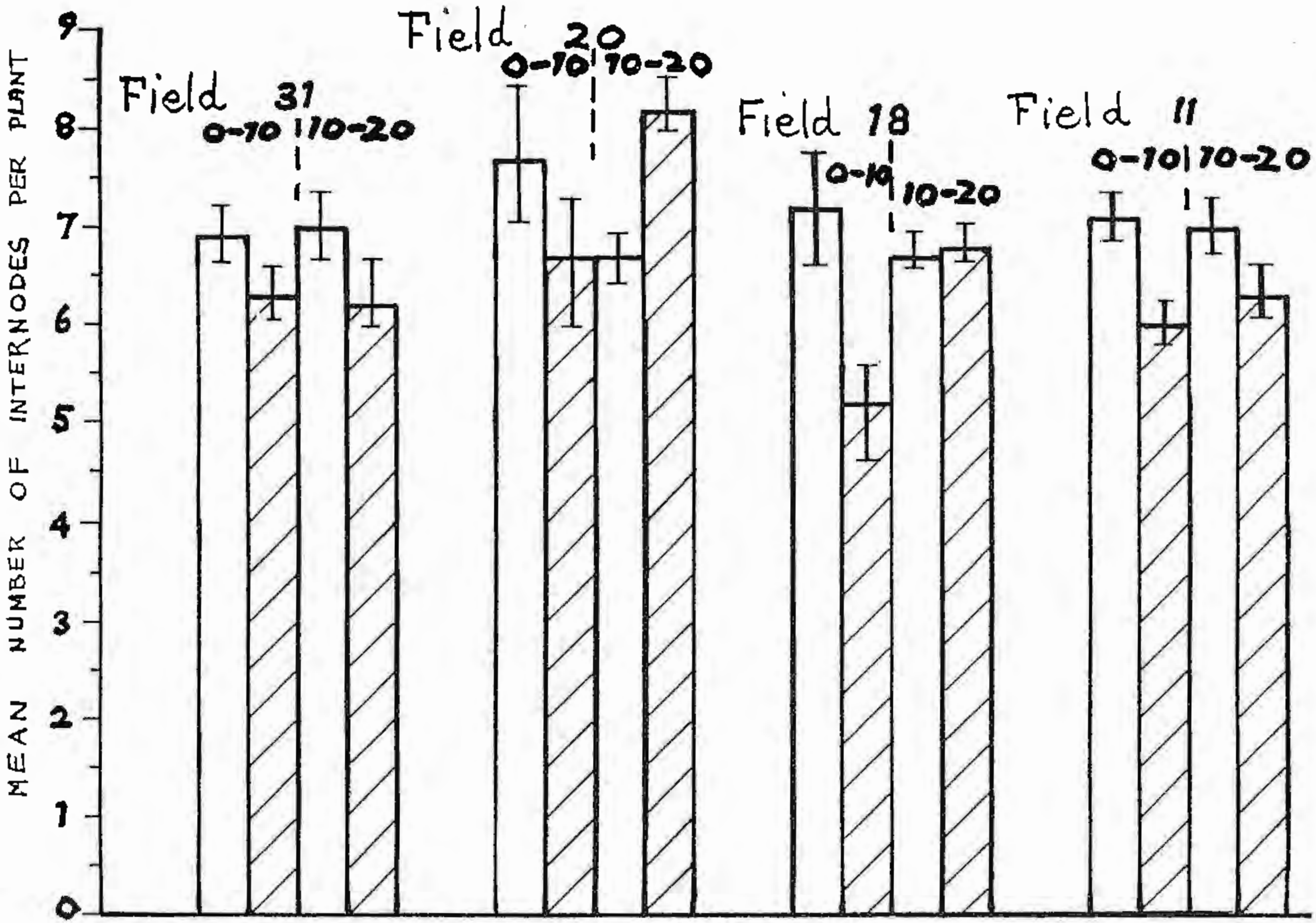


Figure 3f. Number of internodes per plant, harvest 2, in the water-logging experiment. Soil samples were taken from Galathera-prone fields (31 and 20) and non-prone fields (18 and 11) from a depth of either 0–10 or 10–20 cm, property of Auscott Pty. Ltd., Narrabri. Within each pair of columns the watering regimes ("60%" and "110%" saturation) are indicated by non-hatching and hatching respectively. Data are means of six replicates and the length of the bars through the tops of the columns represents ± one standard deviation.



First, consider the supply of Zn. Plants grown in the soils from field 20 had the highest concentrations of Zn (and Cu) in their foliage (table 5) because these soils were inadvertently drawn from the site of a former rates of zinc and copper trial (G. Constable, pers. comm., 1991). Plants on the other soils were Zn deficient under ponded conditions and had marginal Zn levels at 60% moisture (table 5). This presumably also accounts for the superior growth on soils from field 20 in the bioassay (fig. 2) where the soils were always unsaturated. The zinc deficiency proposal is credible, even in the absence of foliar symptoms, because zinc uptake by cotton on the grey cracking clays is poor (Paull and Milham, 1969 and Constable, 1990) and strongly dependent on the mycorrhizal association. In this experiment mycorrhizal infection and consequently zinc uptake were probably suppressed because, in a similar experiment, the roots had low mycorrhizal counts (table 6).

Secondly, consider the effects of ponding on the supplies of N, P and water:

- No soils other than those from field 20 supplied adequate quantities of N (table 5);

- Aside from the soils from field 20, all the surface soils and one of the subsoils supplied inadequate quantities of P (table 5); and,

- To sustain maximal rates of plant growth when the transpiration demand is high requires higher soil moisture levels in pots than in the field (J. Toth, pers. comm., 1992).

Since the plants approximately doubled their dry weight between the harvests (fig. 3), it is reasonable to assume that the transpirational demand would have increased similarly. It is therefore feasible that during the period between the harvests, the 60% moisture treatment became growth–limiting, at least for the 10–20 cm soil from field 20. For this soil alone, the positive effects of increased moisture availability from ponding are not restricted by the negative effects of anoxia: the absence of substantial denitrification in the soil from field 20, 10–20 cm and the lack of foliar symptoms of water–logging (plate 2) are strong evidence that this soil was not anaerobic for an extended period. There are indications of a similar, but transient effect for the 10–20 cm layer from the other Galathera–prone site (field 31). This experiment thus extends the finding from the bioassay, that microbial activity is abnormal in the soil samples drawn from the Galathera–prone sites.

Conclusions

Microbial activity in the soils from the Galathera–prone sites is lower than in the soils from the non–prone sites. In the 10–20 cm layer from field 20, the most Galathera–prone of the sites sampled, microbial activity was so low that anaerobic conditions were not established, even by ponding. That is not to say that anaerobic conditions may not contribute to the occurrence of the syndrome in the field. For the other soils, ponding induced leaf symptoms which were not the same as those of the Galathera syndrome in the field.

The pot environment assessed the productivity of the soils drawn from the different sites, freed from the environmental constraints to growth that occur in the field. In pots the ranking from the most to the least productive is 20 > 18 ≥ 11 > 31 (plate 5 and appendix II B). In the field the ranking is 11 > 18 > 31 > 20 (Constable *et al.*, 1989). This marked difference in rankings indicates that the Galathera syndrome is caused by growth constraints that occur in the field, but not in the glasshouse environment. The underlying chemical and physical causes are being sought through a systematic examination of soil properties (part III).

PART III

FIELD AND LABORATORY EXAMINATION OF SOILS AND COTTON PLANTS

PART III. FIELD AND LABORATORY EXAMINATION OF SOILS AND COTTON PLANTS

A. Background

The field study of soils during November–December 1991 (Hawkins, 1992, attached) disclosed few morphological differences between Galathera and non–Galathera soils and so shed little light on the results of the bioassay. It therefore became apparent that a more detailed study of the soils and of the cotton growing in them was required, so the following pieces of work have been undertaken:

1. A limited soil survey on Auscott, Narrabri, during which 248 soil samples were collected for physical and chemical analysis. A report was prepared (Hawkins, 1992, attached).

2. A *SOILpak* assessment of 3 back–hoe pits (pits 1,3 and 4) and 2 shallower pits (2 and 5) during which 40 samples were collected for physical and chemical tests. A report was prepared (Hawkins, 1992, attached).

3. Measurements of soil water usage by the crop through the 1991–92 growing season using a neutron probe, at a number of access points, strategically placed around the fields. These data have not been assembled or analysed.

4. Observations on and sampling of plants from a number of Galathera and non-Galathera areas in January 1992 for nutrient measurements and again in March, 1992 for measurement of vegetative growth and lint yield. The data are nearly complete but have not been evaluated.

Much of the chemical and physical analysis of soils is done. Nevertheless, measurements of lime content, exchangeable bases, "available" zinc and copper, clay dispersion, unsaturated hydraulic conductivity, and particle size distribution are incomplete. Completion of these tasks including associated data processing, statistics interpretation, and reporting will entail at least 18 months full-time work by a scientist.

Differences among the soils have been or are being sought in pH, electrical conductivity (salt level) exchangeable cations, lime content, organic carbon (C), total nitrogen (N), C/N ratio, clay dispersion, clod shrinkage and particle size. Only some of these are completed and can be dealt with at present.

B. Results and inferences

pH

The pH* range of the soils is rather narrow and those of higher pH have a higher lime content (fig. 4). Thus soils of higher pH will tend to be less dispersive (fig. 6).

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* Methods of analysis used are those set out in Vimpany *et al.*, (1987).

Conductivity

A critical value* for salt–sensitive species in these soils would be about 0.5–0.55 dS m^{-1} (1:5 w/v, soil:water suspension). Only an occasional sample reaches that level, e.g., the surface soil and deep subsoil at site 23 (table 7). Moreover, cotton is moderately (Awad, 1984) to highly (USDA, 1954) salt tolerant, so growth is unlikely to be affected by salt.

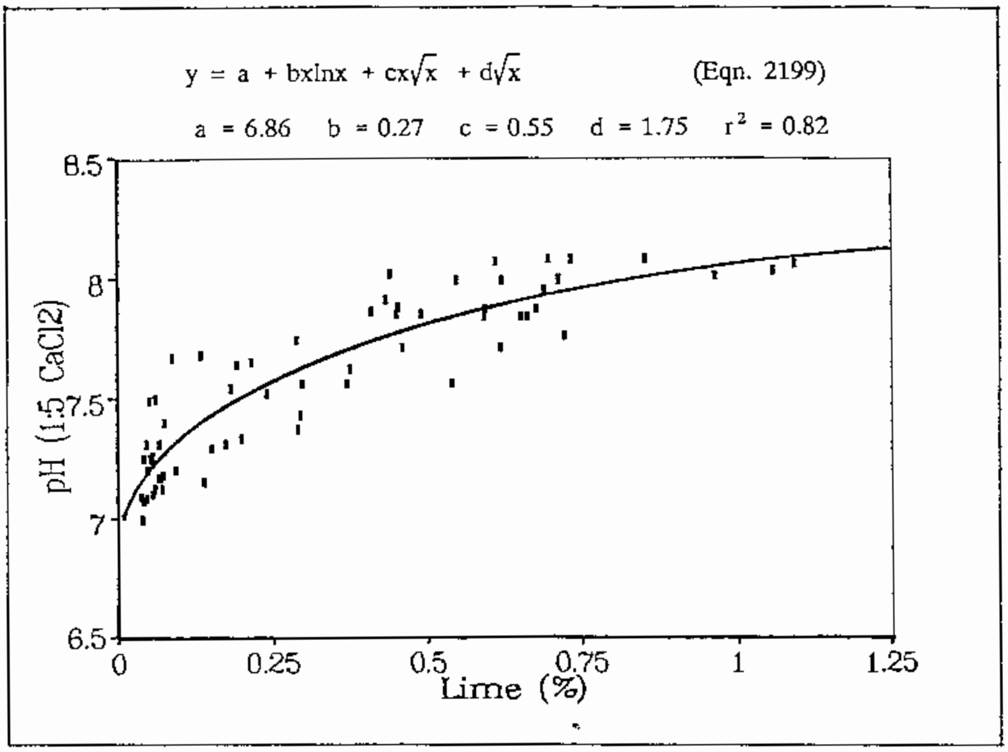

Figure 4. **Lime/pH plot for 74 soil samples from the back–hoe pits and some auger profiles, Auscott Pty. Ltd., Narrabri.**

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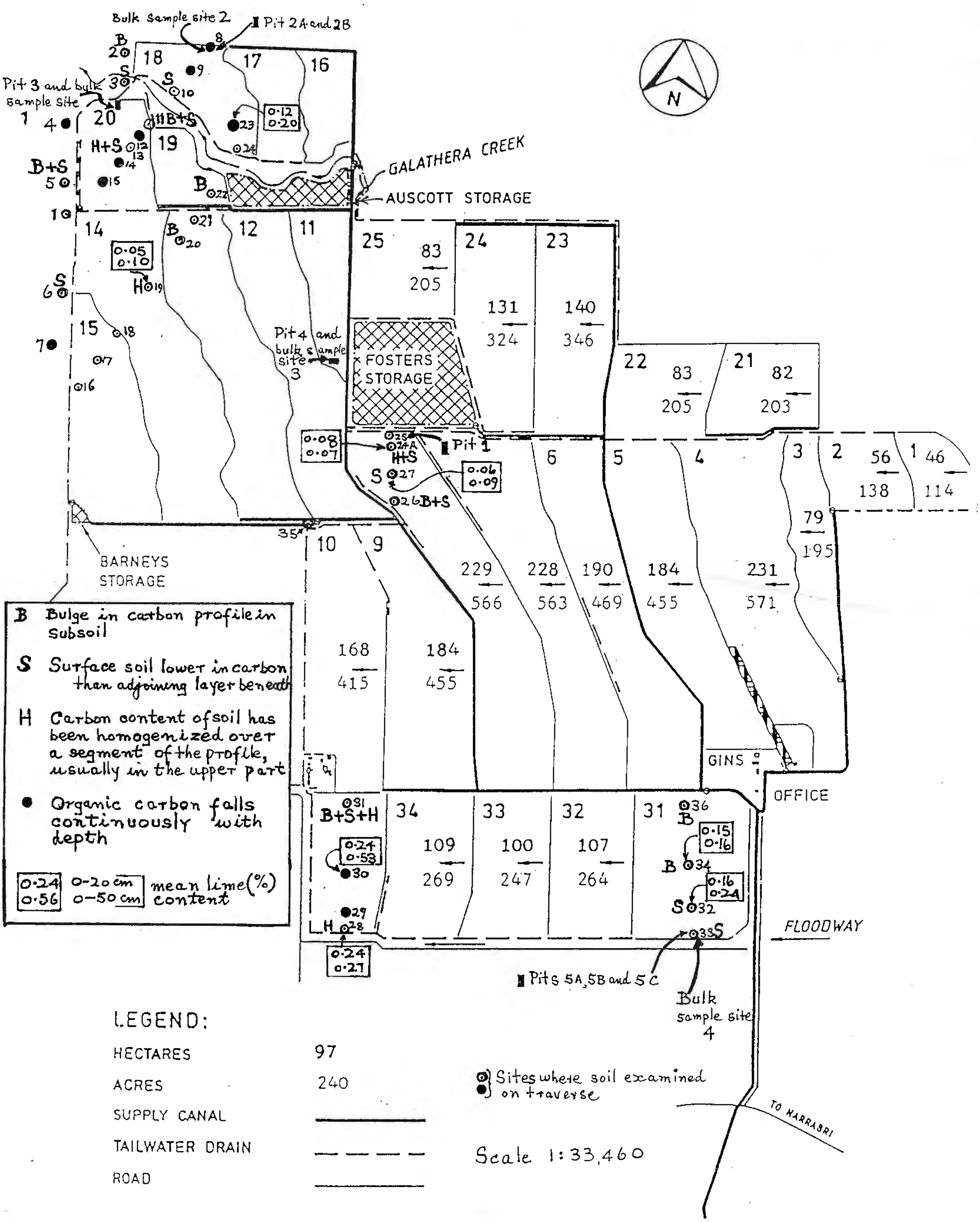
* Based on a range of moisture contents at saturation of 63% to 70%.

MAP 2. **Property of Auscott Pty. Ltd., Narrabri, showing locations of pits, bulk sampling sites, auger borings and some organic carbon and lime contents of soil.**



Soluble salts can assist in preventing soil dispersion, but the levels in these soils are generally quite low and probably have little influence (fig. 5). The dispersion procedure used to test the soils (Vimpany *et al.*, 1987) calls for so large a dilution of the sample in distilled water that it would weaken such relations as might exist in the field–moist state.

Clay dispersion

Along with clod shrinkage (which has been measured but not yet reported) this is an important property since it affects, among other things, aeration, the penetration and movement of water and the environment for the soil microflora.

Dispersion rises with increases in the exchangeable sodium percentage (ESP) (fig. 5). This effect of ESP is mitigated by lime* (fig. 6). The location of pits 1 to 5 plotted on fignre 6 (mean values, 0–50 cm, for ESP and lime only) allows an initial separation of Galathera pits (2 and 4) and non–Galathera pits (1 and 3). The *SOILpak* rating and, to a lesser extent, the rating by bulk density and air–filled porosity (Hawkins, 1992, attached) show that the soil in pit 5 is better than expected, given its location in a Galathera area, at the southern end of field 31 (map 2). If lime were to drop below 0.15%** in this area, a highly dispersive soil would resnlt. Such natural variation

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* The beneficial effect of lime additions to alkaline, sodic soils has been noted by D. McKenzie (pers. comm., 1992) in other experimental work.

** The value of 0.15% lime is to be compared with the value of 0.28% proposed by Yates and McGarity (1981), below which aggregate instability became increasingly common as lime content declined (fig. 6).

probably does occur, possibly over short distances. Figure 7 expresses the same results in more detail and allows a clearer differentiation among the pits. It places pits 1 to 4 in their correct order of productivity and of Galathera proneness. Again pit 5 is better than expected. The values for the two wheel–track samples and one from row 2, pit 3 are displaced to the right in the figure. This suggests that mechanical work can increase the dispersivity of a soil which is already somewhat prone to disperse.

Text continues following table 7 and fig. 6

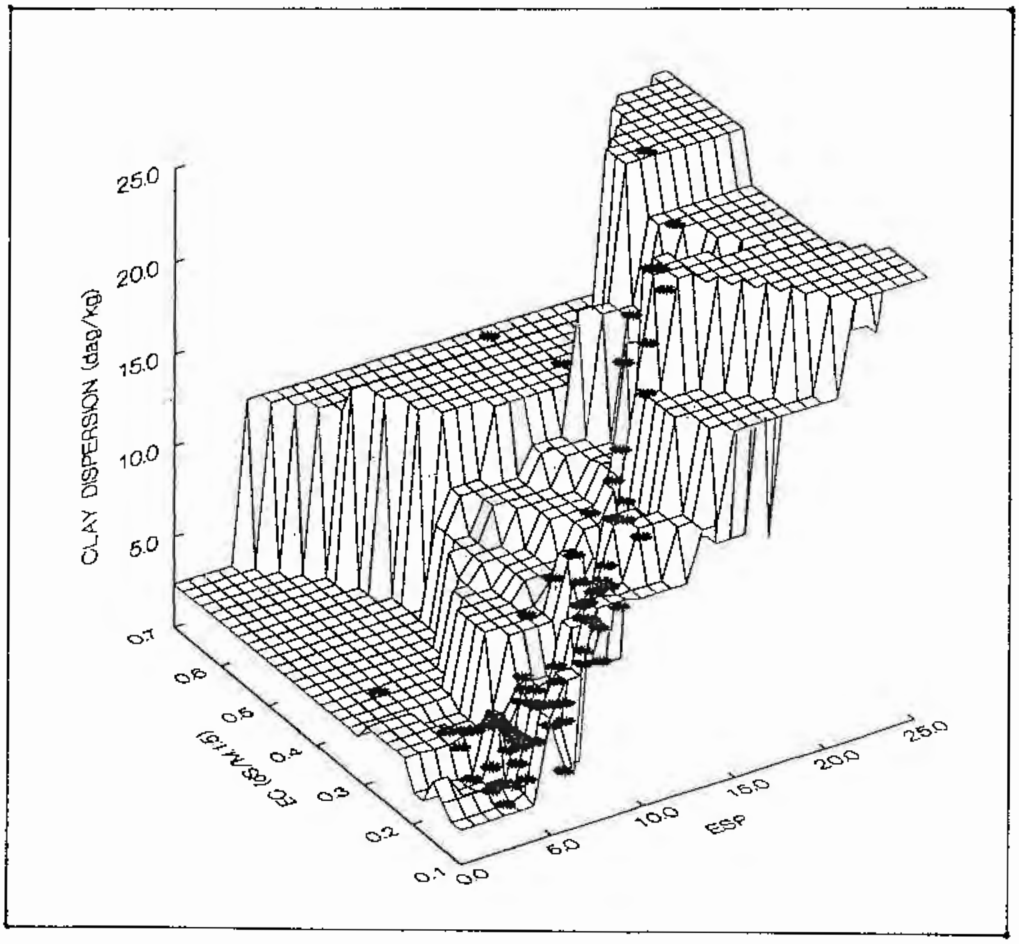


Figure 5. Clay dispersion plotted against exchangeable sodium percentage (ESP) and electrical conductivity (EC) for 73 Auscott soils: stepped figure.

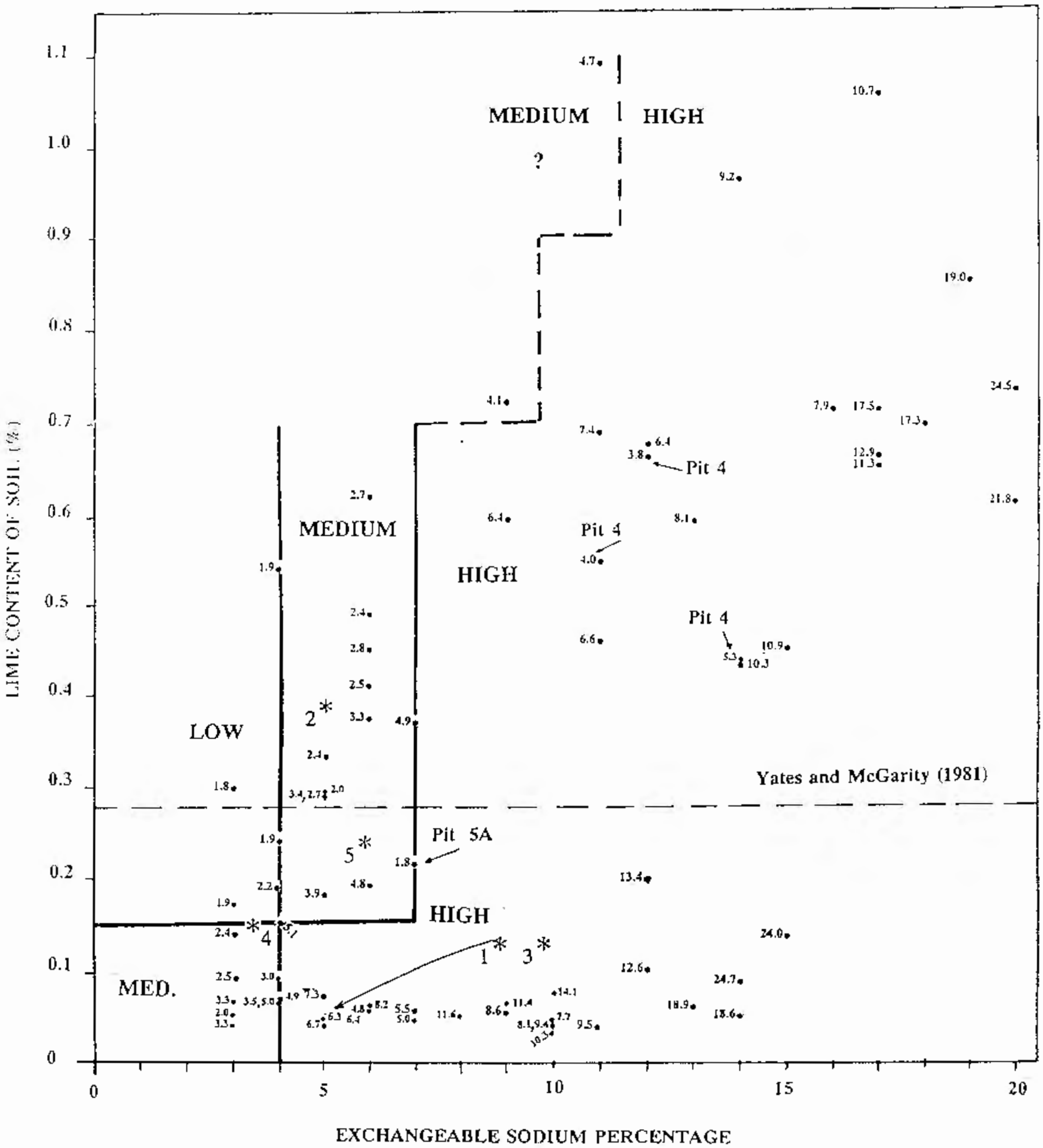
Table 7. **Analytical results for some soils from Auscott, Pty. Ltd., Narrabri to test relationships among clay dispersion, electrical conductivity (EC), or sum of alcohol soluble cations, exchangeable sodium percentage (E.S.P.) and lime content. In column two, (G) = Galathera site, (NG) = non-Galathera site, (G?) = possibly slight Galathera symptoms. Sampling positions in pits are: Row = beneath cotton row, W.T. = beneath wheel track, and Inter = beneath inter-row (see pit wall diagrams, Hawkins, 1992, attached).**

Sample No.	Pit (P) or site (S) No.	Row	Depth (cm)	Clay dispers. (dag kg^{-1})	E.C. in 1:5 $CaCl_2$ (dS m^{-1})	E.S.P. (%)	$CaCO_3$ (%)	Sum of cations sol. in alcohol (cmol(+) kg^{-1})
E92/1297	P1	W.T.	19–26	4.5	0.15	7	NA	0.43
E92/1298	(G)	"	65–78	13.4	0.22	12	0.20	0.73
E92/1299		R 1	0–10	NA	0.18	4	NA	0.27
E92/1300		"	14–20	5.0	0.15	4	0.065	NA
E92/1301		"	52–61	8.6	0.19	9	0.055	0.32
E92/1302		"	82–89	18.9	0.22	13	0.06	0.36
E92/1303		R2	20–27	6.7	0.15	5	0.04	0.31
E92/1304		"	82–89	18.6	0.30	14	0.05	0.67
E92/1305	P2 A	R 4	18–25	2.2	0.14	4	0.19	NA
E92/1306	(NG)	"	35–42	3.3	0.17	6	0.375	0.17
E92/1307	P2 B	R 5	18–25	1.9	0.16	4	0.54	0.19
E92/1308	(NG)	"	32–37	2.5	0.21	6	0.41	0.20
E92/1309		W.T.	20–27	2.8	0.20	6	0.45	0.24
E92/1310	P3	W.T.	18–25	6.3	0.14	5	0.045	0.29
E92/1311	(G)	"	66–73	9.4	0.23	10	0.04	0.41
E92/1312		R 3	14–21	3.3	0.15	3	0.04	NA
E92/1313		"	40–47	5.5	0.15	7	0.055	0.34
E92/1314		"	73–80	7.7	0.21	10	0.045	0.31
E92/1315		Inter.	31–38	4.8	0.14	6	0.055	0.37
E92/1316		"	74–81	8.1	0.23	10	0.04	0.42
E92/1317		R 2	23–30	7.3	0.16	5	0.072	0.27
E92/1318		"	54–61	5.0	0.17	7	0.046	0.21
E92/1319		"	96–103	9.5	0.28	11	0.038	0.44
E92/1320	P4	W.T.	16–23	2.0	0.15	3	0.053	NA
E92/1321	(NG)	R 2	20–27	1.9	0.12	3	0.173	NA
E92/1322		"	46–53	2.4	0.20	6	0.491	0.19
E92/1323		"	82–89	7.9	0.33	16	0.713	0.50
E92/1324		Inter.	23–30	2.7	0.19	5	0.289	0.27
E92/1325		"	68–75	3.8	0.26	12	0.662	0.42
E92/1326		1	20–27	2.5	0.14	3	0.095	NA
E92/1327		"	53–60	4.0	0.26	11	0.548	0.36
E92/1328		"	82–89	5.3	0.30	14	0.440	0.39

Sample No.	Pit (P) or site (S) No.	Row	Depth (cm)	Clay dispers. (dag kg^{-1})	E.C. in 1:5 $CaCl_2$ (dS m^{-1})	E.S.P. (%)	$CaCO_3$ (%)	Sum of cations sol. in alcohol (cmol(+) kg^{-1})
E92/1332	P5A (G)	1	45–52	1.8	0.15	7	0.216	0.35
E92/1333	P5B (G)	2	22–29	2.0	0.15	5	0.294	0.30
E92/1343	S22		75–80	10.3	0.19	10	0.036	0.49
E92/1345	(G)		125–130	12.6	0.28	12	0.102	0.72
E92/1346	S23		0–10	NA	0.53	4	0.100	1.79
E92/1347	(G)		10–20	2.4	0.38	3	0.140	1.23
E92/1348			25–30	3.0	0.24	4	0.093	0.70
E92/1349			35–40	3.4	0.22	5	0.290	0.55
E92/1350			45–50	4.9	0.21	7	0.370	0.46
E92/1351			55–60	6.6	0.23	11	0.460	0.50
E92/1352			65–70	8.1	0.29	13	0.593	0.39
E92/1353			75–80	10.9	0.35	15	0.453	0.62
E92/1354			100–105	12.9	0.53	17	0.663	1.34
E92/1335			125–130	11.3	0.68	17	0.653	1.91
E92/1357	S30		10–20	1.9	0.25	4	0.240	0.68
E92/1358	(G?)		25–30	2.7	0.22	6	0.620	0.50
E92/1359			45–50	4.1	0.24	9	0.723	0.50
E92/1360			55–60	6.4	0.29	12	0.677	0.48
E92/1361			65–70	10.3	0.29	14	0.433	0.53
E92/1362			75–80	17.5	0.36	17	0.713	0.65
E92/1363			85–90	19.0	0.40	19	0.852	1.12
E92/1364			105–110	24.5	0.48	20	0.733	1.18
E92/1365	S34		0–5	NA	0.14	5	0.110	NA
E92/1366	(G?)		16–28	3.9	0.17	5	0.183	0.35
E92/1367			40–45	4.8	0.20	6	0.193	0.45
E92/1368			50–55	6.4	0.30	9	0.595	0.62
E92/1369			60–65	7.4	0.32	11	0.690	0.66
E92/1370			70–75	9.2	0.36	14	0.963	0.71
E92/1371			80–85	10.7	0.41	17	1.057	0.90
E92/1372			90–95	17.3	0.43	18	0.697	0.88
E92/1373			115–120	21.8	0.42	20	0.612	0.73
E92/1374	S24 A		0–10	NA	0.22	4	0.093	0.65
E92/1375	(G)		10–20	3.5	0.22	4	0.065	0.64
E92/1376			20–30	4.9	0.17	4	0.071	0.48
E92/1377			35–40	6.4	0.13	5	0.049	NA

Sample No.	Pit (P) or site (S) No.	Row	Depth (cm)	Clay dispers. (dag kg^{-1})	E.C. in 1:5 $CaCl_2$ (dS m^{-1})	E.S.P. (%)	$CaCO_3$ (%)	Sum of cations sol. in alcohol (cmol(+) kg^{-1})
E92/1378			45–50	8.2	0.13	6	0.059	0.29
E92/1379			55–60	11.6	0.13	8	0.051	0.31
E92/1380			65–70	11.4	0.14	9	0.066	0.36
E92/1381			75–80	14.1	0.17	10	0.075	0.51
E92/1382			100–105	24.7	0.25	14	0.088	0.58
E92/1383			125–130	24.0	0.27	15	0.135	0.70
E92/1384	S27		0–10	NA	0.43	4	0.050	1.44
E92/1385	(G)		10–20	3.3	0.24	3	0.068	0.85
E92/1386			30–35	5.1	0.18	4	0.152	0.48
E92/1387	S28		0–10	NA	0.38	3	0.175	1.31
E92/1388	(G)		13–20	1.8	0.19	3	0.298	0.56
E92/1389			25–30	2.4	0.17	5	0.332	0.36
E92/1392			60–65	4.7	0.26	11	1.092	0.45

Figure 6: The relationship of three soil variables – exchangeable sodium percentage, lime content and percentage clay dispersion after Vimpany *et al.*, 1987 – for 74 soils from the property of Auscott Pty. Ltd., Narrabri. Clay dispersion figures are recorded beside each point. The limits for the low, medium and high dispersion categories (1987) are shown. The point for mean lime and exchangeable sodium percentages for the 0–50 cm depth interval in each back-hoe pit is plotted thus: * beside the number of the pit.



Lime determinations made so far (map 2 and table 7) indicate that soils near or in former streamlines or distributaries of Galathera Creek and, perhaps, Bobbiwaa Creek may be lower in lime than soils distant from these streamlines. That could, in part, account for the prevalence of the Galathera syndrome near former streams. However more data are needed to test this idea.

Coarse aggregates

At the conclusion of the water–logged pot trial the pots of soil (about 2 kg) were dried at 40°C and two replications of each treatment subjected to dry sieving after the mass of soil in each pot had been crushed with a known amount of work – see appendix II A for the method. In table 9 the results are reported as "coarse aggregates, % > 6.7 mm diameter". This test ranks the bulk sampling sites, which are beside the back–hoe pits (map 2) in order from best to worst thus: field 18 > 11 = 31 > 20, on the basis that the greater the proportion of coarse aggregates, the less favourable for plant growth the soil is likely to be. This test separates the non–Galathera sites from the Galathera sites except that pit 5 (site 31) again proved to be better than expected.

Organic carbon

Concentration in the profiles. For air–dry soil from 29 of the auger profiles and the back–hoe pits sampled, table 8 lists percent organic carbon, total nitrogen and C/N ratios. The location of these profiles is given on map 2. This is a modification of map 1 from the earlier field study of these soils (Hawkins, 1992, attached).

In an undisturbed soil profile it is usual for organic carbon, total nitrogen and C/N ratio all to be highest at the surface and to decrease with depth. Carbon usually decreases more rapidly in the upper profile and then relatively more slowly at depth. However, of the 29 profiles or part profiles examined on the traverses (map 2 and table 8*) organic carbon falls steadily with depth in 10 only. Of the other 19 sites, including some on the stock route, 12 show lower carbon in the immediate surface layer compared with the layer next below it: a depletion which suggests erosion, an effect of cropping, or burial of a former surface, e.g., by land levelling.

Mixing in the top 25 – 40 cm and occasionally of a deeper layer (site 13), appears also to have occurred at five sites (map 2). At eight sites, a bulge occurs in the carbon profile, mainly within the top 20–40 cm, suggesting the burial of a former surface during land levelling on the cropped land and some major profile disturbance at sites 5 and 2 on the stock route.

These deviations from the usual are marked on map 2. They indicate considerable disturbance of the virgin soil. Such a disturbance is to be expected, given the agricultural history of this land. Surprisingly the profiles on the stock route also appear to have been disturbed: sufficiently, so far as organic matter is concerned, as to limit their use in establishing the likely level

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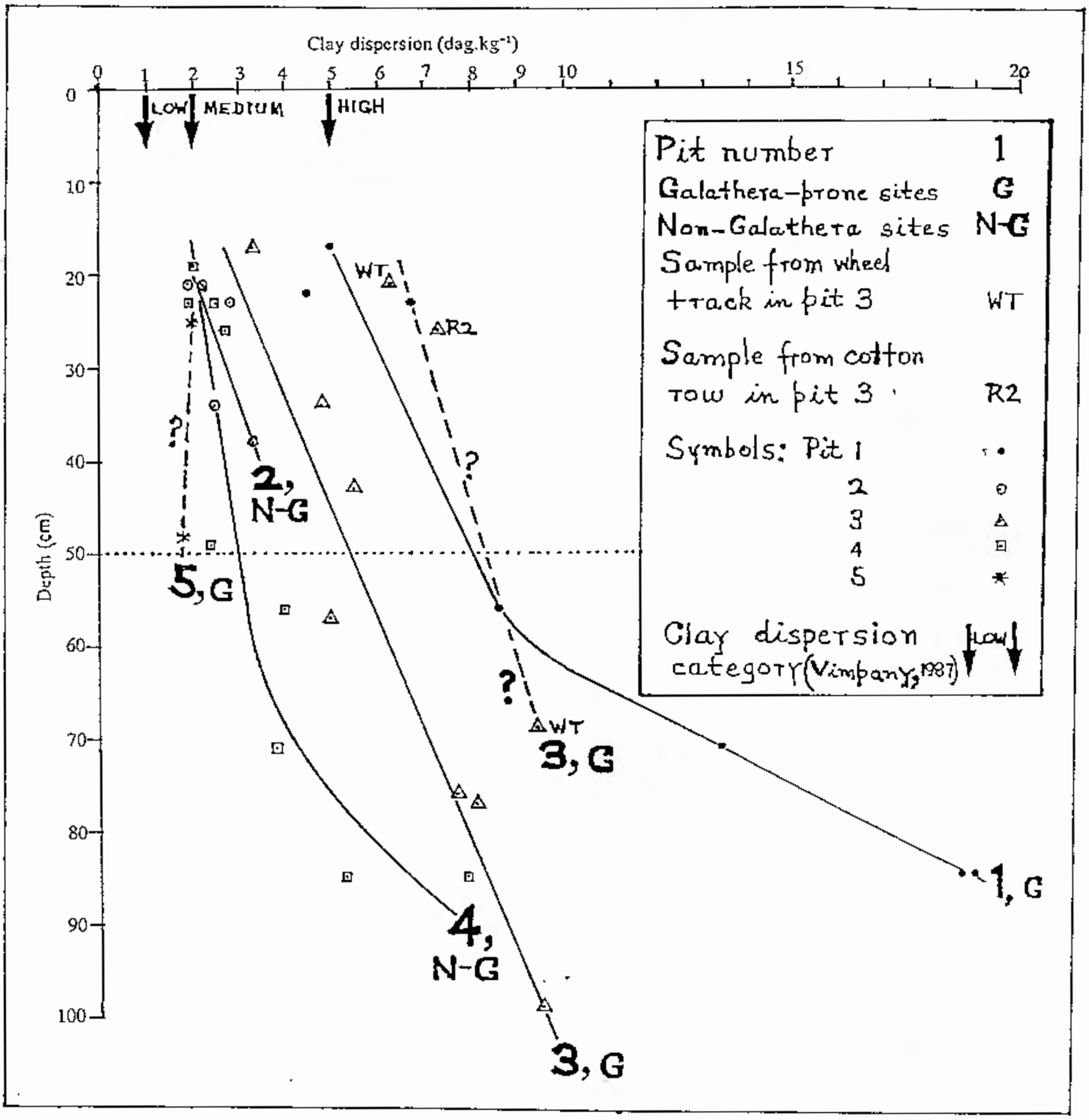
* This includes six profiles on the stock route which were to be used as undisturbed sites for comparison. Three of these (numbers 3,5 and 6) appear to have been depleted of carbon in the 0–10 cm layer and one has a discontinuity at about 30 cm depth (number 2).

Figure 7. Clay disperson for soil samples from the walls of back-hoe pits.



and distribution of organic matter that obtained before the area was cropped. However, if snch a comparison is made, (omitting site 4 as being unusually high) the cropped land appears to have

lost 15 – 20% of its organic carbon in the top 50 cm. This embraces the soil zone of most interest in this report.
The mean value for surface soils is 0.6% and for soil at 50 cm depth, 0.46%.

Little *et al.,* (1992) found a mean level of 0.64% carbon in the top 10 cm of agricultural land on a 2 km–long transect at "Llano", which lies between Galathera Creek and Ten Mile Creek about 8 km due north of Auscott. By contrast, Chan *et al.*, (1988) found a carbon level of 1.2% for pasture land on a grey clay at Walgett, which was reduced to 0.7% after 8–9 years of cropping in an adjoining paddock. McGarry *et al.,* (1988) list organic carbon values for 210 profiles on the Edgeroi map sheet (1:50,000) surrounding Auscott. From a perusal of their data it seems likely that the virgin surface at Auscott would have contained at least 1% carbon (w/w). If so, the organic carbon content has been almost halved.

Spatial distribution. Trends which would have existed across the landscape and down the profile in the virgin soils have been confounded by soil mixing and altered by agricultural practices. The distribution of values in the surface samples from the auger holes indicate that the greyer soils uearer former stream channels may have higher carbon contents. The possible exceptions are sites 32 and 33 in the south of field 31 (map 2).

A ranking of the back–hoe pits in order of decreasing carbon in the top 50 cm of their profiles is 4 > 5 > 3 = 1 > 2. This bears little relationship to their ranking for severity of the Galathera syndrome. This is not unexpected in the light of other findings.

For instance, Little *et al.*, (1992) in their "Llano" transect, on grey cracking clays, observed a higher carbon content in the soils of poorer structure because the poorer soils were in lower positions in the landscape, where they received more run–on.

Yates and McGarity (1981) determined the factors affecting instability of 108 surface soils along the Gwydir River. They found that organic carbon was negatively correlated with aggregate instability in these grey cracking clays, but that it ranked 7th in importance out of the 8 soil properties measured. They concluded that organic carbon assumed more importance as a stabiliser in their light clay group of soils than in the medium or heavy clays. This may reflect the greater range of carbon content in the former group. Thus in these groups of soils, the coefficients relating organic carbon to stability had either negative values (Little *et al.*, 1992) or small, positive values (Yates and McGarity, loc. cit.): carbon levels seemed to be more a consequence of other soil properties than a determinant of them. Nevertheless, it seems unlikely that, once present in the grey clays, organic matter would be unimportant in the maintenance of their stability, even though these soils swell and shrink. Like the Auscott soils, the organic matter levels in both these cases have been lowered below those expected in virgin soils. The effectiveness of the remaining organic matter in maintaining stability may be less than that of the initial organic matter.

Carbon/nitrogen ratio

A substantial error in the estimation of the C/N ratio can be expected, since it combines the error of both carbon and nitrogen measurements; nevertheless, the persistent values of 8.0 or less (table 8) suggest that C/N is low. This is a curious feature and needs further investigation.

Table 8. **Organic carbon, total nitrogen (N) and carbon/nitrogen (C/N) ratios for soils from the property of Auscott Pty. Ltd., Narrabri. Location of sampling sites is shown on map 2. Sampling positions in pits are: Row = beneath cotton row, W.T. = beneath wheel track, Inter. = beneath inter-row (see pit wall diagrams, Hawkins, 1992, attached).**

Pit or Site No.	Sampling position at pit	Depth (cm)	Sample No.	Organic Carbon (%)	Tot. N (%)	C/N ratio
Pit 1	W.T.	19–26	E92/1297	0.74	0.066	11.2
	W.T.	65–78	E92/1298	0.59	0.087	6.8
	Row 1	0–10	E92/1299	0.47	0.075	6.3
		14–20	E92/1300	0.55	0.073	7.5
		52–61	E92/1301	0.51	0.059	8.6
		82–89	E92/1302	0.40	0.056	7.1
	Row 2	20–27	E92/1303	0.47	0.070	6.7
		82–89	E92/1304	0.41	0.050	8.2
Pit 2A	Row 4	18–25	E92/1305	0.51	0.064	8.0
		35–42	E92/1306	0.49	0.069	7.1
Pit 2B	Row 5	18–25	E92/1307	0.49	0.073	6.7
		32–37	E92/1308	0.54	0.071	7.6
	W.T.	20–27	E92/1309	0.47	0.064	7.3
Pit 3	W.T.	18–25	E92/1310	0.49	0.067	7.3
	W.T.	66–73	E92/1311	0.51	0.057	8.9
	Row 3	14–21	E92/1312	0.49	0.072	6.8
		40–47	E92/1313	0.61	0.062	9.8
		73–80	E92/1314	0.55	0.047	11.7
	Inter.	31–38	E92/1315	0.61	0.070	8.7
		74–81	E92/1316	0.57	0.058	9.8
	Row 2	23–30	E92/1317	0.59	0.065	9.1
		54–61	E92/1318	0.55	0.059	9.3
		96–103	E92/1319	0.61	0.044	13.9
Pit 4	W.T.	16–23	E92/1320	0.7	0.078	9.0
	Row 2	20–27	E92/1321	0.59	0.072	8.2
		46–53	E92/1322	0.55	0.048	11.5
		82–89	E92/1323	0.47	0.054	8.7
	Inter.	23–30	E92/1324	0.51	0.063	8.1

Pit or Site No.	Sampling position at pit	Depth (cm)	Sample No.	Organic Carbon (%)	Tot. N (%)	C/N ratio
Pit 4		68–75	E92/1325	0.43	0.057	7.5
	Row 1	20–27	E92/1326	0.75	0.079	9.5
		53–60	E92/1327	0.43	0.054	8.0
		82–89	E92/1328	0.39	0.048	8.1
	W.T.	15–22	E92/1329	0.57	0.083	6.9
	W.T.	126–133	E92/1330	0.55	0.030	18.3
Pit 5A	Row 1	22–29	E92/1331	0.60	0.071	8.5
		45–52	E92/1332	0.50	0.054	9.3
Pit 5B	Row 2	22–29	E92/1333	0.57	0.078	7.3
		38–45	E92/1334	0.51	0.062	8.2
Pit 5C	W.T.	20–27	E92/1335	0.70	0.071	9.9
Site No 2		0–10	E92/1498	0.87	0.095	9.2
		10–20	E92/1499	0.55	0.079	7.0
		20–30	E92/1500	0.45	0.074	6.1
		30–40	E92/1501	0.61	0.076	8.0
		50–60	E92/1502	0.55	0.066	8.3
		70–80	E92/1503	0.39	0.059	6.6
		100–110	E92/1504	0.39	0.048	8.1
Site No 3		0–10	E92/1514	0.68	0.084	8.1
		10–20	E92/1515	0.73	0.091	8.0
		20–30	E92/1516	0.62	0.083	7.5
		30–40	E92/1517	0.55	0.068	8.1
		50–60	E92/1518	0.54	0.074	7.3
		70–80	E92/1519	0.38	0.051	7.5
		100–110	E92/1520	0.43	0.058	7.4
Site No 4		0–10	E92/1426	1.40	0.123	11.4
		10–20	E92/1427	1.02	0.090	11.3
		20–30	E92/1428	0.58	0.073	7.9
		30–40	E92/1429	0.55	0.068	8.1
		50–60	E92/1430	0.50	0.069	7.2
		70–80	E92/1431	0.42	0.061	6.9
		100–110	E92/1432	0.39	0.049	8.0
Site No 5		0–10	E92/1433	0.63	0.083	7.8
		10–20	E92/1434	0.69	0.082	8.4

Pit or Site No.		Depth (cm)	Sample No.	Organic Cabon (%)	Tot. N (%)	C/N ratio
Site No 5		20–30	E92/1435	0.71	0.093	7.6
		30–40	E92/1436	0.69	0.085	8.1
		50–60	E92/1437	0.63	0.073	8.6
		70–80	E92/1438	0.55	0.052	10.6
		100–110	E92/1439	0.32	0.051	6.3
Site No 6		0–10	E92/1440	0.71	0.094	7.6
		10–20	E92/1441	0.74	0.088	8.4
		20–30	E92/1442	0.66	0.080	8.2
		30–40	E92/1443	0.58	0.075	7.7
		50–60	E92/1444	0.50	0.078	6.4
		70–80	E92/1445	0.48	0.063	7.6
		100–110	E92/1446	0.36	0.056	6.4
Site No 7		0–10	E92/1472	0.75	0.084	8.9
		10–20	E92/1473	0.61	0.079	7.7
		20–30	E92/1474	0.58	0.071	8.2
		30–40	E92/1475	0.55	0.067	8.2
		50–60	E92/1476	0.45	0.055	8.2
		70–80	E92/1477	0.40	0.056	7.1
		100–110	E92/1478	0.37	0.050	7.4
Site No 8		0–20	E92/1529	0.51	0.084	6.1
		30–35	E92/1530	0.48	0.086	5.6
		47–50	E92/1531	0.45	0.057	7.9
		55–60	E92/1532	0.40	0.059	6.8
		65–70	E92/1533	0.40	0.060	6.7
		75–80	E92/1534	0.32	0.055	5.8
		100–105	E92/1535	0.30	0.053	5.7
		125–130	E92/1536	0.22	0.044	5.0
Site No 9		0–20	E92/1537	0.50	0.118	4.2
		25–30	E92/1538	0.48	0.085	5.6
		35–40	E92/1539	0.40	0.070	5.7
		45–50	E92/1540	0.32	0.062	5.2
		55–60	E92/1541	0.34	0.061	5.6
		65–70	E92/1542	0.32	0.058	5.5
		75–80	E92/1543	0.36	0.060	6.0

Pit or Site No.		Depth (cm)	Sample No.	Organic Carbon (%)	Tot. N (%)	C/N ratio
Pit No 9		100–105	E92/1544	0.32	0.053	6.0
		120–125	E92/1545	0.24	0.040	6.0
Site No 10		0–17	E92/1505	0.54	0.100	5.4
		25–30	E92/1506	0.79	0.086	9.2
		35–40	E92/1507	0.47	0.067	7.0
		45–50	E92/1508	0.39	0.056	7.0
		55–60	E92/1509	0.39	0.045	8.7
		65–70	E92/1510	0.39	0.051	7.6
		75–80	E92/1511	0.35	0.044	8.0
		100–105	E92/1512	0.34	0.041	8.3
		125–130	E92/1513	0.34	0.045	7.6
Site No 11		0–15	E92/1546	0.69	0.098	7.0
		15–30	E92/1547	0.92	0.083	11.1
		25–30	E92/1548	0.88	0.084	10.5
		35–40	E92/1549	0.46	0.081	5.7
		45–50	E92/1550	0.48	0.066	7.3
		55–60	E92/1551	0.46	0.059	7.8
		65–70	E92/1552	0.40	0.064	6.2
		75–80	E92/1553	0.43	0.061	7.0
		100–105	E92/1554	0.46	0.055	8.4
		125–130	E92/1555	0.43	0.051	8.4
Site No 12		0–12	E92/1521	0.71	0.088	8.1
		15–40	E92/1522	0.50	0.080	6.2
		45–50	E92/1523	0.51	0.059	8.6
		55–60	E92/1524	0.43	0.055	7.8
		65–70	E92/1525	0.42	0.046	9.1
		75–80	E92/1526	0.38	0.043	8.8
		100–105	E92/1527	0.32	0.043	7.4
		125–130	E92/1528	0.36	0.052	6.9
Site No 13		0–12	E92/1556	0.63	0.101	6.2
		15–40	E92/1557	0.88	0.078	11.3
		45–50	E92/1558	0.50	0.065	7.7
		55–60	E92/1559	0.48	0.059	8.1
		65–70	E92/1560	0.50	0.059	8.5

Pit or Site No.		Depth (cm)	Sample No.	Organic Carbon (%)	Tot. N (%)	C/N ratio
Site No 13		75–80	E92/1561	0.58	0.053	10.9
		100–105	E92/1562	0.65	0.057	11.4
		125–130	E92/1563	0.51	0.054	9.4
Site No 14		0–13	E92/1564	0.86	0.101	8.5
		20–25	E92/1565	0.74	0.094	7.8
		25–30	E92/1566	0.75	0.085	8.8
		35–40	E92/1567	0.55	0.085	6.5
		45–50	E92/1568	0.50	0.074	6.8
		55–60	E92/1569	0.55	0.071	7.7
		65–70	E92/1570	0.50	0.063	7.9
		75–80	E92/1571	0.48	0.061	7.9
		100–105	E92/1572	0.42	0.057	7.4
		125–130	E92/1573	0.40	0.051	7.8
Site No 15		0–15	E92/1574	0.79	0.101	7.8
		25–30	E92/1575	0.63	0.084	7.5
		35–40	E92/1576	0.59	0.077	7.7
		45–50	E92/1577	0.58	0.075	7.7
		55–60	E92/1578	0.58	0.068	8.5
		65–70	E92/1579	NA	0.061	
		75–80	E92/1580	NA	0.050	
		100–105	E92/1581	NA	0.048	
		125–130	E92/1582	NA	0.047	
Site No 18		165–170	E92/1447	0.14	0.04	3.5
Site No 19		0–10	E92/1406	0.55	0.060	9.2
		10–20	E92/1407	0.55	0.078	7.1
		25–30	E92/1408	0.55	0.071	7.7
		35–40	E92/1409	0.50	0.083	6.0
		45–50	E92/1410	0.39	0.058	6.7
		55–60	E92/1411	0.36	0.058	6.2
		65–70	E92/1412	0.40	0.058	6.9
		75–80	E92/1413	0.35	0.045	7.8
		100–105	E92/1414	0.34	0.042	8.1
		125–130	E92/1415	0.32	0.028	11.4
Site No 20		0–10	E92/1448	0.92	0.092	10.0
		10–20	E92/1449	0.56	0.100	5.6

Pit or Site No.		Depth (cm)	Sample No.	Organic Carbon (%)	Tot. N (%)	C/N ratio
Site No 20		25–30	E92/1450	0.91	0.091	10.0
		35–40	E92/1451	0.48	0.075	6.4
		45–50	E92/1452	0.36	0.052	6.9
		55–60	E92/1453	0.40	0.056	7.1
		65–70	E92/1454	0.36	0.056	6.4
		75–80	E92/1455	0.36	0.050	7.2
		100–105	E92/1456	0.34	0.046	7.4
		125–130	E92/1457	0.34	0.045	7.6
Site No 22		0–10	E92/1337	0.68	0.080	8.5
		10–20	E92/1338	0.55	0.070	7.9
		25–30	E92/1339	0.79	0.066	12.0
		40–45	E92/1340	0.55	0.070	7.9
		55–60	E92/1341	0.51	0.055	9.3
		65–70	E92/1342	0.51	0.054	9.4
		75–80	E92/1343	0.47	0.050	9.4
		100–105	E92/1344	0.43	0.048	9.0
		125–130	E92/1345	0.39	0.043	9.1
Site No 23		0–10	E92/1346	0.57	0.091	6.3
		10–20	E92/1347	0.59	0.079	7.5
		25–30	E92/1348	0.55	0.068	8.1
		35–40	E92/1349	0.55	0.068	8.1
		45–50	E92/1350	0.45	0.059	7.6
		55–60	E92/1351	0.39	0.057	6.8
		65–70	E92/1352	0.39	0.045	8.7
		75–80	E92/1353	0.39	0.045	8.7
		100–105	E92/1354	0.35	0.042	8.3
		125–130	E92/1355	0.32	0.046	7.0
Site No 24A		0–10	E92/1374	0.51	0.073	7.0
		10–20	E92/1375	0.59	0.070	8.4
		20–30	E92/1376	0.58	0.068	8.5
		35–40	E92/1377	0.59	0.059	10.0
		45–50	E92/1378	0.51	0.057	8.9
		55–60	E92/1379	0.47	0.057	8.2
		65–70	E92/1380	0.47	0.057	8.2
		75–80	E92/1381	0.43	0.050	8.6

Pit or Site No.		Depth (cm)	Sample No.	Organic Carbon (%)	Tot. N (%)	C/N ratio
Site No 24A		100–105	E92/1382	0.47	0.044	10.7
		125–130	E92/1383	0.43	0.043	10.0
Site No 26		0–10	E92/1458	0.54	0.077	7.0
		12–20	E92/1459	0.62	0.077	8.1
		25–30	E92/1460	0.44	0.070	6.3
		43–46	E92/1461	0.55	0.070	7.9
		50–55	E92/1462	0.48	0.055	8.7
		60–65	E92/1463	0.50	0.058	8.6
		70–75	E92/1464	0.50	0.062	8.1
		85–90	E92/1465	0.44	0.052	8.5
		95–100	E92/1466	0.42	0.045	9.3
		125–130	E92/1467	0.39	0.042	9.3
Site No 27		0–10	E92/1384	0.63	0.09	7.0
		10–20	E92/1385	0.71	0.083	8.6
		30–35	E92/1386	0.48	0.076	6.3
Site No 28		0–10	E92/1387	0.59	0.101	5.8
		13–20	E92/1388	0.55	0.076	7.2
		25–30	E92/1389	0.58	0.073	7.9
		40–45	E92/1390	0.41	0.043	9.5
		50–55	E92/1391	0.40	0.053	7.5
		60–65	E92/1392	0.42	0.063	6.7
		70–75	E92/1393	0.42	0.057	7.4
		80–85	E92/1394	0.40	0.055	7.3
		100–105	E92/1395	0.40	0.058	6.9
		125–130	E92/1396	0.37	0.060	6.2
Site No 29		0–10	E92/1416	0.75	0.094	8.0
		14–20	E92/1417	0.66	0.091	7.3
		25–30	E92/1418	0.63	0.080	7.9
		40–45	E92/1419	0.55	0.069	8.0
		50–55	E92/1420	0.55	0.054	10.2
		60–65	E92/1421	0.51	0.050	10.2
		70–75	E92/1422	0.48	0.062	7.7
		80–85	E92/1423	0.48	0.052	9.2

Pit or Site No.		Depth (cm)	Sample No.	Organic Carbon (%)	Tot. N (%)	C/N ratio
Site No 29		100–105	E92/1424	0.43	0.049	8.8
		125–130	E92/1425	0.39	0.034	11.5
Site No 30		0–8	E92/1356	0.55	0.075	7.3
		10–20	E92/1357	0.51	0.079	6.5
		25–30	E92/1358	0.43	0.059	7.3
		45–50	E92/1359	0.47	0.062	7.6
		55–60	E92/1360	0.43	0.063	6.8
		65–70	E92/1361	0.43	0.054	8.0
		75–80	E92/1362	0.40	0.050	8.0
		85–90	E92/1363	0.40	0.053	7.5
		105–110	E92/1364	0.40	0.041	9.8
Site No 31		0–10	E92/1479	0.40	0.064	6.3
		20–25	E92/1480	0.48	0.071	6.8
		30–35	E92/1481	0.48	0.071	6.8
		45–50	E92/1482	0.48	0.069	7.0
		55–60	E92/1483	0.54	0.076	7.1
		65–70	E92/1484	0.50	0.067	7.5
		75–80	E92/1485	0.48	0.061	7.9
		90–95	E92/1486	0.71	0.058	12.2
		98–100	E92/1487	0.51	0.091	5.6
		107–110	E92/1488	0.40	0.060	6.7
Site No 32		0–10	E92/1397	0.47	0.070	6.7
		15–20	E92/1398	0.55	0.071	7.7
		30–35	E92/1399	0.55	0.062	8.9
		45–50	E92/1400	0.42	0.061	6.9
		55–60	E92/1401	0.42	0.055	7.6
		65–70	E92/1402	0.44	0.053	8.3
		75–80	E92/1403	0.40	0.043	9.3
		90–93?	E92/1404	0.40	0.035	11.4
		98–100	E92/1405	0.40	0.042	9.5
Site No 33		0–5	E92/1489	0.48	0.068	7.1
		15–20	E92/1490	0.54	0.074	7.3
		30–35	E92/1491	0.48	0.078	6.2
		50–55	E92/1492	0.42	0.061	6.9
		60–65	E92/1493	0.40	0.062	6.5

Pit or Site No.		Depth (cm)	Sample No.	Organic Carbon (%)	Tot. N (%)	C/N ratio
Site No 33		70–75	E92/1494	0.40	0.059	6.8
		80–85	E92/1495	0.37	0.050	7.4
		90–95	E92/1496	0.36	0.055	6.5
		115–120	E92/1497	0.32	0.042	7.6
Site No 34		0–5	E92/1365	0.51	0.072	7.1
		16–28	E92/1366	0.48	0.075	6.4
		40–45	E92/1367	0.58	0.059	9.8
		60–65	E92/1369	0.59	0.063	9.4
		50–55	E92/1368	0.48	0.062	7.7
		70–75	E92/1370	0.55	0.050	11.0
		80–85	E92/1371	0.50	0.048	10.4
		90–95	E92/1372	0.39	0.047	8.3
		115–120	E92/1373	0.43	0.048	9.0
Site No 36		0–10	E92/1468	0.59	0.076	7.8
		15–20	E92/1469	0.63	0.079	8.0
		35–40	E92/1470	0.75	0.082	9.1
		45–50	E92/1471	0.44	0.065	6.8

GENERAL CONCLUSIONS

1. Field 20 had sufficient phytotoxin(s) present in its surface layer (0–10 cm) to depress cotton growth in the pots, but there was no evidence of phytotoxin(s) in soil from the other Galathera–prone site tested. However, cotton growth in the 0–10 cm layer from fields 11 and 18 was slightly inhibited and phytotoxin(s) were certainly present in the 10–20 cm layer. These are non–Galathera sites; therefore we conclude that although phytotoxins may be inhibiting cotton growth, this is a general phenomenon rather than a specific cause of the Galathera syndrome.

2. The Galathera syndrome is a function of the field environment interacting with as yet unidentified chemical/physical properties of the soil to affect plant root growth directly or indirectly through soil micro–organisms. This premise is supported by the persistent failure to produce the syndrome in the glasshouse using disturbed soils in pots and by evidence of microbial abnormality in the soils.

3. Anaerobic conditions in the glasshouse, in the virtual absence of mycorrhiza, reduced the uptake of a suite of plant nutrients. A similar nutritional pattern occurs in plants suffering from the Galathera syndrome in the field. This is consistent with the inference, made from the field survey data, that poor aeration of a transient nature may contribute to the syndrome.

4. Leaf symptoms produced by water–logging in the glasshouse are not identical to those exhibited by Galathera–affected plants in the field, nor is the reduction in individual plant nutrients uecessarily of the same degree, suggesting that causes other than poor aeration contribute.

5. The data so far assembled on differences between Galathera and non–Galathera soils have been summarised in table 9. It is concluded that Galathera soils have lower air–filled porosities (generally below the critical level) and generally lower *SOILpak* ratings than non–Galathera soils when at or near field capacity. They also tend to disperse more, form more coarse aggregates when wetted and dried and have lower lime contents and/or higher percentages of exchangeable sodium. They may have higher organic matter levels but, so far as soil biological activity is concerned, much depends on the state of this organic matter. The generally narrow C/N ratios in the soils may indicate an organic matter of a residual nature snpporting only low activity. An interesting feature of the most Galathera–prone site (field 20) is that the samples taken from the wheel tracks generally disperse more than those taken from adjoining cotton rows (table 9 and fig. 7). This suggests that mechanical work on a soil can change its fundamental physical properties, should it be one which lies towards the lower end of the stable range.

Table 9. **A summary of soil conditions associated with Galathera-prone and non-Galathera soils.**

Field	Pit No. or bulk sample site (BS) (map 2)	Depth (cm)	Clay dispersion (%) (from table 7)	*SOILpak** dispersion score	Mean air-filled porosity (%)	Coarse aggregates (%> 6.7mm diam.) (appendix III)	*SOILpak** structure rating (F or L value)†	E.S.P.	Lime (%)
GALATHERA-PRONE						SITES			
8	Pit 1	Above 27	5.8 (WT 4.5)		3.5 (WT -1?)		F, 0.4-1.0	4 7	0.05
20	Pit 3 BS 1	above 38 0-10 10-20	5.2 (WT 6.3)	1	5 (WT 0)	57 66	F, 0.5-1.6	5 (WT 5)	0.05
31	Pits 5A, 5B, 5C BS 4	above 52 0-10 10-20	1.9	1-2 (WT 2)	7 (WT 2)	43 54	F, 1.4-2.0 (WT F, 0.3)	6	0.25
NON-GALATHERA						SITES			
18	Pits 2A, 2B BS 2	above 50 0-10 10-20	2.5 (WT 2.8)	0 (WT 0)	10 (WT 2)	31 41	F, 1.0-1.8 (WT F, 0.3)	5 (WT 6)	0.38 (WT 0.45)
11	Pit 4 BS 3	above 30 0-10 10-20	2.4 (WT 2.0)	0-2 (WT 1)	9 (WT 3)	43 47	F, 0.5-1.5 (WT F, 0.4)	4 (WT 3)	0.19 (WT 0.05)

* Daniells, I. and Larsen, D. (Eds.) (1991). *SOILpak* β, a soil management package for cotton production on cracking clays, second edition

† Values that differ by less than 0.5 units are probably not different. WT = wheel track.

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Figure 2e Mean leaf area per plant for cotton in the bioassay. Soils (0–10 cm) were from Galathera–prone fields (20 and 31) and non–Galathera fields (18 and 11) property of Auscott Pty. Ltd., Narrabri. Moisture regimes are indicated by the numbers 35 and 45 above pairs of columns. Within each pair, hatching indicates that activated carbon was mixed through the soil before sowing. The length of the bar below each field number represents the size of the standard error. **Page 14.**

Figure 2f Mean leaf area per plant for cotton in the bioassay. Soils (10–20 cm) were from Galathera–prone fields (20 and 31) and non–Galathera fields (18 and 11) property of Auscott Pty. Ltd., Narrabri. Moisture regimes are indicated by the numbers 35 and 45 above pairs of columns. Within each pair, hatching indicates that activated carbon was mixed through the soil before sowing. The length of the bar below each field number represents the size of the standard error. **Page 15.**

Figure 3a Dry weight of plant tops at harvest 1 in the water–logging experiment. Soil samples were taken from Galathera–prone fields (31 and 20) and non–prone fields (18 and 11) from a depth of either 0–10 or 10–20 cm, property of Auscott Pty. Ltd., Narrabri. Within each pair of columns the watering regimes ("60%" and "110%" saturation) are indicated by non–hatching and hatching respectively. Data are means of six replicates and the length of the bar represents the standard error. **Page 29.**

Figure 3b Plant height at harvest 1 in the water–logging experiment. Soil samples were taken from Galathera–prone fields (31 and 20) and non–prone fields (18 and 11) from a depth of either 0–10 or 10–20 cm, property of Auscott Pty. Ltd., Narrabri. Within each pair of columns the watering regimes ("60%" and "110%" saturation) are indicated by non–hatching and hatching respectively. Data are means of six replicates and the length of the bar represents the standard error. **Page 30.**

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REFERENCES

Allen, S., Constable, G., Nehl, D. and McGee, P. (1992). *Mycorrhizas, early season cotton growth and the Galathera syndrome.* The Australian Cotton Grower, January–February, pp. 16–18.

Awad, A.S. (1984). *Farm water quality – 1. Effect of salinity on plants.* Ag. Note, Agdex 582, NSW Agriculture.

Butler, B.E. (1950). *A theory of prior streams as a causal factor of soil occurrence in the Riverine Plain of South–eastern Australia.* Aust. J. Soil Res., **1,** 231–252.

Chan, K.Y., Bellotti, W.D. and Roberts, W.P. (1988). *Changes in surface soil properties of vertisols under dryland cropping in a semi–arid environment.* Aust. J. Soil Res., **26,** 509–518.

Constable, G. (1990). *The Galathera syndrome.* Unpublished review of experimental results.

Constable, G., Brown, D., Anthony, D., Murray, D. and Williams, R. (1989). *Think tank on nutritional disorders of cotton on Galathera Creek.* Unpublished.

Cooper, A.J. (1973). *Root temperature and plant growth – a review.* Res. Rev. 4, Commonwealth Bureau of Horticultural and Plantation Crops, Commonwealth Agric. Bureaux p.73.

Daniells, I. and Larsen, D. (eds). (1991). Table C 3–1. *SOILpak β, a soil management package for cotton production on cracking clays.* NSW Agriculture, pp. C3–21 to 23.

Hodgson, A.S. and MacLeod, D.A. (1989). *Use of oxygen flux density to estimate critical air–filled porosity of a vertisol.* Soil Sci. Soc. Am. J., **53,** 355–361.

Hawkins, C.A. (1992). *A field examination of soil profiles showing Galathera syndrome and adjacent normal profiles on the property of Auscott Pty. Ltd., Narrabri.* Preliminary report on Cotton Research and Development Corporation, project DAN 61C.

Hulme, R. (1990). *Zinc adsorption characteristics of two grey clays from Galathera Creek in the Namoi Valley.* 4th year project, B. Rur., Sc., University of New England, Armidale, NSW.

Little, I.P., Ringrose–Voase, A.J. and Ward, W.T. (1992). *Surface structure in grey clays of North–western New South Wales in relation to micro–morphology, cation suite and particle size attributes.* Aust. J. Soil Res., **30,** 1–16.

McGarry, D., Ward, W.T. and McBratney, A.B. (1989). *Soil studies in the lower Namoi Valley : methods and data. The Edgeroi data set,* Vols. I and II. Division of Soils, C.S.I.R.O., Brisbane, Queensland.

Nehl, D.B. and Brown, J.F. (1992a). *Mycorrhiza in cotton* **in** *Genes to Jeans*. Proceedings of the Australian Cotton Conference, August 12–14.

Nehl, D.B. and Brown, J.F. (1992b). *A growth disorder of cotton associated with poor mycorrhizal development* **in** Brown, J.F. and Ponter, C.J. (eds) Third graduate seminar in plant pathology and mycology, Department of Botany, University of New England, Armidale, N.S.W.

Paull, R.E. and Milham, P.J. (1969). *Zinc deficiency in cotton.* Agric. Gaz. NSW, **80,** 50–51.

Reuter, D.J. and Robinson, J.B. (eds). (1986). *Plant analysis, an interpretation manual.* Inkata Press, Melbourne, Victoria, pp.48–50.

Toth, J., Milham, P.J., Hillier, G.R. and Kaldor, C.J. (1987). *Use of activated carbon to protect tomato against metribuzin.* Weed Research, **27**, 367–373.

Toth, J., Nurthen, E.J. and Chan, K.Y. (1988). *A simple wick method for watering potted plants which maintains a chosen moisture regime.* Aust. J. Exp. Agric., **28,** 805–808.

U.S. Salinity Laboratory Staff (1954). *Diagnosis and Improvement of Saline and Alkali Soils.* Agriculture Handbook No.60, U.S.D.A., p.67.

Vimpany, I.A., Holford, I.C.R., Milham, P.J. and Abbott, T.S. (1987). *Soil testing service–methods and interpretation.* NSW Agriculture, Biological and Chemical Research Institute, Rydalmere, New South Wales.

Yates, W.J. and McGarity, J.W. (1981). *Structural instability in grey clay surface soils* **in** *The properties and utilisation of cracking clay soils.* Proceedings of a symposium at the University of New England, Armidale, New South Wales.

APPENDICES

Appendix I. DETAILS OF THE BIOASSAY

PART A. Results

Table 10. Results of bioassay for phytotoxins in Galathera soils.

Field No.	Depth (cm)	Treatment: + or − carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
11	0–10	+C	35	1	95 95	72	1.34
			45	2	95 67	57.2 45.86	1.50
			35	3	110 76	50.27 30.41	1.42
			45	4	120 115	59.53 54.58	1.81
			35	5	116 96	43.82 36.56	1.30
			45	6	93 –	56.93 –	0.79 –
			35	7	100 115	38.45 36.07	1.33
			45	8	112 110	45.89 48.77	1.50
			35	9	120 100	38.80 46.51	1.43
			45	10	110 100	42.67 46.74	1.43
			35	11	90 96	41.06 39.74	1.41
			45	12	110 120	64.47 54.76	1.84
			35	13	100 102	37.48 41.69	1.46

Field No.	Depth (cm)	Treatment + or − carbon	Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
11	0–10	+C	45	14	116	42.99	1.40
					115	39.97	
			35	15	115	39.51	1.41
					86	37.97	
			45	16	100	43.33	1.62
					112	56.54	
11	0–10	−C	35	17	110	29.2	1.35
					110	33.5	
			45	18	96	44.84	1.62
					115	52.62	
			35	19	100	33.5	1.24
					102	30.86	
			45	20	116	51.13	1.73
					94	56.35	
			35	21	90	21.19	1.02
					94	35.29	
			45	22	116	53.29	1.52
					96	45.97	
			35	23	86	43.19	1.39
					80	30.24	
			45	24	110	40.63	1.46
					116	42.76	
			35	25	112	30.54	1.38
					120	42.39	
			45	26	112	42.75	1.62
					129	49.34	
			35	27	66	38.77	1.15
					80	38.64	
			45	28	86	35.66	1.23
					95	47.55	

Field No.	Depth (cm)	Treatment: + or – carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
11	0–10	–C	35	29	100 105	45.01 35.37	1.39
			45	30	115 115	54.92 52.87	1.67
			35	31	105 86	34.28 32.70	1.20
			45	32	118 135	36.36 35.63	1.41
11	10–20	+C	35	1	96 102	33.56 36.50	1.26
			45	2	100 104	36.69 37.80	1.31
			35	3	105 114	49.77 42.20	1.51
			45	4	115 105	59.78 35.41	1.50
			35	5	120 110	38.12 45.53	1.38
			45	6	105 110	40.37 41.43	1.53
			35	7	110 110	43.22 52.16	1.67
			45	8	70 –	27.86 –	0.47 –
			35	9	86 110	39.67 33.73	1.26
			45	10	100 90	38.35 40.51	1.43
			35	11	120 110	37.33 44.19	1.49

Field No.	Depth (cm)	Treatment: + or – carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
11	10–20	+C	45	12	120 90	48.34 36.34	1.58
			35	13	115 135	34.15 26.96	1.28
			45	14	85 80	36.53 36.30	1.20
			35	15	96 105	37.05 29.19	1.31
			45	16	112 105	45.18 22.83	1.39
11	10–20	–C	35	17	120 117	36.97 37.87	1.39
			45	18	45 105	15.21 41.57	0.85
			35	19	100 100	29.54 25.99	1.13
			45	20	105 95	33.10 29.94	1.15
			35	21	105 100	30.96 36.60	1.35
			45	22	115 110	47.55 49.27	1.61
			35	23	115 110	39.53 25.80	1.43
			45	24	110 115	39.53 25.80	1.56
			35	25	115 115	25.80 47.55	1.28
			45	26	96 122	49.05 44.66	1.40

Field No.	Depth (cm)	Treatment: + or − carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
11	10–20	−C	35	27	115 96	25.84 35.44	1.08
			45	28	105 110	30.80 41.40	1.22
			35	29	96 75	30.78 20.70	0.89
			45	30	100 96	38.99 37.00	1.38
			35	31	90 96	26.10 36.40	1.07
			45	32	106 91	38.32 34.07	1.31
18	0–10	+C	35	1	104 95	49.62 38.02	1.38
			45	2	120 120	30.49 42.23	1.35
			35	3	115 125	49.31 43.57	1.62
			45	4	120 120	54.61 48.40	1.47
			35	5	96 120	34.41 34.69	1.27
			45	6	125 125	58.87 48.85	1.88
			35	7	120 120	46.36 35.22	1.63
			45	8	100 110	51.97 48.28	1.66
			35	9	115 100	54.33 38.46	1.72

Field No.	Depth (cm)	Treatment		Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
		+ or − carbon	Percent saturation				
18	0–10	+C	45	10	125 115	58.09 44.91	1.83
			35	11	90 110	27.65 41.03	1.16
			45	12	120 140	48.38 60.05	2.05
			35	13	132 125	43.85 50.32	1.81
			45	14	110 96	50.13 57.71	1.86
			35	15	115 110	33.75 33.17	1.32
			45	16	115 110	46.71 47.65	1.77
18	0–10	−C	35	17	110 92	47.09 41.82	1.56
			45	18	105 126	36.23 52.11	1.40
			35	19	110 110	36.82 46.00	1.43
			45	20	110 110	40.98 35.98	1.38
			35	21	120 120	36.74 42.53	1.45
			45	22	126 120	60.51 53.34	1.95
			35	23	120 112	47.15 38.89	1.60
			45	24	130 112	53.14 45.35	1.87

Field No.	Depth (cm)	Treatment: + or – carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
18	0–10	–C	35	25	100 105	29.93 35.94	1.38
			45	26	110 110	43.01 41.33	1.56
			35	27	105 110	34.22 44.73	1.33
			45	28	120 120	56.67 53.27	1.80
			35	29	100 115	40.81 42.04	1.47
			45	30	100 120	53.82 48.00	1.58
			35	31	120 115	34.04 42.43	1.44
			45	32	115 90	49.30 38.01	1.49
18	10–20	+C	35	1	105 100	37.92 39.15	1.26
			45	2	110 100	51.00 56.70	1.70
			35	3	110 105	26.43 39.42	1.28
			45	4	110 110	53.68 48.56	1.81
			35	5	110 120	38.89 56.73	1.56
			45	6	130 124	72.39 63.50	2.12
			35	7	120 98	51.70 35.74	1.42

Field No.	Depth (cm)	Treatment: + or − carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
18	10–20	+C	45	8	110 100	52.15 36.15	1.30
			35	9	105 122	45.46 47.21	1.64
			45	10	100 82	36.49 31.13	1.07
			35	11	112 110	42.55 48.65	1.45
			45	12	120 112	59.74 56.59	1.80
			35	13	114 110	35.60 39.87	1.49
			45	14	120 110	56.09 39.95	1.55
			35	15	100 82	40.33 39.47	1.22
			45	16	115 115	54.19 43.35	1.70
18	10–20	−C	35	17	115 75	39.53 26.74	1.09
			45	18	120 120	55.15 45.49	1.72
			35	19	100 100	31.45 29.43	1.14
			45	20	80 80	40.57 41.57	1.22
			35	21	105 100	31.52 39.36	1.34
			45	22	90 106	30.50 42.47	1.10

Field No.	Depth (cm)	Treatment: + or – carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm²)	Dry wt. (g)
18	10–20	–C	35	23	100 106	28.67 42.27	1.44
			45	24	130 120	60.44 55.08	2.03
			35	25	115 95	30.46 37.59	1.29
			45	26	120 96	51.50 39.88	1.36
			35	27	108 120	44.65 37.37	1.53
			45	28	114 110	42.07 20.94	1.30
			35	29	110 100	42.97 39.12	1.40
			45	30	105 115	45.97 53.47	1.53
			35	31	100 110	30.05 35.79	1.32
			45	32	110 100	48.90 27.91	1.32
20	0–10	+C	35	1	130 150	62.97 72.89	2.51
			45	2	138 136	95.49 76.80	2.67
			35	3	118 120	68.65 59.16	2.29
			45	4	155 140	110.48 79.90	2.94
			35	5	132 149	66.19 68.77	2.29

Field No.	Depth (cm)	Treatment: + or − carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
20	0–10	+C	45	6	150	102.00	2.60
					147	49.39	
			35	7	130	63.77	2.41
					131	67.37	
			45	8	156	90.86	3.08
					155	95.47	
			35	9	126	73.23	2.42
					130	50.48	
			45	10	156	100.07	3.18
					170	101.91	
			35	11	138	86.06	2.81
					125	72.94	
			45	12	160	119.75	3.09
					154	85.33	
			35	13	138	87.60	2.62
					132	66.59	
			45	14	164	85.45	3.23
					152	106.12	
			35	15	126	70.12	2.34
					125	55.22	
			45	16	150	90.16	2.95
					140	84.12	
20	0–10	−C	35	17	115	61.87	2.03
					126	61.39	
			45	18	138	77.17	2.22
					130	54.75	
			35	19	115	49.31	2.19
					125	81.70	
			45	20	145	91.70	2.78
					130	87.23	

Field No.	Depth (cm)	Treatment		Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
		+ or − carbon	Percent saturation				
20	0–10	−C	35	21	126 128	66.61 76.32	2.49
			45	22	160 146	89.49 90.85	2.78
			35	23	124 124	71.03 51.23	2.43
			45	24	135 145	76.81 96.97	2.71
			35	25	130 114	60.28 61.02	2.09
			45	26	126 132	67.51 70.84	2.17
			35	27	140 140	57.49 59.59	2.17
			45	28	142 152	94.79 88.30	2.72
			35	29	134 125	70.19 62.18	2.45
			45	30	175 170	102.98 98.03	3.24
			35	31	130 128	71.21 65.30	2.35
			45	32	132 105	81.78 56.34	2.08
20	10–20	+C	35	1	110 115	66.10 54.90	1.83
			45	2	120 120	70.22 62.88	2.13
			35	3	– 102	109.15	1.72

Field No.	Depth (cm)	Treatment: + or – carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
20	10–20	+C	45	4	110 112	54.41 58.61	1.87
			35	5	112 110	60.32 33.83	1.79
			45	6	110 100	44.61 40.58	1.36
			35	7	110 113	44.59 84.57	2.24
			45	8	115 100	59.34 42.23	1.67
			35	9	115 112	38.50 41.36	1.47
			45	10	90 115	29.34 51.98	1.38
			35	11	110 100	50.01 38.68	1.45
			45	12	110 110	66.32 86.21	2.31
			35	13	118 92	52.36 25.96	1.13
			45	14	126 115	66.11 68.23	2.07
			35	15	110 100	44.90 41.54	1.60
			45	16	100 105	26.73 53.22	1.32
20	10–20	–C	35	17	115 120	48.87 41.99	1.67
			45	18	100 115	42.48 73.84	1.81

Field No.	Depth (cm)	Treatment: + or − carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
20	10–20	−C	35	19	135 120	57.34 61.60	2.01
			45	20	150 120	79.64 72.99	2.44
			35	21	145 120	67.16 60.55	2.34
			45	22	105 115	39.34 60.12	1.55
			35	23	135 120	45.15 53.30	2.04
			45	24	132 115	73.61 50.48	2.32
			35	25	120 135	53.03 66.94	2.29
			45	26	125 136	61.63 62.72	2.13
			35	27	125 135	55.59 67.68	2.44
			45	28	125 115	82.60 56.53	2.42
			35	29	115 130	63.69 40.39	1.85
			45	30	118 110	67.60 42.64	1.82
			35	31	100 120	37.95 63.21	1.79
			45	32	120 110	62.56 64.35	2.11
31	0–10	+C	35	1	95 90	25.19 27.39	1.07

Field No.	Depth (cm)	Treatment + or − carbon	Treatment Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
31	0–10	+C	45	2	94 105	23.33 29.88	1.14
			35	3	115 95	37.50 31.89	1.41
			45	4	105 115	52.07 45.79	1.70
			35	5	90 90	21.74 27.86	1.19
			45	6	95 105	27.90 33.31	1.21
			35	7	110 –	27.86 –	0.51 –
			45	8	110 110	24.86 34.82	1.22
			35	9	90 100	20.81 25.59	1.07
			45	10	90 110	31.20 34.56	1.30
			35	11	95 100	27.38 27.52	1.15
			45	12	90 100	33.59 37.03	1.28
			35	13	125 110	28.07 31.89	1.24
			45	14	115 115	33.34 33.93	1.33
			35	15	85 110	16.04 24.78	0.97
			45	16	110 110	32.24 35.33	1.34

Field No.	Depth (cm)	Treatment: + or − carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
31	0–10	−C	35	17	100 100	22.05 24.09	1.09
			45	18	106 120	37.68 40.83	1.59
			35	19	100 88	31.37 24.02	1.17
			45	20	110 120	38.05 23.17	1.43
			35	21	95 102	31.19 18.69	1.24
			45	22	95 100	36.60 48.95	1.55
			35	23	100 100	26.14 19.27	1.02
			45	24	105 100	28.96 29.43	1.27
			35	25	100 90	28.79 29.00	1.09
			45	26	106 –	39.00 –	0.77 –
			35	27	80 90	31.09 31.34	1.12
			45	28	100 106	29.35 35.26	1.31
			35	29	105 90	35.11 29.23	1.21
			45	30	120 100	34.57 21.60	1.20
			35	31	100 88	23.89 15.97	0.97

Field No.	Depth (cm)	Treatment + or − carbon	Treatment Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
31	0–10	−C	45	32	88 100	21.08 30.64	0.97
31	10–20	+C	35	1	100 90	40.49 31.99	1.36
			45	2	85 80	25.94 22.26	0.98
			35	3	85 82	25.22 24.93	1.07
			45	4	80 100	32.11 23.87	1.05
			35	5	82 100	27.28 36.96	1.18
			45	6	82 85	24.31 25.04	0.96
			35	7	110 106	31.83 37.27	1.30
			45	8	92 92	26.77 30.19	1.20
			35	9	90 96	23.09 24.99	1.05
			45	10	115 100	42.02 35.76	1.44
			35	11	100 85	34.68 40.33	1.25
			45	12	100 100	24.89 29.83	1.10
			35	13	110 100	33.12 27.56	1.16
			45	14	100 90	27.60 34.35	1.21

Field No.	Depth (cm)	Treatment: + or – carbon	Treatment: Percent saturation	Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
31	10–20	+C	35	15	90 110	28.95 27.87	1.24
			45	16	115 104	35.70 35.11	1.31
31	10–20	–C	35	17	105 100	30.38 34.57	1.26
			45	18	95 105	35.34 31.71	1.29
			35	19	105 80	32.50 26.33	1.05
			45	20	110 90	49.06 38.40	1.60
			35	21	90 90	30.90 27.15	1.22
			45	22	116 105	33.18 43.04	1.54
			35	23	105 106	20.47 21.30	0.94
			45	24	100 105	25.62 29.35	1.15
			35	25	100 100	29.12 32.22	1.15
			45	26	85 100	26.76 41.95	1.23
			35	27	95 100	27.15 21.47	0.95
			45	28	105 110	42.69 37.26	1.42
			35	29	100 90	21.15 23.57	0.92

Field No.	Depth (cm)	Treatment		Pot No.	Plant height (mm)	Leaf area (cm^2)	Dry wt. (g)
		+ or − carbon	Percent saturation				
31	10–20	−C	45	30	100 100	26.24 29.86	1.06
			35	31	100 105	22.14 29.58	1.05
			45	32	100 95	35.24 24.77	1.14

PART B. Statistical analyses

Experimental design and analysis

Four fields were sampled. At each site, soil samples were taken at 2 depths: 0–10 cm and 10–20 cm. The samples from each depth were bulked. Soil for the pot trials was drawn from the bulked samples. Statistical analyses were carried out for each site separately, using repeated measurements analysis of variance. Because the soil samples were bulked, there is no estimate of the variability at each site available.

Explanation of tables of results

The first section shows the results of the repeated measurements analysis for each field: the tests of the treatment effects averaged over depths; the effect of depth; and the interaction of treatment * depth. If an interaction term is significant, the effect of the treatment is different at each depth. [* = significant at 5% level; ** = significant at 1% level; *** = significant at .1% level; ns = not significant.]

The next section shows the result of the analysis of variance at each depth for each field; that is, the tests of significance of treatment effects at each depth of each field.

The final section gives the mean and standard error of the mean for each field.
Depth 1 = 0–10cm; depth 2 = 10–20cm.
MR 1 = ~35; MR 2 = ~45. Carbon 1 = no carbon; Carbon 2 = + carbon.

Table 11. Statistics for the bioassay

CARBON * MOISTURE REGIME DRY WEIGHT

Field	11	18	20	31
Carbon	*	ns	ns	ns
Moisture regime	**	**	**	**
Carbon * MR	ns	ns	ns	*
Depth	**	ns	***	ns
Depth * C	ns	ns	***	ns
Depth * MR	*	ns	*	ns
Depth * C * MR	ns	ns	ns	ns
Depth 1 C	ns	ns	**	ns
MR	***	*	***	***
C * MR	ns	ns	ns	ns
Depth 2 C	ns	ns	**	ns
MR	ns	ns	ns	ns
C * MR	ns	ns	ns	*

Table 11 (continued)

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
Carbon 1	1.3925	.0355	1.5431	.0524	2.4250	.0565	1.2356	.0339
Carbon 2	1.4863	.0355	1.6050	.0524	2.7144	.0565	1.2275	.0339
MR 2	1.5588	.0355	1.6750	.0524	2.7775	.0565	1.3362	.0339
1	1.3200	.0355	1.4731	.0524	2.3619	.0565	1.1269	.0339
C 1 MR 2	1.5325	.0501	1.6287	.0742	2.5875	.0800	1.3575	.0479
C 1 MR 1	1.2525	.0501	1.4575	.0742	2.2625	.0800	1.1138	.0479
C 2 MR 2	1.5850	.0501	1.7213	.0742	2.9675	.0800	1.3150	.0479
C 2 MR 1	1.3875	.0501	1.4887	.0742	2.4613	.0800	1.1400	.0479
Depth 2								
Carbon 1	1.2563	.0509	1.3831	.0669	2.0644	.0821	1.1856	.0425
Carbon 2	1.3775	.0509	1.5231	.0669	1.7088	.0821	1.1787	.0425
MR 2	1.3350	.0509	1.5394	.0669	1.9194	.0821	1.2300	.0425
1	1.2987	.0509	1.3669	.0669	1.8537	.0821	1.1344	.0425
C 1 MR 2	1.3100	.0720	1.4475	.0947	2.0750	.1161	1.3037	.0601
C 1 MR 1	1.2025	.0720	1.3188	.0947	2.0537	.1161	1.0675	.0601
C 2 MR 2	1.3600	.0720	1.6312	.0947	1.7637	.1161	1.1562	.0601
C 2 MR 1	1.3950	.0720	1.4150	.0947	1.6538	.1161	1.2012	.0601

Table 11 (continued)

CARBON * MOISTURE REGIME PLANT HEIGHT

Field	11	18	20	31
Carbon	ns	ns	ns	ns
Moisture regime	ns	ns	***	ns
Carbon * MR	ns	ns	ns	ns
Depth	ns	*	***	*
Depth * C	ns	ns	***	*
Depth * MR	*	ns	***	*
Depth * C * MR	ns	ns	ns	ns
Depth 1 C	ns	ns	*	ns
MR	*	ns	***	**
C * MR	ns	ns	ns	ns
Depth 2 C	ns	ns	***	ns
MR	ns	ns	ns	ns
C * MR	ns	ns	ns	ns

Table 11 (continued)

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
Carbon 1	103.125	2.6744	112.125	2.2776	133.969	2.2949	100.312	1.5134
Carbon 2	103.125	2.6744	114.469	2.2776	141.344	2.2949	102.781	1.5134
MR –45%	107.562	2.6744	115.469	2.2776	146.438	2.2949	105.031	1.5134
–35%	98.688	2.6744	111.125	2.2776	128.875	2.2949	98.062	1.5134
C 1 MR 2	109.625	3.7821	114.000	3.2210	141.438	3.2455	105.125	2.1403
C 1 MR 1	96.625	3.7821	110.250	3.2210	126.500	3.2455	95.500	2.1403
C 2 MR 2	105.500	3.7821	116.938	3.2210	151.438	3.2455	104.938	2.1403
C 2 MR 1	100.750	3.7821	112.000	3.2210	131.250	3.2455	100.625	2.1403
Depth 2								
Carbon 1	102.844	3.1287	105.469	2.5260	122.219	1.9724	99.750	1.8585
Carbon 2	102.969	3.1287	109.094	2.5260	109.031	1.9724	95.500	1.8585
MR –45%	99.594	3.1287	108.875	2.5260	114.969	1.9724	98.156	1.8585
–35%	106.219	3.1287	105.688	2.5260	116.281	1.9724	97.094	1.8585
C 1 MR 2	101.625	4.4246	107.250	3.5724	120.062	2.7894	101.312	2.6283
C 1 MR 1	104.062	4.4246	103.688	3.5724	124.375	2.7894	98.188	2.6283
C 2 MR 2	97.562	4.4246	110.500	3.5724	109.875	2.7894	95.000	2.6283
C 2 MR 1	108.375	4.4246	107.688	3.5724	108.188	2.7894	96.000	2.6283

Table 11 (continued)

CARBON * MOISTURE REGIME LEAF AREA

Field	11	18	20	31
Carbon	**	*	ns	ns
Moisture regime	***	***	***	**
Carbon * MR	ns	ns	ns	ns
Depth	***	ns	***	ns
Depth * C	ns	ns	**	ns
Depth * MR	**	ns	**	ns
Depth * C * MR	ns	ns	ns	ns
Depth 1 C	*	ns	*	ns
MR	***	**	***	**
C * MR	ns	ns	ns	ns
Depth 2 C	ns	*	ns	ns
MR	ns	**	ns	ns
C * MR	ns	ns	ns	*

Table 11 (continued)

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
Carbon 1	40.5419	1.3214	43.8197	1.4465	73.5081	2.0390	29.8534	1.2997
Carbon 2	45.2344	1.3214	45.3466	1.4465	80.1659	2.0390	30.3922	1.2997
MR 2	48.7447	1.3214	48.6994	1.4465	87.4637	2.0390	33.6641	1.2997
1	37.0316	1.3214	40.4669	1.4465	66.2103	2.0390	26.5816	1.2997
C 1 MR 2	46.4169	1.8687	47.5656	2.0457	82.8462	2.8836	33.3794	1.8381
C 1 MR 1	34.6669	1.8687	40.0737	2.0457	64.1700	2.8836	26.3275	1.8381
C 2 MR 2	51.0725	1.8687	49.8331	2.0457	92.0813	2.8836	33.9487	1.8381
C 2 MR 1	39.3962	1.8687	40.8600	2.0457	68.2506	2.8836	26.8356	1.8381
Depth 2								
Carbon 1	34.6291	1.4509	39.6525	1.9432	58.6637	2.4513	30.6397	1.3723
Carbon 2	38.5878	1.4509	46.1463	1.9432	52.1497	2.4513	30.3847	1.3723
MR 2	37.7419	1.4509	47.2959	1.9432	58.5881	2.4513	32.0694	1.3723
1	35.4750	1.4509	38.5028	1.9432	52.2253	2.4513	28.9550	1.3723
C 1 MR 2	37.2663	2.0519	43.8694	2.7481	62.0500	3.4667	34.4044	1.9407
C 1 MR 1	31.9919	2.0519	35.4356	2.7481	55.2775	3.4667	26.8750	1.9407
C 2 MR 2	38.2175	2.0519	50.7225	2.7481	55.1262	3.4667	29.7344	1.9407
C 2 MR 1	38.9581	2.0519	41.5700	2.7481	49.1731	3.4667	31.0350	1.9407

PART C. Soil Moisture

Table 12. Soil moisture contents in the bioassay (measured on day 16).

Field†	Depth (cm)	Moisture content (g/100g oven-dry soil)		Moisture saturation* (%)	
		Lower level	Higher level	Lower level (~35)	Higher level (~45)
11	0–10	29	34	41	49
	10–20	27	34	40	51
18	0–10	18	23	26	34
	10–20	31	38	46	57
20	0–10	27	32	39	46
	10–20	20	25	30	38
31	0–10	21	26	36	44
	10–20	18	24	31	41

* Calculated using saturated moisture levels from table 2 and expressed as g/100g of oven-dry soil.

† These are the numbers of the fields used by Auscott Pty. Ltd., Narrabri.

Appendix II. DETAIL OF THE WATER-LOGGING EXPERIMENT

PART A. Methods

Field and glasshouse procedures

The eight bulk samples used in the bioassay were used in this experiment. Twelve seeds of *Gossypium hirsutum* c.v. Sicala) were sown directly into pots containing 2 kg of air-dried soil. Pots were lined with a plastic bag to prevent drainage. Seven mL of a fertiliser solution, containing 44 g/L $(NH_4)_2$ HPO4, 78 g/L NH_4NO_3 and 54 g/L K_2SO_4, was applied to each pot.

One week after sowing each soil was watered to either "60%" or "100%" of saturation. The two moisture regimes were maintained by watering to weight daily. The total number of treatments in the trial was 16 (4 soils x 2 depths x 2 moisture levels). Each treatment was replicated six times and pots were randomised in blocks.

Early in the trial, it was apparent that plants at the higher moisture level were growing normally. This may have been because drying between waterings increased aeration sufficiently to overcome any effects of water-logging. Therefore, from day 17 after sowing, these pots were watered to "110%" of saturation (i.e., free water was standing on the surface) and this treatment was maintained until the end of the experiment.

Twenty one days after sowing the seedling population was reduced to five uniform plants per pot.

On day 39 after sowing, three plants were harvested from each pot. The leaf area, shoot length and dry weight of tops were determined. All leaves were bulked for chemical analysis.

A final harvest was conducted on day 62 after sowing. Shoot length, internode number and dry weight of tops were measured on the remaining two plants and they were scored for the severity of a chlorotic symptom on new leaves, which resembled manganese toxicity.

Laboratory Procedures

Methods of foliar analysis. Material was dried rapidly at 80°C, then ground to pass a 1 mm sieve. Nitrogen was determined using a Leco N–analyser. The remainder of the elements was determined using ICPOES after digestion of the material in HNO_3 in pressurised teflon vessels. The accuracy of these procedures has been verified using international reference materials of certified composition.

Method of determining "100%" moisture content of soils. 400 g of air–dry soil was placed in a small pot with holes in the bottom. The weights of the soil and the pot were recorded. The pot of soil was covered and placed in a dish of water overnight. The lower part of the pot was immersed while the top of the soil in the pot stood approximately 60 mm above the water level. Next day the pot of soil was removed from the water and allowed to drain on the bench for a few hours and then weighed. This procedure resulted in near saturation of these soils (table 2). Moisture was expressed as a percentage of the air–dry soil but in table 2 is calculated as a fraction of the weight of oven–dry soil.

Method of scoring plants for stunting, chlorosis and necrosis. Progressively more severe expressions of the disorder were recognised from stunting of the plant through to leaf "burn" as follows:

- plants are stunted,
- apart from the emerging leaf, all other leaves are pale green in colour,
- leaves mid–way down the shoot develop a strong interveinal chlorosis,
- small reddish–brown spots then develop at the vein endings,
- large areas of interveinal tissue may "burn".

Based on these stages the numerical scoring system below was used to rate the disorder.

No symptoms	0
Generalised paleness	1
Strong interveinal pattern	2
Spotting (mild to moderate)	3
Burn or severe spotting	4

Dry sieving of soil at completion of the pot trial after applying a known amount of work.*

- Spread one hand across the top of the dried mass of soil in the pot so as to support the soil as much as possible – spread fingers.

- Up–end the pot between both hands and draw the pot upwards away from the mass of soil slowly (while supporting the core with the other hand) trying to keep the dried mass of the core of soil intact. Do this over a broad, shallow tray to catch any loose soil. If the plastic bag is embedded a short distance into the bottom of the dried core, free it carefully, so as to disrupt the core as little as possible.

- While still supporting the core on one hand, use the other hand to tip any loose soil from the tray, into the mould. Then, using both hands, lower the core, bottom first, into the mould and drop it the last 2–3 cm.

- Now take the rammer (face 50 mm diam., mass 2.7 kg) and place its guide resting vertically on the centre of the soil core in the mould. Raise the sliding rammer up the guide to its limit and drop it on the soil core. Repeat this operation 5 more times, around the periphery of the core so as to cover the whole of the core with rammer blows. Total blows 6; work each drop = 8J (see below for calculations) therefore total work = 48J.

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* The apparatus used in this test is specified in the Roads and Traffic Authority (NSW) Test Method T111.

- Tip the crushed mass of soil from the mould into a tray and weigh the soil. Record its mass.

- Place a receiving pan under the bottom of a nest of 8 sieves standing on the floor and pour the soil onto the top sieve. Rock the nest of sieves by hand 16 times backwards and forwards.

- Remove each sieve from the nest one at a time, pour its contents into a tray and record the weight of soil retained. Beyond about sieve 4 from the top it will be found that not all the soil that can pass through the sieve has done so. Therefore it will be necessary to agitate each sieve in turn sufficiently to cause the soil fine enough to pass to do so. Return the soil that so passes to the next sieve down. Repeat procedure for each of the remaining sieves. Determine the mass of soil retained on each sieve and in the bottom collecting pan.

- Record all weights beside the sieve aperture on the columned sheet.

- The set of sieves used were of apertures (mm): 26.5, 19.0, 13.2, 9.5, 6.7, 4.75, 2.36, 1.18.
- The rammer has a mass of 2.7 kg and it has a free fall of 300 mm.

- The mould used to confine the soil mass during work is 150 mm in diameter and 170 mm deep, mounted on a rigid concrete block. Its volume is 3.00 L.

- The soil cores tested were about 11 cm diam. at the top, 10 cm diam. at the bottom (tapered) and 12 cm high.

Calculation of work*

Work per blow =	2.7	x	9.8	x	0.3
	↑		↑		↑
	mass of rammer (kg)		acceler. due to gravity (ms^{-2})		distance of fall under gravity (m)

= 7.94 J

6 blows = 48 J

* This calculation assumes that the kinetic energy acquired by the rammer during its fall equals the work done.

PART B. Results

Table 13. Results of glasshouse trial with water-logged cotton.

Harvest 1

Field	Depth (cm)	Saturation of soil (%)	Mean plant height per pot (mm)	Leaf area, total per pot (cm^2)	Dry wt., total per pot (g)
11	0–10	60	230	491	2.06
		60	237	571	2.46
		60	210	542	2.18
		60	237	365	2.94
		60	232	532	2.07
		60	263	669	3.03
		"110"	228	429	2.30
		"110"	210	400	1.78
		"110"	178	349	2.36
		"110"	193	520	2.61
		"110"	215	408	2.23
		"110"	205	571	2.78
11	10–20	60	197	470	2.22
		60	220	583	2.54
		60	218	620	2.97
		60	200	524	2.23
		60	242	619	3.05
		60	248	628	2.94
		"110"	207	493	2.50
		"110"	233	582	2.70
		"110"	198	451	2.48
		"110"	208	475	2.47
		"110"	235	512	2.23
		"110"	198	451	2.36
18	0–10	60	233	592	2.75

Field	Depth (cm)	Saturation of soil (%)	Mean plant height per pot (mm)	Leaf area, total per pot (cm^2)	Dry wt., total per pot (g)
18	0–10	60	242	606	2.69
		60	200	477	1.93
		60	227	583	2.77
		60	263	623	2.88
		60	232	624	2.75
		"110"	170	205	2.03
		"110"	170	366	2.23
		"110"	157	289	1.92
		"110"	178	302	1.97
		"110"	162	247	1.43
		"110"	207	394	2.47
18	10–20	60	230	601	3.06
		60	250	631	2.95
		60	205	476	2.13
		60	223	507	2.04
		60	248	531	2.46
		60	242	644	2.92
		"110"	222	421	2.63
		"110"	228	474	2.48
		"110"	227	461	2.70
		"110"	188	350	1.95
		"110"	195	350	1.98
		"110"	232	432	2.03
20	0–10	60	238	675	3.16
		60	240	753	3.42
		60	257	724	3.49
		60	267	680	2.92
		60	245	685	3.23
		60	287	480	4.11
		"110"	205	465	2.97

Field	Depth (cm)	Saturation of soil (%)	Mean plant height per pot (mm)	Leaf area, total per pot (cm^2)	Dry wt., total per pot (g)
20	0–10	"110"	183	313	2.24
		"110"	235	578	2.56
		"110"	248	648	2.78
		"110"	287	915	2.65
		"110"	187	445	4.00
20	10–20	60	233	613	3.07
		60	257	594	2.54
		60	238	596	3.18
		60	233	564	2.63
		60	233	317	3.00
		60	222	569	2.61
		"110"	260	649	2.86
		"110"	262	697	2.92
		"110"	252	759	3.39
		"110"	255	810	3.33
		"110"	243	716	3.15
		"110"	295	791	3.60
31	0–10	60	213	465	2.00
		60	205	455	1.85
		60	223	563	2.73
		60	228	519	2.71
		60	230	562	2.78
		60	233	538	2.55
		"110"	185	346	1.94
		"110"	252	406	2.38
		"110"	188	376	2.05
		"110"	210	476	2.18
31	0–10	"110"	207	425	2.30
		"110"	200	422	2.42
31	10–20	60	193	395	1.56

Field	Depth (cm)	Saturation of soil (%)	Mean plant height per pot (mm)	Leaf area, total per pot (cm^2)	Dry wt., total per pot (g)
31	10–20	60	217	468	1.90
		60	213	469	2.26
		60	212	447	1.82
		60	207	541	2.66
		60	237	543	2.40
		"110"	232	459	2.40
		"110"	230	417	2.27
		"110"	210	435	2.22
		"110"	195	387	2.39
		"110"	185	316	1.82
		"110"	227	434	2.25

Harvest 2

Field	Depth (cm)	Saturation (%)	Symptoms score*	Mean plant height per pot (mm)	Internode No. (mean per pot)	Dry wt., total per pot (g)
11	0–10	60	0	325	7	6.44
		60	0	358	7.5	7.41
		60	0	302	7	5.39
		60	0	310	6	6.59
		60	0	320	7.5	6.57
		60	0	360	7.5	9.14
		"110"	3	275	5.5	4.11
		"110"	3	293	6.5	4.75
		"110"	2	188	5.5	2.25
		"110"	1	275	6.5	4.54
		"110"	2	255	5.5	3.83
		"110"	3	275	6.5	5.23
11	10–20	60	0	305	7	6.6
		60	0	318	6.5	6.5
		60	0	298	6.5	5.03
		60	0	290	6.5	5.17
		60	0	305	7.5	5.35
		60	0	315	8	6.83
		"110"	3	267	6.5	4.65
		"110"	3	275	6.5	3.83
		"110"	3	218	5.5	3.45
		"110"	3	248	5.5	3.79
		"110"	2	258	7.5	5.43
		"110"	3	248	6.5	3.55
18	0–10	60	0	310	8	4.83
		60	0	310	6	7.19
		60	0	318	7	6.32
		60	0	283	6.5	6.02
		60	0	355	7.5	7.02

* see page 109

Field	Depth (cm)	Saturation (%)	Symptoms score*	Mean plant height per pot (mm)	Internode No. (mean per pot)	Dry wt., total per pot (g)
18	0–10	60	0	338	8	7.6
		"110"	3	175	3	1.34
		"110"	4	160	4	1.09
		"110"	4	218	5.5	2.05
		"110"	3	200	5.5	2.15
		"110"	3	260	7.5	3.22
		"110"	3	195	5.5	1.69
18	10–20	60	0	300	7	4.14
		60	0	312	6.5	4.52
		60	0	325	6.5	3.70
		60	0	325	6.5	2.86
		60	0	348	7.5	4.51
		60	0	275	6.5	4.01
		"110"	3	258	6.5	6.13
		"110"	4	290	7.5	5.37
		"110"	3	250	6.5	6.69
		"110"	4	265	6.5	6.81
		"110"	3	263	6.5	7.69
		"110"	3	253	7.5	4.83
20	0–10	60	0	325	7	8.14
		60	0	308	7	8.39
		60	0	335	7.5	9.38
		60	0	355	7.5	9.69
		60	0	340	8	6.7
		60	0	398	9.5	8.42
		"110"	1	212	5	3.46
		"110"	1	185	4	2.27
		"110"	0	312	9	6.02
		"110"	0	385	8.5	7.92
		"110"	0	378	8	8.43

* see page 109

Field	Depth (cm)	Saturation (%)	Symptoms score*	Mean plant height per pot (mm)	Internode No. (mean per pot)	Dry wt., total per pot (g)
20	0–10	"110"	0	238	6	4.32
20	10–20	60	0	305	6	6.42
		60	0	310	7	6.51
		60	0	315	7.5	6.83
		60	0	283	6.5	6.28
		60	0	278	6.5	6.40
		60	0	305	6.5	7.28
		"110"	0	350	8	8.07
		"110"	0	440	8.5	10.95
		"110"	0	368	7.5	7.39
		"110"	0	438	7.5	11.09
		"110"	0	385	9.5	8.85
		"110"	0	430	8.5	9.49
31	0–10	60	0	310	7.5	5.85
		60	0	315	6	4.40
		60	0	288	6.5	5.14
		60	0	305	7	6.5
		60	0	298	7	6.03
		60	0	333	7.5	5.90
		"110"	3	215	5	3.04
		"110"	3	300	7	3.62
		"110"	3	228	6	2.41
		"110"	3	280	6.5	4.62
		"110"	3	295	6.5	3.44
		"110"	3	290	7	3.80
31	10–20	60	0	308	8	6.28
		60	0	313	7	6.67
		60	0	298	7.5	6.27
		60	0	328	6.5	5.23
		60	0	313	6	6.05

* see page 109

Field	Depth (cm)	Saturation (%)	Symptoms score*	Mean plant height per pot (mm)	Internode No. (mean per pot)	Dry wt., total per pot (g)
31	10–20	60	0	307	7	5.63
		"110"	4	348	7.5	5.93
		"110"	3	285	5.5	3.58
		"110"	3	258	5.5	2.98
		"110"	3	255	6.5	3.16
		"110"	2	228	5.5	3.02
		"110"	4	303	7.5	4.08

* see page 109

PART C. Statistical analyses

Experimental design and analysis

Refer to appendix I B for details. One variable (internode number) was transformed as indicated in the results.

Explanation of tables of results

The first section shows the results of the repeated measurements analysis for each field: the tests of the treatment effects averaged over depths; the effect of depth; and the interaction of treatment * depth. If an interaction term is significant, the effect of the treatment is different at each depth. [* = significant at 5% level; ** = significant at 1% level; *** = significant at .1% level; ns = not significant.]

The next section shows the result of the analysis of variance at each depth for each field; that is, the tests of significance of treatment effects at each depth of each field.

The final section gives the mean and standard error of the mean for each field.
Depth 1 = 0–10cm; depth 2 = 10–20cm.
MR 1 = 60; MR 2 = 110.

Table 14. Statistics for the experiment with water-logged cotton.

HARVEST 1 DRY WEIGHT

Field	11	18	20	31
Moisture regime	ns	*	ns	ns
Depth	ns	ns	ns	ns
Depth * MR	ns	ns	*	ns
MR Depth 1	ns	*	ns	ns
MR Depth 2	ns	ns	ns	ns

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	2.4567	.1602	2.6283	.1421	3.3883	.2108	2.4367	.1295
2	2.3433	.1602	2.0083	.1421	2.8667	.2108	2.2117	.1295
Depth 2								
MR 1	2.6583	.1185	2.5933	.1628	2.8383	.1148	2.100	.1332
2	2.4567	.1185	2.2950	.1628	3.2083	.1148	2.225	.1332

Table 14 (continued)

HARVEST 1	PLANT HEIGHT			
Field	11	18	20	31
Moisture regime	ns	**	ns	ns
Depth	ns	**	ns	ns
Depth * MR	ns	**	*	ns
MR Depth 1	*	**	ns	ns
MR Depth 2	ns	ns	*	ns

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	234.83	7.0447	232.83	7.8282	255.67	12.8194	222.0	7.6594
2	204.83	7.0447	174.00	7.8282	224.17	12.8194	207.0	7.6594
Depth 2								
MR 1	220.83	7.737	233.00	7.3794	236.00	6.1466	213.17	7.0612
2	213.17	7.737	215.33	7.3794	261.17	6.1466	213.17	7.0612

Table 14 (continued)

HARVEST 1 LEAF AREA

Field	11	18	20	31
Moisture regime	*	***	ns	**
Depth	ns	*	ns	ns
Depth * MR	ns	**	*	ns
MR Depth 1	ns	***	ns	**
MR Depth 2	ns	**	*	*

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	528.33	37.4696	584.17	25.9063	666.17	66.2717	517.0	18.7588
2	446.17	37.4696	300.50	25.9063	560.67	66.2717	408.5	18.7588
Depth 2								
MR 1	574.0	23.3031	565.00	25.3986	542.17	36.7453	477.17	22.0654
2	494.0	23.3031	414.67	25.3986	737.00	36.7453	408.00	22.0654

Table 14 (continued)

HARVEST 1 N

Field	11	18	20	31
Moisture regime	***	***	ns	***
Depth	*	***	ns	ns
Depth * MR	**	***	*	ns
MR Depth 1	***	***	**	***
MR Depth 2	***	***	ns	**

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	5.6708	.1486	5.5257	.0918	5.7008	.1630	5.4625	.1371
2	4.1815	.1486	3.4747	.0918	4.5985	.1630	4.2275	.1371
Depth 2								
MR 1	5.6143	.1142	5.6865	.1913	5.2597	.2591	5.5162	.2073
2	4.7115	.1142	4.4410	.1913	5.5130	.2591	4.4385	.2073

Table 14 (continued)

HARVEST 1 P

Field	11	18	20	31
Moisture regime	***	***	ns	**
Depth	ns	ns	*	ns
Depth * MR	ns	***	***	ns
MR Depth 1	***	***	**	**
MR Depth 2	*	***	**	*

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	.5382	.0209	.6462	.0247	.6221	.0274	.4840	.0224
2	.3713	.0209	.2429	.0247	.4826	.0274	.3648	.0224
Depth 2								
MR 1	.5182	.0263	.4933	.0214	.5563	.0262	.5466	.0446
2	.4273	.0263	.3307	.0214	.6853	.0262	.4053	.0446

Table 14 (continued)

HARVEST 1 K

Field	11	18	20	31
Moisture regime	ns	**	ns	ns
Depth	ns	*	ns	ns
Depth * MR	ns	*	ns	ns
MR Depth 1	ns	**	ns	ns
MR Depth 2	ns	ns	ns	ns

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	3.5716	.1449	3.3181	.1722	3.4193	.1520	3.2876	.1169
2	3.6230	.1449	2.5193	.1722	3.5021	.1520	3.2059	.1169
Depth 2								
MR 1	3.5082	.0884	3.3007	.0943	3.5118	.1054	3.3120	.1656
2	3.6326	.0884	3.0999	.0943	3.5820	.1054	3.3079	.1656

Table 14 (continued)

HARVEST 1 Cu

Field	11	18	20	31
Moisture regime	ns	ns	ns	ns
Depth	ns	ns	*	ns
Depth * MR	ns	ns	ns	ns
MR Depth 1	ns	ns	*	ns
MR Depth 2	ns	ns	ns	ns

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	10.1721	.7118	10.7086	2.1756	11.1998	.5033	6.0724	1.1018
2	7.1916	.7118	11.2134	2.1756	8.8900	.5033	8.2812	1.1018
Depth 2								
MR 1	11.4261	1.2932	9.9197	.8653	8.9601	1.1385	8.1731	.5347
2	10.7227	1.2932	9.1700	.8653	7.4559	1.1385	6.7488	.5347

Table 14 (continued)

HARVEST 1 Mg

Field	11	18	20	31
Moisture regime	***	***	***	***
Depth	ns	ns	*	ns
Depth * MR	ns	ns	***	ns
MR Depth 1	***	***	***	***
MR Depth 2	***	***	ns	***

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	1.2065	.0294	1.2152	.0485	1.1374	.0348	1.3764	.0265
2	.9484	.0294	.7765	.0485	.8054	.0348	1.0652	.0265
Depth 2								
MR 1	1.2009	.0256	1.1974	.0217	1.0844	.0147	1.3380	.0387
2	1.0088	.0256	.8477	.0217	1.0440	.0147	1.0764	.0387

Table 14 (continued)

HARVEST 1 Na

Field	11	18	20	31
Moisture regime	***	**	***	***
Depth	***	ns	ns	ns
Depth * MR	ns	ns	ns	ns
MR Depth 1	**	**	***	***
MR Depth 2	***	ns	**	**

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	.0478	.0021	.0704	.0051	.0602	.0087	.1135	.0062
2	.0636	.0021	.0924	.0051	.1286	.0087	.1626	.0062
Depth 2								
MR 1	.0628	.0033	.0744	.0031	.0868	.0083	.0839	.0175
2	.0865	.0033	.0844	.0031	.1393	.0083	.1652	.0175

Table 14 (continued)

HARVEST 1 Mn

Field	11	18	20	31
Moisture regime	***	***	*	***
Depth	ns	*	**	ns
Depth * MR	ns	ns	*	ns
MR Depth 1	**	**	**	***
MR Depth 2	***	***	ns	***

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	220.834	6.1424	177.308	8.579	157.918	5.7709	102.957	3.1833
2	178.440	6.1424	128.365	8.579	128.837	5.7709	78.861	3.1833
Depth 2								
MR 1	250.735	11.326	217.978	10.6213	169.473	7.0139	106.160	3.3870
2	180.636	11.326	138.413	10.6213	170.180	7.0139	84.066	3.3870

Table 14 (continued)

HARVEST 1 Ca

Field	11	18	20	31
Moisture regime	***	***	***	*
Depth	**	ns	**	ns
Depth * MR	*	ns	**	ns
MR Depth 1	***	***	***	ns
MR Depth 2	**	***	*	**

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	5.4056	.1566	6.0383	.2411	5.4304	.1918	4.5211	.3458
2	4.1094	.1566	3.6138	.2411	3.7087	.1918	3.9461	.3458
Depth 2								
MR 1	5.5973	.1622	5.8134	.1489	5.4393	.0931	5.0869	.1655
2	4.8761	.1622	4.2968	.1489	5.0340	.0931	4.0932	.1655

Table 14 (continued)

HARVEST 1 S

Field	11	18	20	31
Moisture regime	***	***	***	***
Depth	*	ns	ns	ns
Depth * MR	*	**	**	ns
MR Depth 1	***	***	***	***
MR Depth 2	***	***	ns	***

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	1.3402	.0498	1.4334	.0507	1.4209	.0782	1.3896	.0320
2	.06554	.0498	.5033	.0507	.6003	.0782	.7443	.0320
Depth 2								
MR 1	1.3281	.0372	1.1747	.0326	1.2379	.0535	1.3788	.0546
2	.8563	.0372	.6788	.0326	1.0872	.0535	.8367	.0546

Table 14 (continued)

HARVEST 1 Zn

Field	11	18	20	31
Moisture regime	***	***	***	***
Depth	**	**	*	ns
Depth * MR	***	ns	**	ns
MR Depth 1	***	***	***	***
MR Depth 2	***	***	ns	***

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	25.2294	.5290	19.9955	.6485	39.5368	1.3759	19.5930	.8447
2	12.3499	.5290	9.1659	.6485	25.2548	1.3759	11.9220	.8447
Depth 2								
MR 1	22.4279	.6234	24.0678	.6514	37.1732	1.9016	20.9648	.4075
2	12.8179	.6234	11.2653	.6514	35.8222	1.9016	11.1062	.4075

Table 14 (continued)

HARVEST 2 DRY WEIGHT

Field	11	18	20	31
Moisture regime	***	***	ns	***
Depth	ns	*	ns	ns
Depth * MR	ns	**	**	ns
MR Depth 1	***	***	**	**
MR Depth 2	*	**	*	***

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	6.9233	.4718	6.4967	.3616	8.4533	.7768	5.6367	.3042
2	4.1183	.4718	1.9233	.3616	5.4033	.7768	3.4883	.3042
Depth 2								
MR 1	5.9133	.3233	6.2533	.3492	6.6200	.4476	6.0217	.3578
2	4.1167	.3233	3.9567	.3492	9.3067	.4476	3.7917	.3578

Table 14 (continued)

HARVEST 2 PLANT HEIGHT

Field	11	18	20	31
Moisture regime	**	***	ns	**
Depth	*	*	ns	ns
Depth * MR	ns	*	**	ns
MR Depth 1	**	***	ns	*
MR Depth 2	***	**	***	ns

Means and standard errors

Field	11		18		20		31	
Depth 1	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
MR 1	329.167	12.885	319.000	12.436	343.500	26.365	308.167	11.530
2	260.167	12.885	201.333	12.436	285.000	26.365	268.000	11.530
Depth 2								
MR 1	305.167	6.481	314.167	8.312	299.333	12.123	311.167	12.570
2	252.333	6.481	263.167	8.312	401.833	12.123	279.500	12.570

Table 14 (continued)

HARVEST 2 SQUARE ROOT INTERNODE NO.

Field	11	18	20	31
Moisture regime	**	*	ns	ns
Depth	ns	ns	ns	ns
Depth * MR	ns	*	*	ns
MR Depth 1	*	*	ns	ns
MR Depth 2	ns	ns	**	ns

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	3.7611	.0648	3.7807	.1544	3.9314	.1784	3.7165	.0778
2	3.4611	.0648	3.1835	.1544	3.6368	.1784	3.5535	.0778
Depth 2								
MR 1	3.7385	.0777	3.6728	.0514	3.6492	.0670	3.7377	.0961
2	3.5538	.0777	3.6947	.0514	4.0585	.0670	3.5502	.0961

Table 14 (continued)

HARVEST 2 SCORE

Means and standard errors

Field	11		18		20		31	
	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se	$\bar{x}$	se
Depth 1								
MR 1	0		0		0		0	
2	2.33	.333	3.33	.211	.333	.211	3	0
Depth 2								
MR 1	0		0		0		0	
2	2.83	.167	3.33	.211	0		3.167	.307

ATTACHMENT

ATTACHMENT

A FIELD EXAMINATION OF SOIL PROFILES SHOWING "GALATHERA SYNDROME" AND ADJACENT "NORMAL" PROFILES ON THE PROPERTY OF AUSCOTT PTY. LTD., NARRABRI.

C.A. HAWKINS

Report to the Director of Chemistry,
Biological and Chemical Research Institute, NSW Agriculture

Assistance and Advice

Technical Assistant, N. Haddad, organised the field work, carried out the laborious field duties and contributed ideas. R. Lawrie described the profiles on the stock route, assisted with the field work and contributed ideas. All statements in the report remain those of the author, however.

Special thanks are due to Auscott Pty. Ltd. and to Mr. D. Anthony, Manager, Narrabri, for allowing access to the cotton fields, for having the backhoe pits dug and for providing data on, and the benefit of long experience with, the Galathera problem. Ms. S. Forsell, Agronomist, Auscott, Narrabri collected much data and many maps, helped with the day-to-day requirements and provided the benefit of her experience.

Thanks are due to the staff and the Manager of Narrabri Agricultural Research Station (Mr. R. Martin) for much discussion and for assistance with equipment, machinery and access to the laboratory.

Quite a number of workers with long experience discussed the Galathera problem and it became obvious that the author was a learner in problems of cotton growing on the "black" soils. My engagement to carry out the work was therefore surprising.

A FIELD EXAMINATION OF SOIL PROFILES SHOWING "GALATHERA SYNDROME" AND ADJACENT "NORMAL" PROFILES ON THE PROPERTY OF AUSCOTT PTY. LTD., NARRABRI.

1. INTRODUCTION

Thirty-five sites were examined and sampled* for possible laboratory tests, to about 1.3 m depth, with a spade and hand auger. As well, three backhoe pits and two shallow pits were examined and sampled to about 1 metre and 50-60 cm respectively. In addition, two composite bulk samples - at 0-10 cm and 10-20 cm - were drawn** from each of 4 sites - 2 sites in land showing Galathera symptoms and 2 in "non-Galathera" sites.

The positions of the sites are shown on map 1 - with this report. Also shown (approximately) on map 2 are areas reputed to produce more severe and less severe symptoms of Galathera syndrome (S. Forsell, Agronomist, Narrabri - pers. comm., 1991).

This work, supported by the Cotton Research and Development Corporation,*** aims to establish whether there are clear and consistent morphological and chemical differences between soils producing Galathera syndrome and adjacent, more "normal" soils. It forms a background to the screening of these two groups for the presence of phytotoxins, by glasshouse and laboratory means.

This preliminary report, prepared after completion of the field work and before laboratory and glasshouse results are available, records what was observed in the field and from the undisturbed cores taken from the pits.

2. EXAMINATION OF SOILS ON TRAVERSES

The 36 sites are shown on map 1. The soils were examined to a depth of 1.2-1.3 m in most cases. A few were shallower (0.5 m) spade holes. The soils of Auscott are grey, cracking clays with an A - C profile. In the system of Northcote

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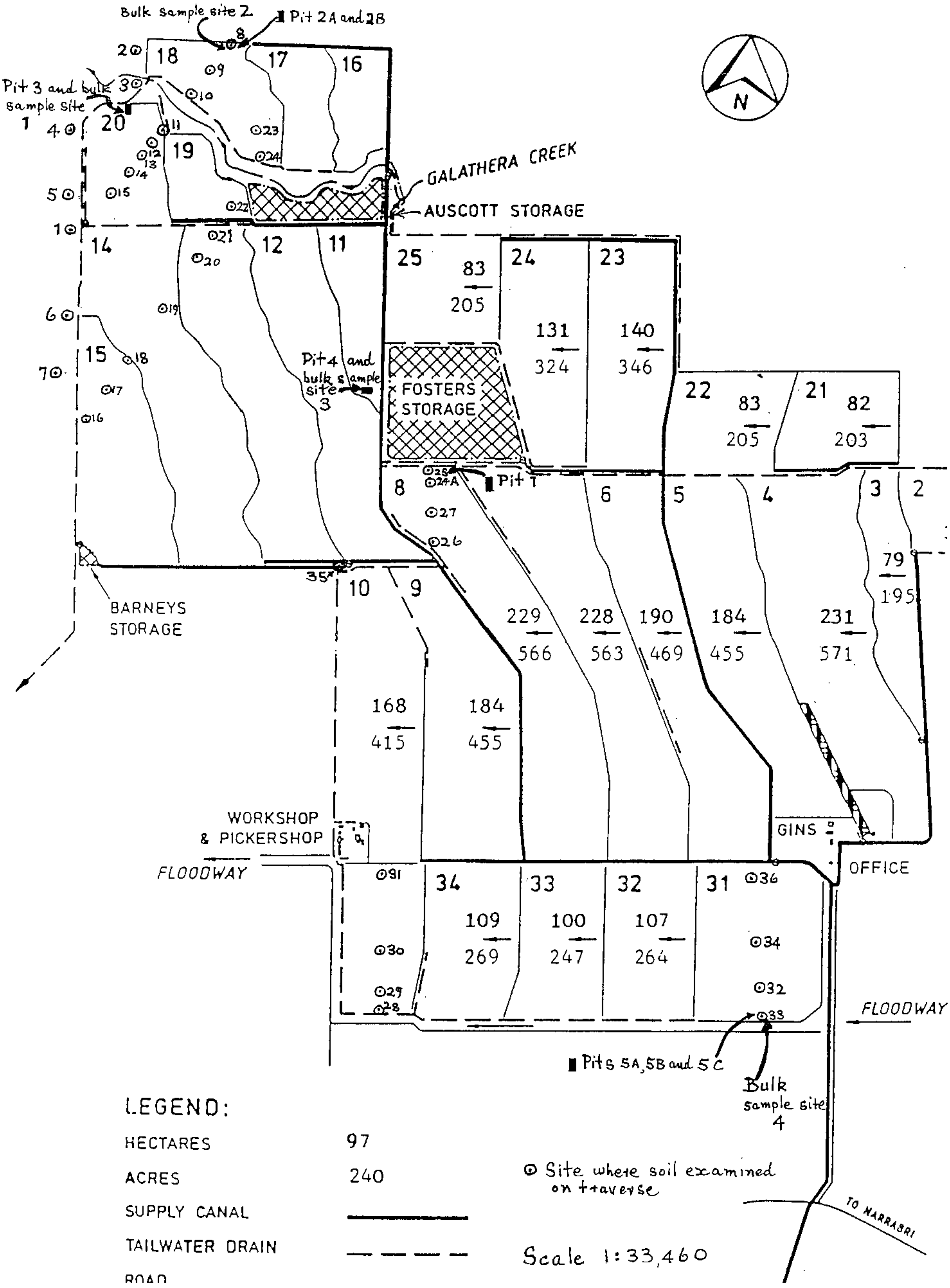
* Field work was carried out November 18 to December 6, 1991.

** All 0-10 cm composites and one of the 10-20 cm composites (that at bulk sample site 4) consisted of 120-140 cores, taken with a 10 cm auger, beside the cotton rows at regularly spaced intervals over an area 30m x 30m at each site. The 10-20 composites from sites 1 to 3 were each taken from 4 positions (1 in each quarter) within the 30m x 30m square from which the corresponding 0-10 cm sample came.

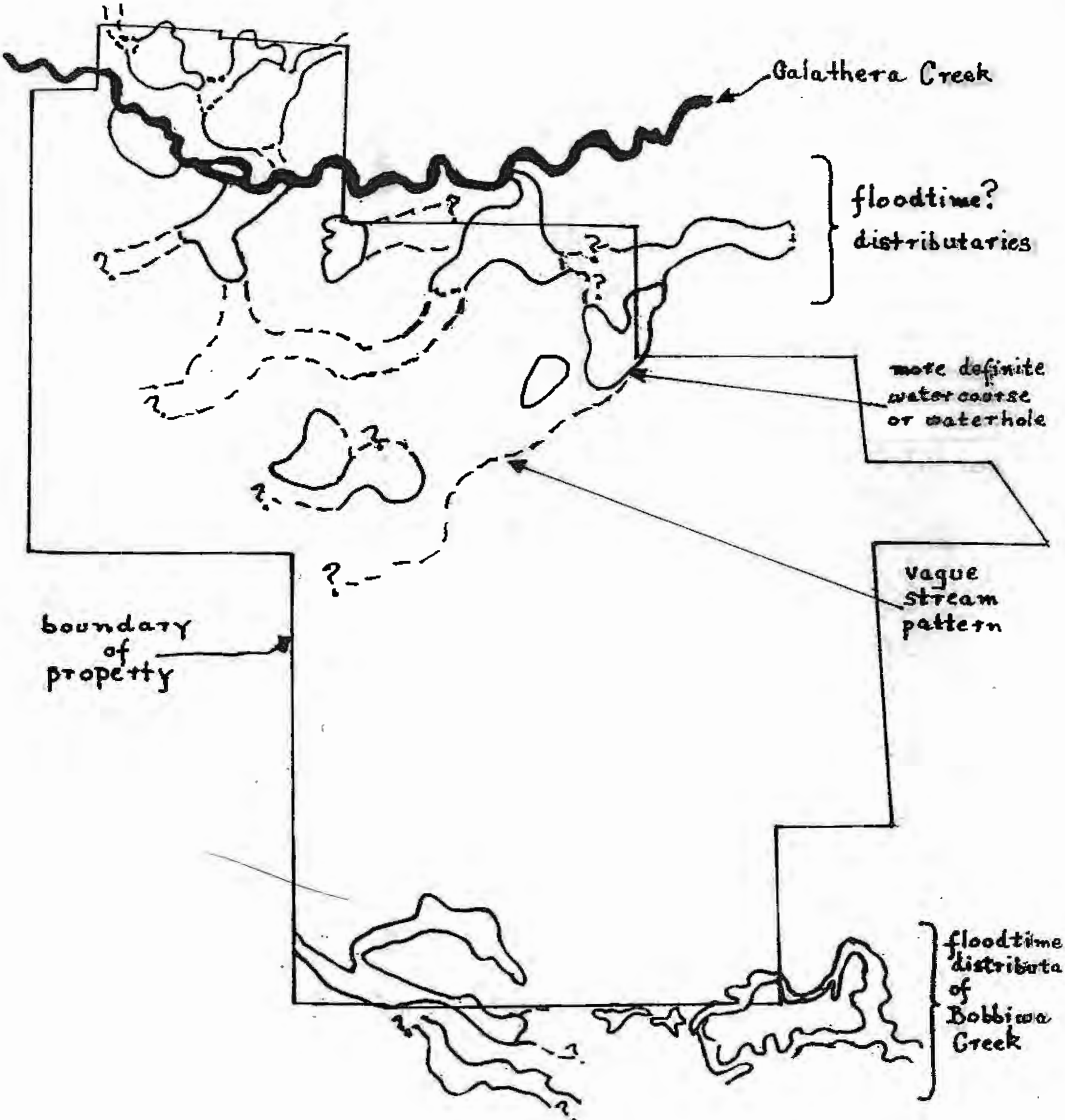
*** Project DAN 61C - Involvement of Phytotoxins, probably Herbicides in the Galathera Syndrome (1991-92).

MAP 1

AUSCOTT - NARRAB



OVERLAY FOR MAP 2

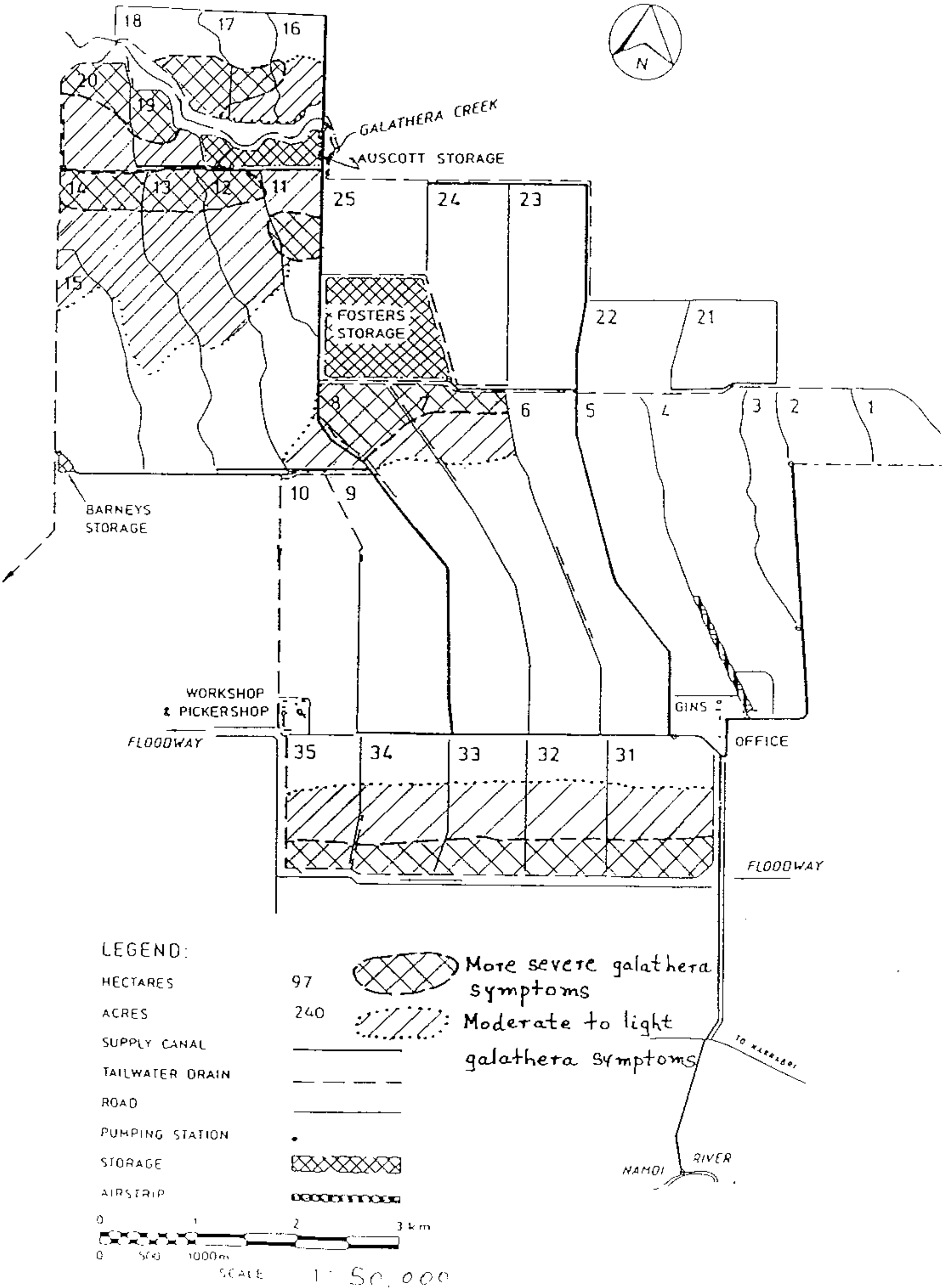


EPHEMERAL WATERWAYS

(sketched from air photos—Narrabri, run 3E, 1962

MAP 2

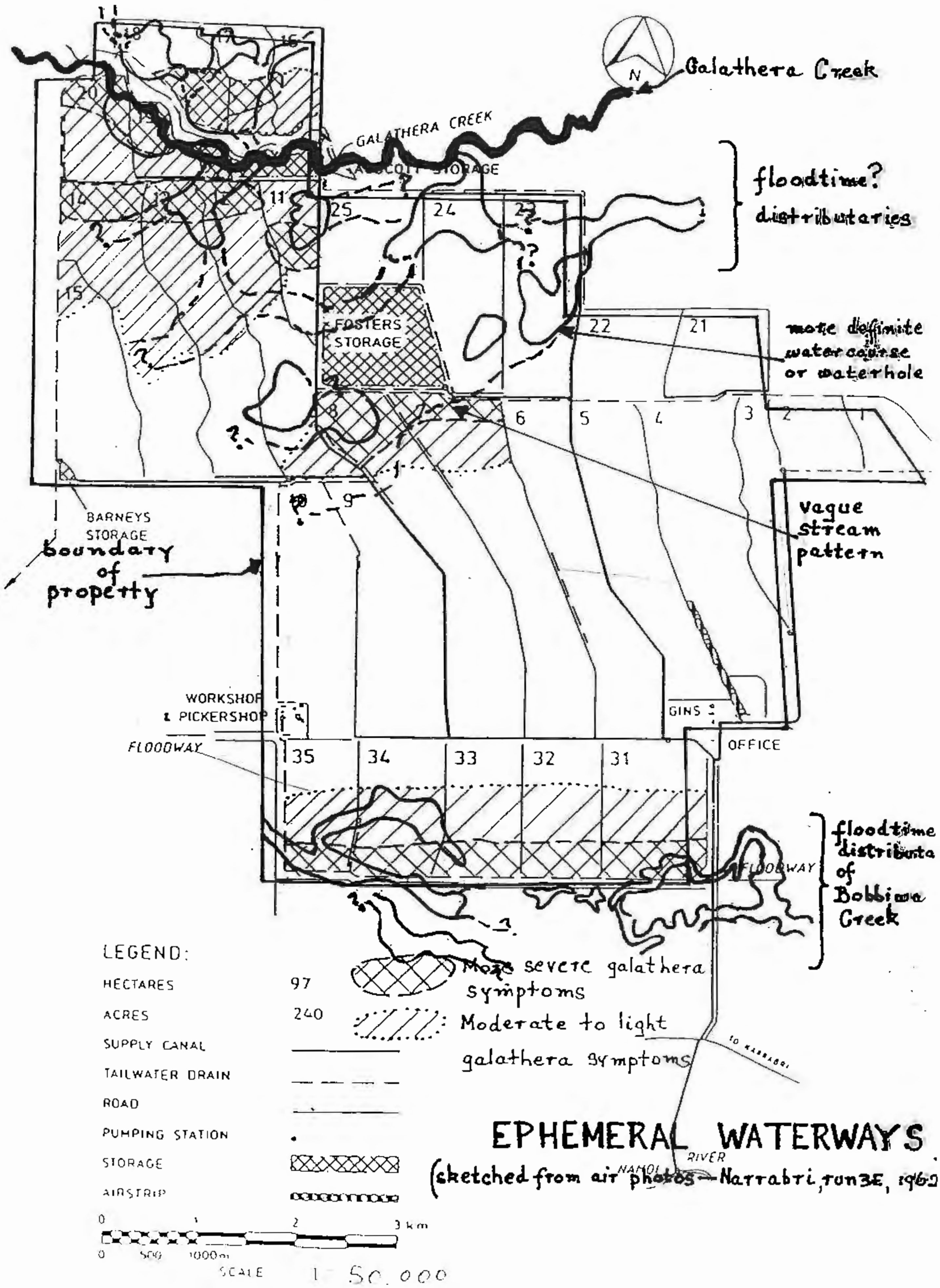
AUSCOTT - NARRABRI



MAP 2

AUSCOTT - NARRABRI

OVERLAY FOR MAP 2



(1974) they are Ug 5.15 or 5.16. In the system of Isbell (1989) they are Vertosols, Sub-order 4, Great Group 5. They were named Helebah series by Hawkins and Flint (1958) and renamed Gommel series by Ward (1992).

2.1 Variation in Soil across the Property

Leaving aside, for the moment, the bewildering array of structure and consistence states these soils display sequentially, as they swell and shrink, wet-up and dry-out, the variation in their other visible morphological properties across the Auscott property is quite small. Two phases or types can be discerned - a grey subsoil phase and a brown subsoil phase. The former occurs nearer the streamlines, the latter more distant from streams - see overlay to map 2 for location of the more frequently flooded land on the property. A "grey" profile and a "brown" profile are described below, omitting structure and consistence.

Grey subsoil phase e.g. site 13, map 1.

0 cm	dark, grey brown (10YR 3/2)* medium clay; grades to
50 cm	dark grey (10YR 3/1) medium clay; some greyish-brown streaks appear at 84 cm; grades to
110 cm	dark grey (10YR 3/1) heavy clay; remains thus to 130 cm maximum; continuing. May be a trace of gravel throughout.

Brown subsoil phase e.g. site 8, map 1.

0 cm	dark, grey brown (10YR 3/2) light medium clay or medium clay; trace of lime at 18 cm; continues thus to
30 cm	dark, grey brown (10YR 3/2) medium clay; trace lime; grades to
80 cm	dark, grey brown (10YR 3/3) medium clay; trace lime; grades to
100 cm	grey brown (10YR 4/4) medium clay; trace lime; grades to
122 cm	mottled, light grey brown (7.5YR 4/4) and grey brown (10YR 4/4) medium clay; trace lime; remains thus to 130 cm maximum; continuing. May be a trace of gravel throughout.

* All colours are of field-moist soils.

2.2 Structure and Consistence

The self-mulching, grey clays are renowned for their swelling and shrinking and attendant changes. The soils on Auscott are typical in this regard.

The reader is referred to the "SOILpak" (Daniells & Larsen, 1991) rating diagrams of the backhoe pits with this report for descriptions of typical structure and consistence, given there in the "shorthand", notebook form used in field descriptions. The particular system of structure and consistence employed in this report is that of Butler (1955) because this system, better than others available, seemed able to express the small, subtle differences observable in the field, differences, which it is believed, may be important for plant growth. Relevant extracts from this system are attached to this report (appendix 1) but some additional identification and discussion of key properties are needed here.

2.2.1 Key structural and consistence properties: Of first importance is the *grade of structure*. The size of the structural units does, of course, influence the control exercised over root penetration by structure, but the definiteness and clarity of separation of structural units (structural grade) is of primary importance in providing pathways through which roots may move easily and spaces where they may find enough oxygen. If such easy paths are more frequent, as would be the case where strongly-separate structural aggregates or units are small rather than large, so much the better - the size of aggregates is important as well as the grade. Thus, whether aggregate separation is present, whether strongly or weakly expressed and *whether preserved at high moisture contents* are key considerations.

Consistence is determined by crushing, with a compressive, shearing force between thumb and finger, a small (2 cm) clod or a natural structural unit (a ped) extracted from the pit face and then "working" the debris in the hand for a few seconds. The aim is to find out the state of the soil within the clod or ped before it was crushed. This state is revealed by:

(i) the strength within the clod or structural unit; that is, the force required to crush the piece of soil (see examples below and appendix 1). This gives some estimate of the force the root has to exert to penetrate the unit.

(ii) whether (and this is important in these grey, cracking clays) within the *apparently* homogeneous clods dug from the pit face, there are, in fact, lines of weakness (ped faces) not readily discernible when the clods are inspected but clearly indicated by the way the soil behaves when work is applied to it; that is to say, are there smaller, structural units present as indicated by the appearance of a population of small units of an approximately uniform size and shape when the compressive, shearing force is first applied to the clod. This state is described as "crumbly".

(iii) whether or not the small peds of the population produced when the clod is first crushed run together into lumps on further working in the hand and the degree or extent to which this occurs; that is to say is the soil material sufficiently coalescent to be called "labile" (C_4 or C_5) after first being crumbly or

(iv) whether no population of small peds appears (not crumbly) rather the moist clod ruptures purely according to the way the force is applied to it and then the pieces run together again into lumps; that is to say the soil is simply labile or

(v) whether, worst of all, the moist clod is sufficiently plastic, in the unworked state, to crack but not break into separate pieces and the whole mass ends up as a reworked lump of clay (plastic, coalescent 5) at the end of the exercise.

The moisture state is, of course, important in determining how the soil behaves during manipulation so the moisture state is given first in the consistence description. In the Butler system* 12 moisture states are recognized from dry 1 to wet 3 through dry 1, 2 and 3; moderately moist 1, 2 and 3; moist 1, 2 and 3 and wet 1, 2 and 3. See appendix 1 for how to determine these. Note that moist 3 (M_3) corresponds to field capacity and moderately moist 3 (MM_3) to wilting point. As the soil dries it is normally expected that, in clay soils, the force required to crush homogeneous, small clods will increase. An exception in these grey clays is the thin, dry crust which forms at the surface. This *crumbles* into very small aggregates with a small force.

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* The moisture scale in the Butler (1955) system seems similar to that in the Soilpak manual except plastic limit is not included.

2.2.2 Explanation of structure and consistence "shorthand".

Examples are taken from the soilpak rating diagrams in this report.

No structure; massive: monolithic - the soil breaks into fragments of no particular size and shape, depending solely upon how force is applied to the mass

Platy structure of weak grade

Structure description **A, mass. to PL;**

Consistence description **M_3 (3 LA C_4)**

Coalescent 4 - sufficiently high to identify the soil as "labile".

Soil at field capacity

Labile - at first ruptures but pieces then run together

Moderate force, exerted between thumb and finger

Strong or high grade

Structural units are akin to spheroids

Structure description **III SPH;**

loose

Description of consistence not possible - already all in fine, separate - aggregate state; may be dry or moist

Moderate or intermediate grade

Angular blocky peds

Lenticular peds

Structure description **II ABL and LE;**

Aggregates formed when clod first breaks run together on further work to give C4: therefore labile.

Consistence description **M_2 (2 CR C_3+LA C_4)**

Moist 2 (in upper part of available range)

Coalescent 3: this is the limit of coalescence for a soil to be still crumbly; at C4 it has to be labile.

Small but significant force

Crumbly - indicates that a population of small peds appears at first break

2.2.3 Comments on structure and consistence:

The structure and consistence values record what is readily observable - these soils, when in the upper part of the plant- available moisture range, are soft and weak unless well compacted. It is probable that force 2 is well within the power of a growing root to exert and force **3** is still within their capacity but force 4 may be greater than a root can exert. This assessment may not be in agreement with the findings of Hulme *et al.* (1991).

2.3 General Comment on Soil Differences

It was observed after rainstorms that, compared with Galathera prone areas, the non-Galathera lands seemed to impound water for a shorter time in the furrows, showed less signs of clay dispersion where water had pooled temporarily and generally appeared better drained internally. They also appeared to be softer.

3. EXAMINATION OF SOILS OF PITS

Five backhoe pits were dug (see map 1) so that the soil could be examined and sampled to about 1 m - see soilpak rating diagrams with this report. Pits 1, 3 and 5 were in "Galathera syndrome" areas; pits 2 and 4 in "normal" soils. All five pits were inspected and three were sampled before pit closure. At two sites (2 and 5) sampling was only possible to about 0.5 m after pit closure - in new, shallower pits, dug by hand nearby.

The soils were rated by the Soilpak method (Daniells & Larsen, *loc. cit.*) and undisturbed cores taken for determination of bulk density and related physical properties. Undisturbed clods were taken for shrinkage measurements and disturbed samples for chemical analysis. Shear-vane and dispersion tests were made. The soilpak ratings and the position on the pit faces of undisturbed cores and undisturbed clods are shown on the rating diagrams with this report. Disturbed samples were taken at the same depth and as close as possible to the core samples. Shear-vane readings and dispersion test were done at depths indicated on the diagrams, often close to core sample sites.

3.1 Soilpak Ratings

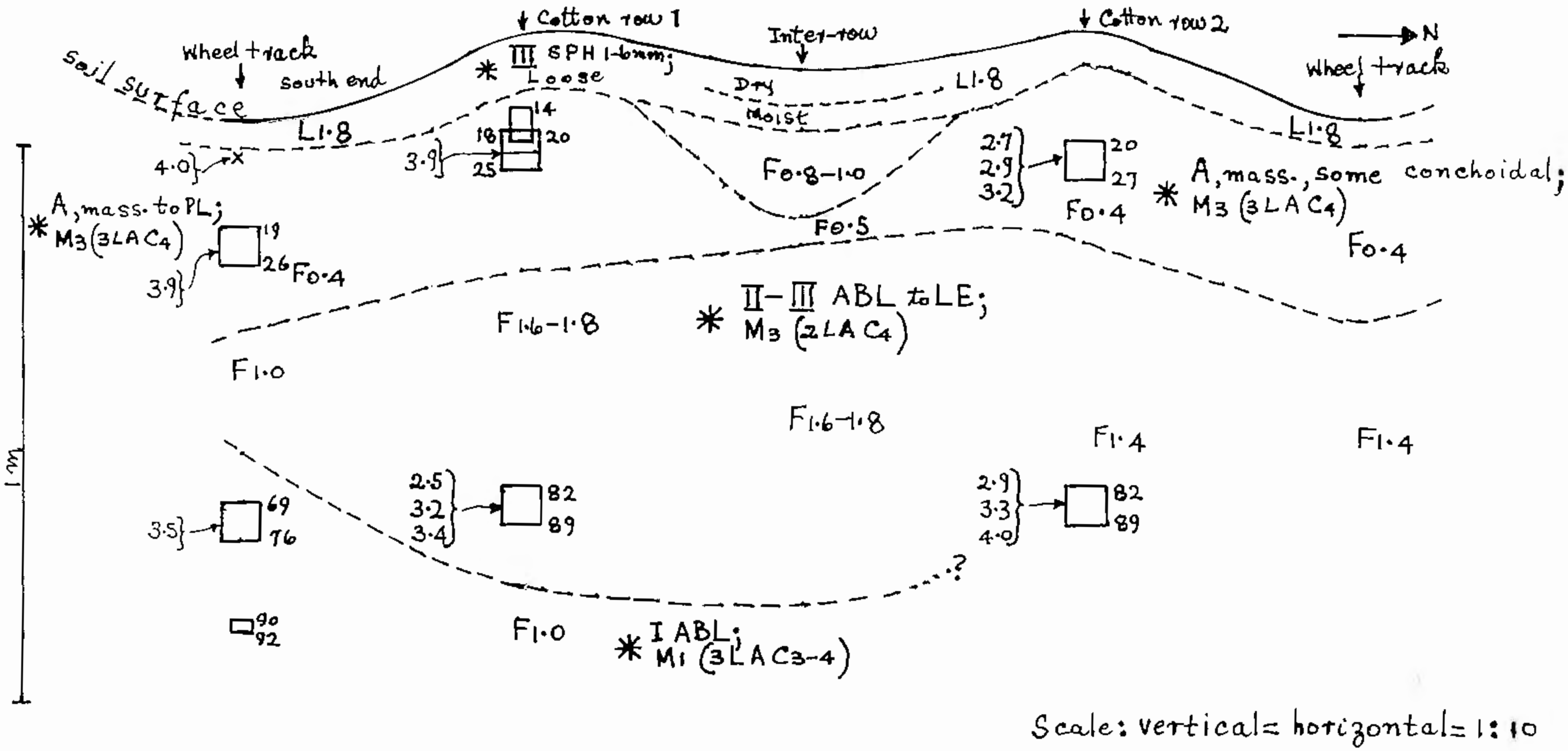
Ratings are given as F and L values in the diagrams. It is probable that values of F and L less than 0.5 units apart are not different in magnitude. In table 1 a rationalization and simplification of the zones and values in the diagrams is attempted. From table 1 the pits can be arranged in order, from better to poorer, as follows:-

for zone 2:5 > 2 = 3 > 4 > 1
for zone 3:3 > 2 > 4

but if scores differing by less than 0.5 are not, in reality, different, then pits 2, 3 and 4 are scarcely separable by these scores. On field evidence and past performance, site 5 should have been poorer.

Ratings in the lower part of the profiles (zone 3) are generally better than those for the middle part of the profile (zone 2) in pits 1 and 3 but not in pit 4. There are no samples from zone 3 for pits 2 and 5. Below zone 3 - generally below 1 m depth - pits 1 and 3 have a lower score than they have in zone 3.

These results indicate that zone 1 is best for plant growth when moisture is available there. Zone 3 may be next best in the Galathera syndrome sites - ahead of zone 2 - but not in non-Galathera sites. Zone 4 may be poorer than zone 3.



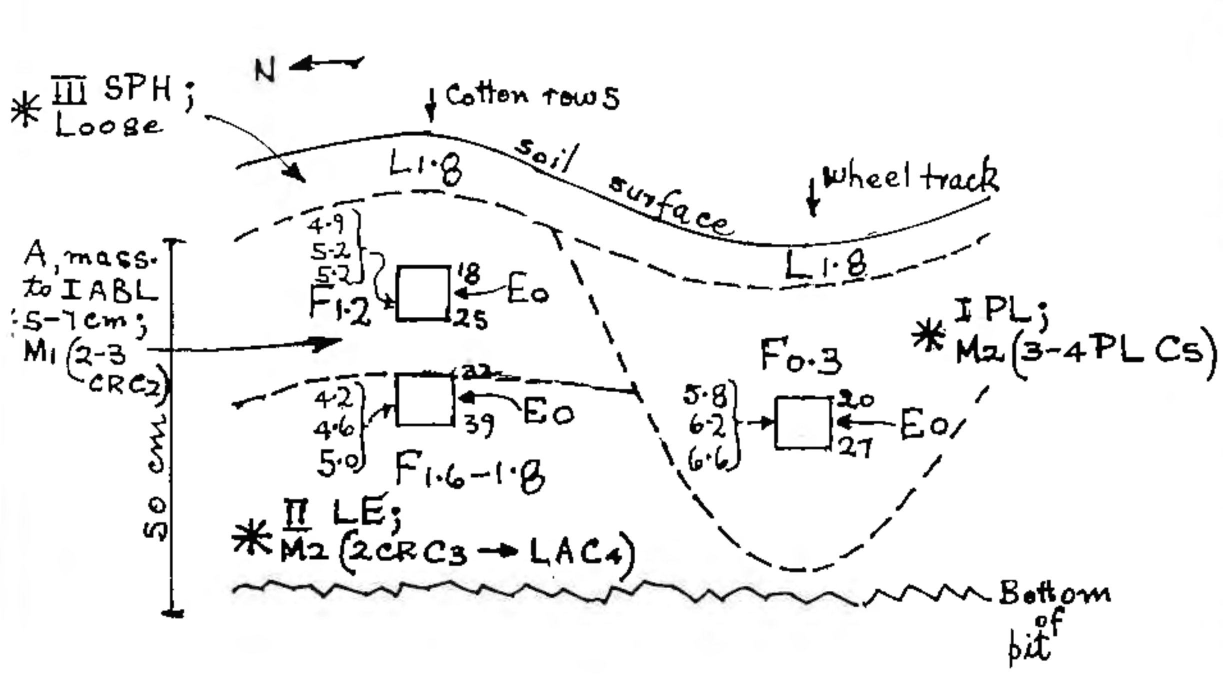
PIT 1 (WEST WALL)— SOILpak RATING—TABLE C3-1

Legend

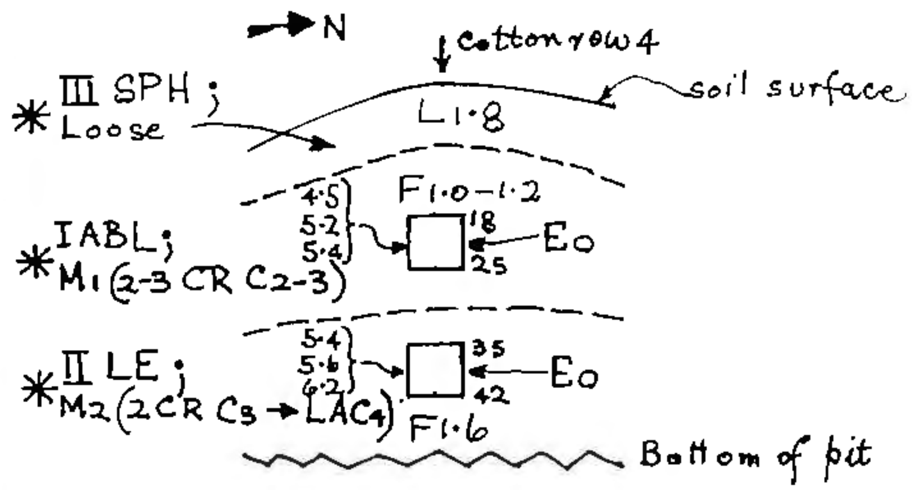
Fo·5	Soilpak structure rating
*	Structure and consistence description – see text
dashed line	Rating zones
Shearvane readings near core 4·0} □ 19 26	Position of core or clod sample (depth-cm)

Sampled 27.11.91

G.A.H. 14.12.



PIT 2B—EAST WALL



PIT 2A–WEST WALL

PIT 2 — SOILpak RATINGS — TABLE C3-1

Vertical and horizontal scale 1:10

<u>Legend</u>

F1·2 — Soilpak β structure rating

* — Structure and consistence description – see text

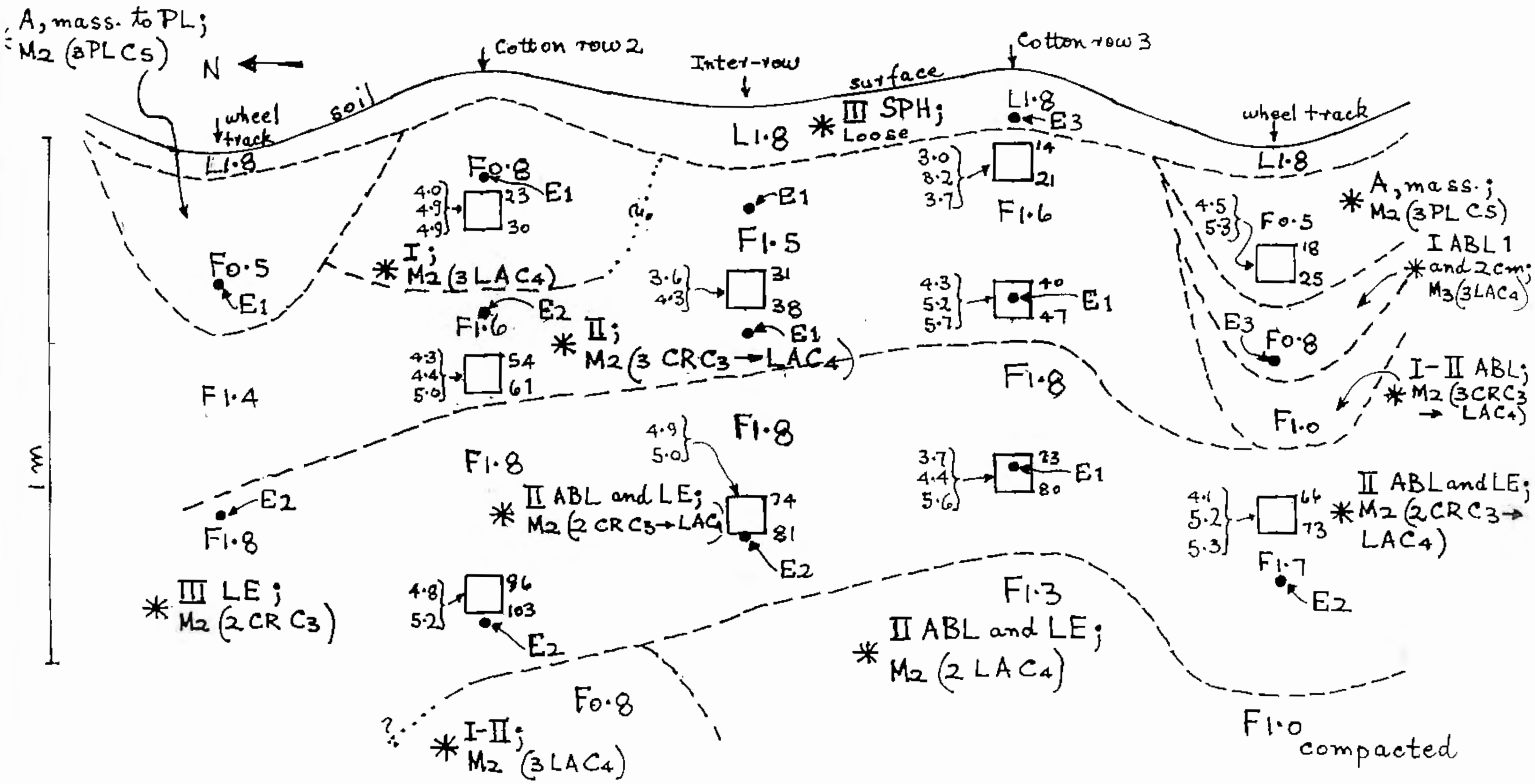
- - - — Rating zones

Eo — Dispersion on wetting (field-moist state, unworked)

Shear vane readings around core (4·9, 5·2, 5·2) — Position of core or clod sample (depth shown in cm) (18, 25)

Sampled 4·12·91

k. a. H. 14·12·91



PIT 3 (EAST WALL) — SOILpak RATINGS—TABLE C3-1

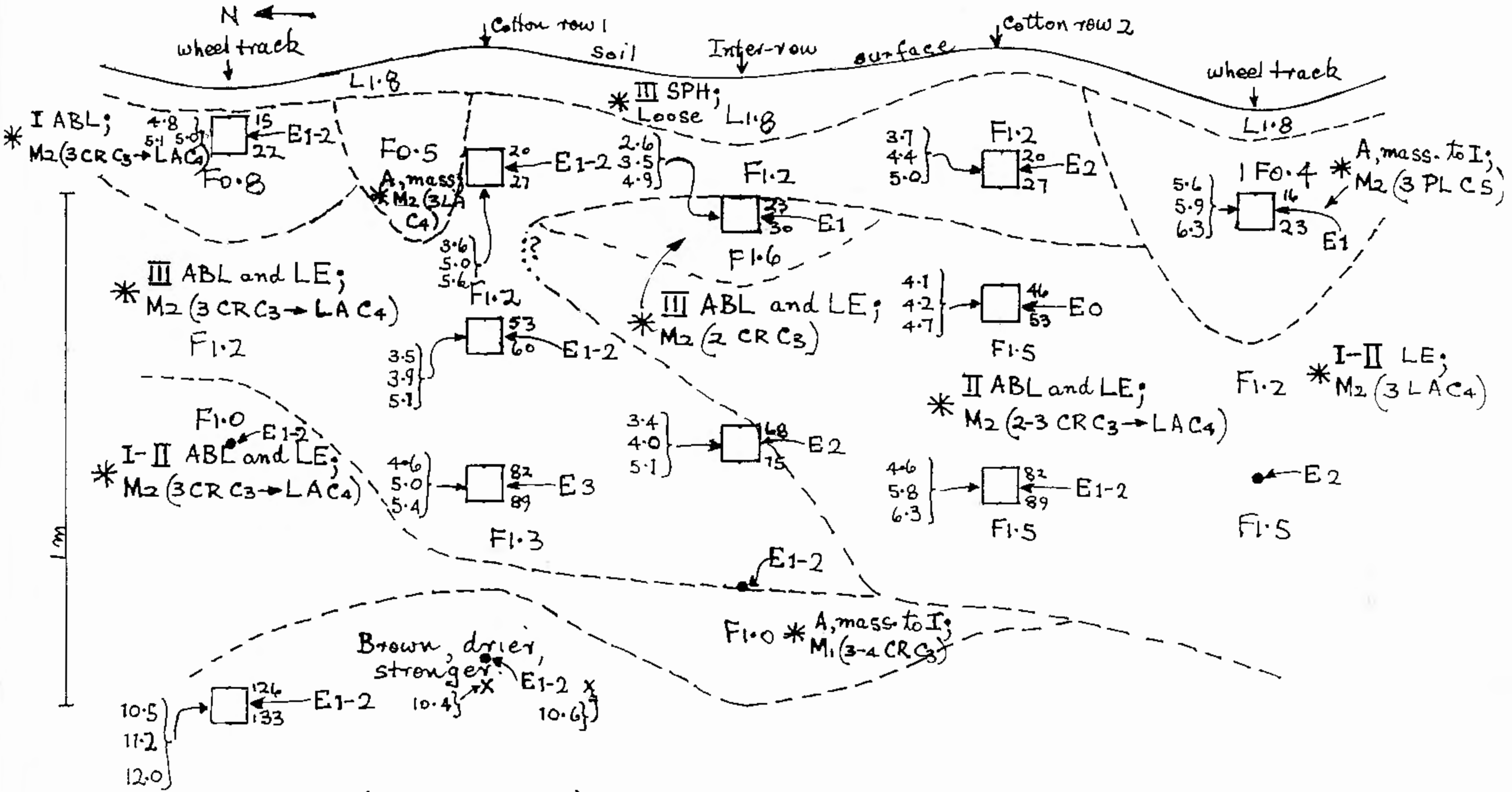
Vertical and horizontal scale 1:10

Sampled 29.11.91

Legend

●E1	Dispersion (soilpak) of field-moist soil — unworked
F1·2	Soilpak 3 structure rating
✳	Structure and consistence description — see text
(dashed line)	Rating zones
Shear vane readings near core 4·0, 4·9, 4·9 → □ 18 25	Position of core or clod sample (depth shown in cm)

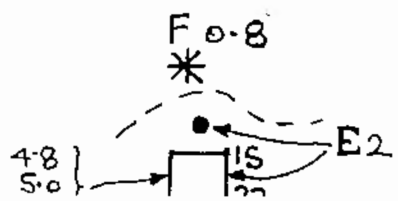
G.a.K. 14.12.91



PIT 4 (EAST WALL) — SOILpak RATINGS — TABLE C3-1

Legend

Vertical and horizontal scale 1:10



Soilpak β structure rating

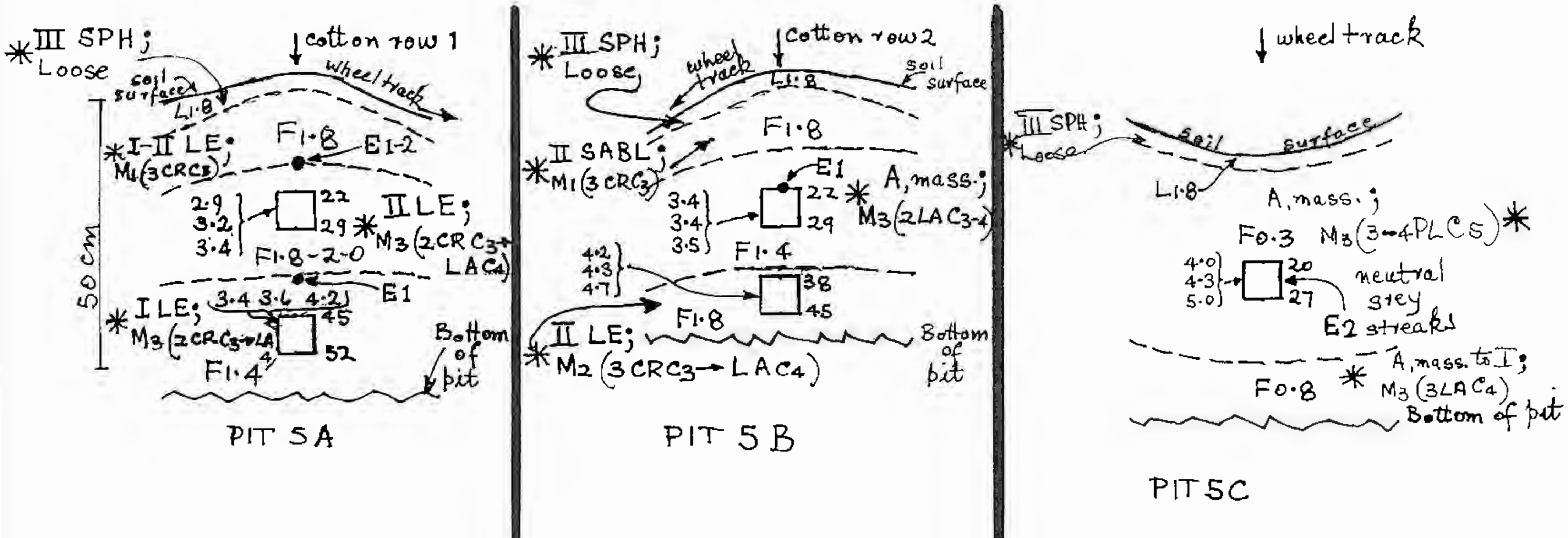
Structure and consistence description — see text

Rating zones

Dispersion (soilpak) of field-moist soil — unworked

Shear vane readings, mostly

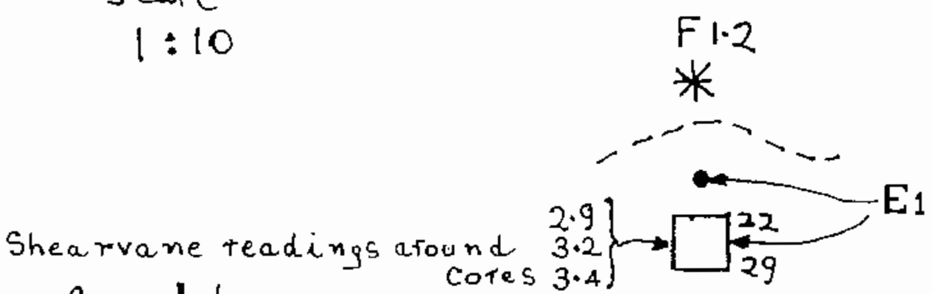
Position of core or clod sample (depth ...



PIT 5— SOILpak RATINGS —TABLE C3-1

Vertical and horizontal scale 1:10

Legend



Soilpak β structure ratings

Structure and consistence description — see text

Rating zones

Dispersion (soilpak) of field-moist soil — unworked

Position of core or clod (depth shown in cm)

Sampled 3.12.91

l. a. H. 14.12.91

Table 1: Rationalisation of Soilpak scores for the pits W.T. - wheel track, I.R. - inter-row, Row - cotton row

Zone No: *	PIT 1 W.T	PIT 1 ROW 1	PIT 1 I.R.	PIT 1 ROW 2	PIT 1 W.T.
1 3-13cm thick	←	←	L 1.8	→	→
2 20-60, 90cm thick	←	F 0.4 →	F 0.9 F 0.5	←	F 0.4 →
3 22-70cm thick	F 1.0	←	F 1.7 →	←	F 1.4 →
4 20+ to 40+ cm thick	←	F 1.0	→		

PIT 2A, 2B ROW 5	PIT 2A, 2B ROW 4	PIT 2A, 2B W.T.
←	L 1.8	→
F 1.2 F 1.7	F 1.1 F 1.6	F 0.3 F 1.7

PIT 3 W.T.	PIT 3 ROW 2	PIT 3 I.R.	PIT 3 ROW 3	PIT 3 W.T.
←	←	L 1.8	→	→
F 0.5 F 1.4	F 0.8 F 1.6	F 1.5	F 1.6	F 0.5 F 0.8 F 1.0
←	←	F 1.8	→	F 1.7
—	F 0.8	F 1.3	F 1.3	F 1.0

PIT 4 W.T.	PIT 4 ROW 1	PIT 4 I.R.	PIT 4 ROW 2	PIT 4 W.T.
←	←	L 1.8	→	→
F 0.8 F 1.2	F 0.5 F 1.2	F 1.2 F 1.6 F 1.5	F 1.2 F 1.5	F 0.4
F 1.0	F 1.3 ←	F 1.3 F 1.0	→	F 1.2 F 1.5
—	—	—	—	

PITS 5A, 5B, 5C ROW 1	PITS 5A, 5B, 5C ROW 2	PITS 5A, 5B, 5C W.T.
←	L 1.8	→
F 1.8 F 1.9 F 1.4	F 1.8 F 1.4 F 1.8	F 0.3 F 0.8

* counting from the surface

3.2 Assessment of Soils based on Ratings of Undisturbed Cores

Table 2 lists data calculated from the mass of the cores before and after drying at 105°C and their volume before drying. Table 3 attempts an assessment of the pits, using data from table 2.

3.2.1 Summary of assessments in table 3:

(i) Upper-profile samples When rated on the state of the soil in the 14-30 cm zone, directly below the cotton rows, part of pits 2, 4 and 5 have satisfactory porosities, while the duplicate samples from these same pits come close to, but do not reach, the limiting porosity of 0.1 $m^3.m^{-3}$ (Hodgson 1986). Next come pits 1 and 3 and a wheel track sample from pit 4 with lower porosities and, at very low porosities, a group of wheel track samples.

(ii) Mid - profile samples These range between 32 and 61 cm in depth. None has a satisfactory porosity and only one, an inter-row sample from pit 3, comes close. Pits 2, 4 and 5 are the best of this quite low group followed by pits 1 and 3, with a group of wheel track samples last.

(iii) Bottom samples These are generally from the depth range 68 to 103 cm (one is a deeper sample - 126 to 133). No deep samples were taken from pit sites 2 and 5. Of the ten samples from pits 1, 3 and 4, nine have low to very low porosities. Four are beneath wheel tracks but that may have no influence because of their depth - see comments on group 6 in table 3.

If one applies Hodgson's later threshold porosity of 0.14 $m^3.m^{-3}$ (Hodgson & McLeod, 1989 - quoted by Hulme *et al., loc. cit.* - only one core (pit 2A, row 4, 18-25 cm deep) has a satisfactory porosity. However the state of the soils has to be viewed in the context of the irrigation schedule and rain received. Sampling of the pits took place in late November when the young cotton crop had had limited opportunity to dry out the soil following the initial irrigation and some flushing in October. Also 45 mm of rain fell 11 days before sampling began and a further 20-30 mm fell part way through sampling.

3.3 General Comments

In the upper part of the soil profile exposed in the pits, compaction is clearly evident beneath wheel tracks but is not so clear under cotton rows or in the inter-row. However, the superiority of sites 2, 4 and 5 compared with 1 and 3 may indicate greater compaction under cotton rows at the latter two sites, of soils more prone to such damage because of their mineralogy and chemistry.

Table 2: Derived data from measurements made on undisturbed soil cores taken from pits*

LOCATION		SOIL DATA		WATER DATA		POROSITY DATA Total	Water-filled	Air-filled
Cotton row	Depth (cm)	Vol. fraction ($m^3.m^{-3}$)	B.D. ($kg.dm^{-3}$)	θg ($g.g^{-1}$)	θv ($cm^3.cm^{-3}$)	Volume ($m^3.m^{-3}$)	Volume ($m^3.m^{-3}$)	Volume ($m^3.m^{-3}$)
				PIT 1, FIELD 8				
Row 1	18-25	0.47	1.24	0.40	0.50	0.53	0.50	0.03
"	82-89							
Wheel track	19-26	0.48	1.28	0.41	0.53	0.52	0.53	-0.01
"	69-76	0.49	1.31	0.38	0.49	0.51	0.49	0.02
Row 2	20-27	0.45	1.19	0.43	0.51	0.55	0.51	0.04
"	82-89	0.50	1.32	0.36	0.48	0.50	0.48	0.02
				PIT 2A and 2B, FIELD 18				
Pit 2A								
Row 4	18-25	0.46	1.22	0.27	0.33	0.54	0.33	0.21
"	35-42	0.54	1.42	0.30	0.43	0.46	0.43	0.03
Pit 2B								
Row 5	18-25	0.50	1.31	0.32	0.42	0.50	0.42	0.08
"	32-39	0.50	1.32	0.33	0.43	0.50	0.43	0.07
Wheel track	20-27	0.52	1.38	0.33	0.46	0.48	0.46	0.02
				PIT 3, FIELD 20				
Row 2	23-30	0.49	1.31	0.35	0.46	0.51	0.46	0.05
"	54-61	0.48	1.27	0.37	0.47	0.52	0.47	0.05
"	96-103	0.50	1.34	0.36	0.48	0.50	0.48	0.02
Inter-row	31-38	0.46	1.23	0.39	0.48	0.54	0.48	0.06
"	74-81	0.49	1.31	0.35	0.46	0.51	0.46	0.05
Row 3	14-21	0.46	1.22	0.41	0.49	0.54	0.49	0.05
"	40-47	0.48	1.28	0.36	0.47	0.52	0.47	0.05
"	73-80	0.50	1.32	0.36	0.48	0.50	0.48	0.02
Wheel track	18-25	0.49	1.31	0.39	0.51	0.51	0.51	0.00
"	66-73	0.51	1.35	0.35	0.48	0.49	0.48	0.01

LOCATION		SOIL DATA		WATER DATA		POROSITY DATA Total	Water-filled	Air-filled
Cotton row	Depth* (cm)	Vol. fraction	B.D. (kg.dm^{-3})	θg (g.g^{-1})	θv (cm^3.cm^{-3})	Volume (m^3.m^{-3})	Volume (m^3.m^{-3})	Volume (m^3.m^{-3})
PIT 4, FIELD 11								
Right								
Wheel track	16-23	0.52	1.39	0.33	0.45	0.48	0.45	0.03
Row 2	20-27	0.49	1.30	0.33	0.43	0.51	0.43	0.08
"	46-53	0.50	1.32	0.34	0.45	0.50	0.45	0.05
"	82-89	0.52	1.37	0.33	0.45	0.48	0.45	0.03
Inter-row	23-30	0.50	1.33	0.33	0.44	0.50	0.44	0.06
"	68-75	0.51	1.35	0.35	0.47	0.49	0.47	0.02
Row 1	20-27	0.47	1.24	0.33	0.41	0.53	0.41	0.12
"	53-60	0.51	1.35	0.35	0.48	0.49	0.48	0.01
"	82-89	0.52	1.38	0.34	0.47	0.48	0.47	0.01
Left								
wheel track	15-22	0.50	1.32	0.35	0.46	0.50	0.46	0.04
"	126-133	0.54	1.43	0.28	0.40	0.46	0.40	0.06
PIT 5A and 5B, FIELD 31								
Pit 5A								
Row 1	22-29	0.49	1.29	0.32	0.42	0.51	0.42	0.09
"	45-52	0.53	1.42	0.30	0.43	0.47	0.43	0.04
Pit 5B								
Row 2	22-29	0.47	1.25	0.32	0.41	0.53	0.41	0.12
"	38-45	0.51	1.36	0.33	0.45	0.49	0.45	0.04
Pit 5C								
Wheel track	20-27	0.51	1.35	0.35	0.47	0.49	0.47	0.02

* See map 1 for location of pits and the Soilpak rating diagrams for position of cores in pit faces.

Table 3: Rating and grouping of soil cores in decreasing order of favourableness for plant growth (principally air-filled porosity) and increasing compaction (inferred).

GROUP	FEATURES OF GROUP			SOILS IN GROUP*			COMMENTS AND RATING
	B.D.**	**Moisture** (θg)**	**Air-filled** porosity**	**Pit No.**	**Cotton low**	**Depth (cm)**	
1A	low	low	high	2A	Row 4	18-25	Has high shrink-swell capacity yet maintains high porosity at low moisture: that is has adequate pores for aeration. Best soil.
1B	low	interm.	high	4 5B	Row 1 Row 2	20-27 22-29	Similar to 1A but may be slightly less favourable for plant growth. Site 5 was chosen as a poorer soil showing Galathera symptoms.
2	interm.	interm.	interm.	5A 4 2B 2B	Row 1 Row 2 Row 5 Row 5	22-29 20-27 18-25 32-39	Shows a regression in conditions for plant growth compared with group 1B but better aerated than group 3. This may simply be due to it being drier. Sites 2 and 4 said to be Galathera - free.
3	low	high	low to very low	1 1 3 3 3	Row 2 Row 1 Inter-row Row 3 Row 2	20-27 18-25 31-38 14-21 54-61	Has high shrink-swell capacity and poor aeration at high moisture. Susceptible to damage but does not appear to have been compacted or may have recovered. Sites 1 and 3 were chosen as areas producing severe Galathera symptoms.
4A	interm.	high	low	3 3 3 4	Row 2 Row 3 Inter-row Left wheel track	23-30 40-47 74-81 15-22	Appear to have suffered a reduction in total porosity at high moisture levels either due to compaction (row 2 and and wheel track) or natural confinement in the subsoil (inter-row sample) or perhaps both (row 3).

Table 3 continued

GROUP	FEATURES OF GROUP B.D.**	Moisture** (θg)	Air-filled** porosity	SOILS IN GROUP* Pit No.	Cotton low	Depth (cm)	COMMENTS AND RATING
4B	interm.	interm.	low	4 4	Row 2 Inter-row	46-53 23-30	Much the same as 4A except moisture slightly lower. Site 4 chosen as a non-Galathera site - soil may be better drained internally than Galathera sites.
5A	high	interm.	low	5B 5A 4	Row 2 Row 1 Left wheel track	38-45 45-52 126-133	Their high bulk density and intermediate moisture levels not withstanding, these have low air-filled porosities. It is inferred that they have been compacted or that their basic mineralogy and chemistry make them inferior soils. Confinement at depth may be the cause in the deep sample from pit 4.
5B	high	interm.	very low	4 4 2A 2B 4	Row 2 Row 1 Row 4 Wheel track Right wheel track	82-89 82-89 35-42 20-27 16-23	These are in poor condition either because they are deep in the subsoil and therefore confined during swelling (pit 4) or have been compacted by implements (pits 2A and 2B and right wheel track, pit 4).
6	interm.	high	very low	4 1 3 3 4 1	Row 1 Row 2 Row 2 Row 3 Inter-row Wheel track	53-60 82-89 96-103 73-80 68-75 19-26	Except for the first sample listed, these are either deep in the profile, where overburden confinement during swelling could produce higher bulk density at high moisture content, or are at the surface and have been compacted by wheel traffic whilst moist and soft.

Table 3 continued

GROUP	FEATURES OF GROUP			SOILS IN GROUP*			COMMENTS AND RATING
	B.D.**	Moisture** (θg)	Air-filled** porosity	Pit No.	Cotton low	Depth (cm)	
				1	Wheel track	69-76	Their reduced total porosity reflects their poor status. Compaction under wheel tracks is said not to extend beyond about 70 cm depth.
				3	Wheel track	18-25	
				3	Wheel track	66-73	
				5C	Wheel track	20-27	

* Groups labelled "A" and "B" are believed to be closer together than adjacent groups labelled with greater or lesser figures.

** The categories "high", "intermediate", "low" and "very low" are relative only and are defined as follows:

	High	Intermediate	Low	Very low
Bulk density (B.D.)	>1.35	1.28 - 1.35	1.19 - 1.27	
Moisture (θg)	>0.34	0.28 - 0.34	0.20 - 0.27	
Air-filled porosity	≥ 0.10	0.07 - 0.09	0.04 - 0.06	0.00 - 0.03

Site 5 was chosen as a Galathera - prone site but seems to be better than expected - see earlier comment.

Beneath a wheel track at pit 5, in the compacted zone of the upper profile, blue - grey (i.e. neutral grey)* colours were observed as a halo around a piece of buried cotton stem from a previous crop. These colours are clear evidence of reducing conditions. This occurrence is a reminder of the role of organic matter in the reducing process. Paradoxically, lowered organic matter in soils subject to poor aeration may lessen the severity of reduction and its impact on oxygen supply to the root. Soil sterilization might be expected to have the same effect at first, depending upon how deeply that treatment penetrates but later, when the microflora recover, the reverse effect might be observed.

4. DISCUSSION

Over a number of years several physical, chemical and biological causes of the Galathera condition have been suggested and tested - Constable (1990a, 1990b, 1991) Allen (1991) Anon (1991). No single definitive cause has been identified. The project, of which this field work forms a part, aims to eliminate (or implicate) one more possible cause - herbicide residues - but also aims to check on the physical and chemical properties of the soils and differences among them relevant to the growth of cotton. From the work done so far, the following hypothesis is put forward.

4.1 Hypothesis

Although there are only small differences apparent in soil morphology across the soil sequence on Auscott, the Galathera condition appears to occur on the greyer, more frequently flooded soils (map 2 and overlay). Affected areas can be sharply defined but the severity of the condition often decreases over some distance - see map 2. These observations would be consistent with some property or properties of the soils which change with distance from the streams. Such properties as exchangeable sodium, lime content, organic matter levels and fine-clay content could do that. But the occurrence of small plants is not confined to the Galathera syndrome areas. Noticeable variation in plant height was observed elsewhere, though less commonly in the better areas. Whilst, in a young crop, this variation could be due to causes other than adverse soil conditions, it would also be consistent with small pockets of poorer soil scattered through the fields, both horizontally and vertically, such that individual young plants, with an, as yet, small root system, could be severely affected temporarily, while their neighbours may not be (P. Cull, Consultant, Narrabri; pers. comm., 1991). The Galathera areas may

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* On the Munsell chart these colours are seen to be independent of hue and to have zero chroma, indicating that they are pure mixtures of black and white - that is pure greys or neutral greys.

simply have more of these poorer sites, in a worse state, than non-Galathera areas - their frequency and their harshness for plant roots may decrease slowly outwards from the streams.

The distinguishing feature of Galathera syndrome is said to be the recovery by the affected cotton later in the growing season: from there on it grows more rapidly than the unaffected crop. This can be explained as a consequence of a much larger root system which, later in the season, is not confined to the poor sites and which, by that time, has dried out the deeper subsoil, from the wet state it was in after the initial irrigation of the season, thereby creating for itself a better-aerated subsoil environment. This may sustain the crop for the short period of anaerobic conditions in the upper profile produced by each irrigation. The late starter now "bolts" to catch up.

New ground does not suffer from the Galathera condition: it appears after the "honeymoon" seasons of early high yields - when the organic matter has declined and the repeated irrigation and the passage of implements has begun to take effect. The greyer soils deteriorate faster under cropping than the browner subsoil phase - they are more prone to damage due to their mineralogy, physics and chemistry.

For example, the head ditch end of field 20, on a Galathera - syndrome site, was shown to have a significantly higher exchangeable sodium percentage than the tail ditch end of the same field and also higher than field 15, a non-Galathera site. Soil breakdown in water was correspondingly higher at the head of field 20 than at its tail or in field 15 - see soil analysis results, June 1986, B. & C.R.I., in appendix II.

If the above hypothesis is correct, physical deterioration would be the likely cause of the syndrome. In section 2.2.3 it was stated that, when moist, the Auscott soils are soft and weak. Therefore poor aeration, not soil strength, would appear to be the likely problem. There is nothing new in all this - see Hodgson (*loc. cit.*) Hulme et al (*loc. cit.*) and McKenzie *et al.* (1991). Also the importance of macropores is emphasised by Daniells & Larsen (*loc. cit.*). Compaction may not be the only way to induce poor aeration.

Poor aeration would account for retarded growth, low petiole nitrogen (reduced N uptake aggravated by denitrification), high levels of manganese in the plant, unfavourable biological conditions in the soil, changes in growth with time as the soils wet and dry, the differences in growth, on Galathera - prone areas, of winter (non-irrigated) and summer (irrigated) crops, the greater sensitivity of cotton to the Galathera condition compared with wheat, safflower and (possibly) *Dolichos lab lab*, improved yields of cotton following Dolichos (more organic N, protected from denitrification and more macropores in the soil) and progressive deterioration of the soils under continued cropping. In the soils most affected an increase in soluble phosphorus should be detectable if reducing conditions develop early in the season.

Judged by the porosities of the undisturbed cores, pits 2 and 4 (non-Galathera sites) and 5 (in Galathera - prone land) are better than 1 and 3 (Galathera sites) in the upper profile, marginally better? in mid-profile and no different in the deeper subsoil.

Judged by the Soilpak ratings, in the upper profile, pit 5 is best, 2 and 3 are equal, 4 comes next and 1 is poorest. In mid-profile 3 is best? followed by 2 then 4. No statistical analysis was attempted.

Observations on the undisturbed cores ranked the pits best if the pits are judged by past yields and growth patterns. The poorer performance of Soilpak may simply reflect the inexperience of the operator.

The results of the phytotoxin screening and the laboratory results for samples from the traverses and the pits are awaited with interest.

21.1.1992

References.

Allen, S (1991) Auscott Field 20, 1990-91. Unpublished results of V.A.M. trials.

Anon. (1991) Galathera syndrome update and summary. Unpublished farm trial report.

Anthony, D. (1990) Mycorrhizal update. Unpublished summary.

Butler, B.E. (1955) A system for the description of soil structure and consistence in the field. J. Aust. Instit. Agric. Sci. 21, No. 4, 239-49.

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

Constable G. Brown, D. Anthony, D. Murray, J. and Williams R. (1989) Think tank on nutritional disorders of cotton on Galathera Creek. Unpublished.

Constable, G. (1990a) The Galathera syndrome. Unpublished review and experimental results.

Constable, G. (1990b) Nutrition. Unpublished results of zinc, potassium, gypsum and lime experiments on cotton.

Constable, G. (1991) Phosphorus x zinc experiment Auscott, Field 20 1990-91. Unpublished data.

Daniells, I and Larsen, D. (Eds.) (1991) Soilpak ß, a soil management package for cotton production on cracking clays. N.S.W. Agriculture.

Hawkins, C.A. and Flint, S.E. (1958) Soil association map, part of County Jamison N.S.W. NSW Dept. of Agriculture and W.C. and I.C. Unpublished.

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

Hulme, P.J. McKenzie, D.C. Abbott, T.S. and MacLeod, D.A. (1991) Changes in the physical properties of a vertisol following an irrigation of cotton as influenced by the previous crop. Aust. J. Soil Res., 29 425-42.

Isbell, R.F. (1989) A classification of Australian soils (first approximation). Tech. mem. 32, Division of Soils, C.S.I.R.O. (unpublished)

McDonald, R.C. Isbell, R.F. Speight, J.G. Walker, J. and Hopkins, M.S. (1990) Australian soil and land survey field handbook, 2nd Edit. Inkata Press.

McGarry, D. Ward, W.T. and McBratney, A.B. (1989) Soil studies in the lower Namoi Valley : methods and data. 1 The Edgeroi data set. Division of Soils, C.S.I.R.O., Brisbane.

McKenzie, D.C. Abbott, T.S. Anthony, D.T.W. Hulme, P.J. MacLeod, D.A. and Higginson, F.R. (1990) Management of subsoil degradation in an Australian vertisol used for irrigated cotton production. Trans. 14th Int. Congress of Soil Science, Kyoto, VI, 176-181.

McKenzie, D.C. Abbott, T.S. and Higginson, F.R. (1991). The effect of irrigated crop production on the properties of a sodic vertisol. Aust. J. Soil Res., 29, 443-53.

Northcote, K.H. (1974) A Factual key for the recognition of Australian soils, C.S.I.R.O. Rellim Technical Publications, Adelaide.

Thomson, H and Cull, P. (1989) Wheel track compaction - the effects on plant growth and yield of cotton. The Australian Cotton Grower, August - October 50-53.

Ward, W.T. (1992) Soils and landscapes near Narrabri and Edgeroi, N.S.W. with data analysis using fuzzy k - means. Soils and Land Use Series No. 63, Division of Soils, C.S.I.R.O.

APPENDIX I

A SYSTEM FOR THE DESCRIPTION OF SOIL STRUCTURE AND CONSISTENCE IN THE FIELD

By B. E. BUTLER

Summary

A system for the field description of soil structure and consistence is outlined. In the description of structure it follows fairly closely the traditional approach, though there is a more definite integration of the concept of the *ped*. An attempt has also been made to separate clearly the parameters of soil structure—grade, shape, and size. Consideration is also given to the breakdown of primary structural units. The system makes a new approach to the description of consistence. This is based on an assessment of the yield-point, and on the effect of a small, prescribed amount of work done on a piece of the soil material. To evaluate the effect of the work done, two concepts, coalescence and pulverescence, are introduced. The consistence parameters of a number of soil materials are discussed in relation to moisture status and texture.

Introduction

In scientific work one of the purposes of descriptive method is to effect a preliminary segregation of the data which will facilitate quantitative studies. In soil survey work in New South Wales it has been apparent for some years that the existing descriptive systems for soil structure and consistence (Templin et al. 1945; Anon 1948, U.S.D.A. 1951) did not serve this purpose adequately. In many instances differences were apparent between soil materials which these systems could not distinguish. Since 1945 soil surveyors in the region have adopted a series of changes in their descriptive methods, and these have finally culminated in a system which seems sufficiently distinct to justify publication. The system has been in regular use by four or five soil surveyors for several years now, and some confidence can be entertained that it is both usable and broad enough in scope to cover the range of soil conditions likely to be encountered.

The description of the physical conditions of soil materials in the field is mainly subdivided under the three headings of texture, structure and consistence. A comprehensive description should include other features also, as indicated by Smith & Cernuda (1952) but these will not be elaborated in this report. Texture, in the field, refers to the physical characteristics of the material when it is kneaded into a homogeneous state. Consistence on the other hand refers to its physical characteristics without preliminary kneading. Structure refers to form and orderliness in a mass of soil.

The system of structure and consistence description has been embodied in a code to assist recording, and this will be presented *pari passu*.

Preliminary Considerations

Peds

The scope of the term *soil structure* is quite wide (Zakharov 1927, Yoder 1937, Russell 1938, and Nikiforoff 1941). The soil surveyor's or soil morphologist's use of the term has a restricted significance and follows in the tradition set by Zakharov (1927) who defined soil structure as "the very fragments or clods into which the soil breaks up". The breaking of a mass of soil, the size, shape and orientation of the pieces are the essential considerations in this context. The concept of the *ped* (U.S.D.A. 1951, p.225) develops these ideas further, and it is adopted as a central idea in this report.

When a mass of soil material is broken down it may happen that the resulting pieces are all of one particular size and shape. When such a characteristic population of pieces occur they are called peds, and defined in terms of size, shape and orientation. The actual size and shape of peds from different soil materials

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may differ widely, though peds from the one soil material are uniform.* In contrast to peds, a soil material may break into *fragments* which have no uniform size and shape, or into its ultimate particles. Soil materials do occur having the property of breaking down entirely to peds, in fact some are in this form even without any preliminary breaking. In many soil materials, however, the result of breaking is that, whilst a proportion of the material occurs as peds, some considerable proportion of it consists of fragments and ultimate particles. The proportion of peds depends on both the tendency of the soil material to form peds, and also on the amount of work done on the soil mass. With increasing amounts of work done on a soil mass several successive populations of peds may be produced, each smaller than the preceding one; and sooner or later an increasing proportion of fragments and ultimate particles appear. In the final case all soil materials would be reduced to their ultimate particles, and any differences due to a special arrangement of particles would be obliterated.

A few words may be added about the breaking of materials. A material which has a uniform force of cohesion throughout its mass will break into such pieces and in such a manner depending solely on the way in which it is stressed. The predisposition of certain soil materials to break into peds clearly indicates that the force of cohesion in the mass is *not* uniform. Moreover, there must be an orderly variation in the force of cohesion and this orderly variation may be different along the different axes. Furthermore, the fact that some soil materials will break down into successive populations of peds of smaller and smaller size as more work is done on them, indicates that the pattern of cohesion may be not only orderly but complex too, and may be likened in graphical representation to a wave-on-wave arrangement. This complex variation in the cohesion factor may pass through the macro-scale, where it is expressed by visible peds, well across into the micro-scale where its final expression will be determined by the size of the ultimate soil particles. Its expression in the micro-scale should be sought in its influence on the cohesive properties of the material. A datum for comparison here would be the cohesive properties of the same material when any specific orderliness (it may be called fabric) has been destroyed by kneading or other work done.

There is a clear basis for distinguishing those soil materials which break down to form peds — *pedal** soil materials, from the non-pedal or *apedal** soil materials; and this is whether or not the pieces into which it breaks have some characteristic size and shape, or if the sizes and shapes depend solely on the manner in which it is stressed during the examination. It may be mentioned here that some soil materials are pedal in the larger sizes but apedal if broken finer, e.g., some of the coarser B horizons of solodised solonetzs. On the other hand the lower horizons of krasnozems are usually apedal in the larger sizes, though with well-developed peds in the $\frac{1}{4}$ and $\frac{1}{8}$ inch range.

Consistence

The consistence of a soil material is the strength and kind of cohesion manifest in it. The strength of cohesion can be determined as the magnitude of the force needed to cause disruption or distortion. The *kind* of cohesion is determined in this present system by the characteristics which develop in the material when a certain amount of work is done on it. The kind of cohesion in the soil material *before* any work is done on it is the specific information sought, so the amount of work done is selected

*It seems reasonable that simple multiples in size and shape may be credited as peds.

*It seems more consistent to use the terms pedal and apedal for structured and structureless respectively, since the terms refer specifically to the criterion by which they are determined. Moreover the introduction of the term apedal avoids the contradiction of stating that the structure of a given soil is "structureless".

as the minimum needed to give a reaction.

Scale of Forces

In the assessment of consistence, and to a lesser extent in assessing structure, it is necessary to be able to refer to the magnitude of force, specifically the force needed to overcome cohesion in the soil material. For a field descriptive procedure the method so far adopted has been the standardisation of the force exerted in manipulating a piece of soil in the hand. Since the strength of a piece of soil varies with the size of the piece, the forces listed below refer specifically to a ped or fragment about ½ inch size. Where smaller pieces must be used, allowance must be made on the basis of the size-strength relationship (Marshall & Quirk 1950). The manipulation involves a compressive shear force exerted between thumb and fingers, and the force nominated is that which is just sufficient to cause breaking or bending. The scale of forces is:—

(1) Force 1—a very small, almost nil, force. Code 1. Sometimes it is convenient to employ force zero to indicate actual separateness, as in loose sands.
(2) Force 2—a small, but significant, force. Code 2.
(3) Force 3—a moderate force. Code 3.
(4) Force 4—a strong force, but conveniently within the power of thumb and fingers. Code 4.
(5) Force 5—a very strong force, at and passing beyond the capability of thumb and fingers. Code 5.

This scale of forces is used, without variation, for any determination referring to structure or consistence.

Scale of Moistness

Each description of consistence is referred to a moisture stage of the soil material. Experience indicates that soil structure, too, especially structure grade, varies with moistness. For field description the moistness scale of Canada (Anon 1948) has been adapted here. A modification has been made by subdividing each moisture stage into three*. The moisture scale is specified as follows:—

(1) Dry—the material becomes darker, or assumes a lower colour value (Munsel notation) when moisture is added. Code D, and subdivided into D_1, D_2 and D_3; D_1 being driest, and D_3 contiguous to the moderately moist stage.
(2) Moderately moist, the material is not dry and it is not moist or wet. Code MM, and subdivided into MM_1, MM_2, and MM_3; the lastnamed being contiguous to the moist stage.
(3) Moist—the material is capable of being rolled between thumb and fingers into homogeneous rods not more than ⅛" diameter and at least ½" long. Code M and subdivided into M_1, M_2 and M_3; the lastnamed being contiguous to the wet stage. The magnitude of the force needed and the time taken to mould the rod is irrelevant.
(4) Wet—the material will wet and/or stick to the fingers when moulded. Code W, and subdivided into W_1, W_2 and W_3; the lastnamed being wettest.

It will be apparent that non-coherent materials such as sands and silts cannot conform to the "moist" specification. Local practice is usually to place such materials in this range by judgment, however, the alternative course of not referring them to the moist range at all would not cause serious misunderstanding.

From field observation it seems that the wilting point of a soil is MM_1 and field capacity is M_3. Air dryness is D_1, D_2 or D_3 depending on the atmospheric

*This subdivision of each moisture stage has been criticised in Australia as unreal and unreplicable; however, soil surveyors who regularly use this system prefer its retention. The threefold subdivision accommodates the degrees of perfection with which the individual example matches the specification. For example, the moist stage requires that the material should be mouldable into rods ⅛" diameter and at least ½" long; the "moist 1" material will just do this; the "moist 2" material fills these specifications liberally; and the "moist 3" material is similar but in addition it tends to be sticky.

humidity. However, these indications have not yet been confirmed, neither is it known whether the moisture stages can be correlated with pF values or with per cent. moisture content.

Structure

The points to be evaluated in the structure description are:—

(1) The grade of structure, or the completeness with which the soil mass occurs as, or will break into peds.

(2) The shape of the peds and their orientation.

(3) The size of the peds.

(4) The breakdown of the primary peds to secondary peds—when applicable.

The descriptive system and the code presented here follows generally that proposed by Hubble (1948).

Grade of Structure

This is the readiness and completeness with which a mass of soil material will break down into peds (U.S.D.A. 1951, p.220). It is the difference between inter- and intra-aggregate cohesion (Nikiforoff 1941). There is little prospect of measuring these forces adequately in the field, and the course adopted in this system is simply to drop a spadeful of undisturbed soil material from a sufficient height to cause disruption. The structure grade is assessed as follows:—

(1) Apedal—none of the material occurs in the form of peds; it consists wholly of fragments and/or ultimate particles. Code A.

(2) Weak—up to one-third of the material consists of peds, the remainder of fragments of disorganised shapes and sizes or of ultimate particles. Code I.

(3) Moderate—between one-third and four-fifths of the material consists of peds. Code II.

(4) Strong or high—over four-fifths of the material consists of peds. Code III.

Shape and Orientation of Peds

The earlier naming of structure forms as "granular", "nutty" (e.g., Northcote et al. 1954, p.17) and other naturalistic forms is unfortunate for clarity since each is likely to involve both size and shape connotations, besides being vague on what is the naturalistic form intended, e.g., what *nut* nutty refers to. It is more desirable to entirely separate size and shape considerations, and refer all shapes to geometric forms which allow of no variations of individual interpretation. Under these circumstances no special definitions are called for. The following terms have been used locally:—

(1) Blocky or cubic, referring to the form of a cube. Subdivided into angular blocky (code ABL) and subangular blocky (code SABL) according to the sharpness of the corners.

(2) Prismatic: referring to the form of a prism with the longer axis in the vertical plane. Subdivided into angular prismatic (code APR) and subangular prismatic (SAPR) according to the angularity of the vertical edges. The nature of the top of the prism, whether domed, flat or pointed, may be added as a postscript.

(3) Polyhedral: referring to the shape of those polyhedrons having more than six sides. Code PH. Only forms with sharp corners are known to occur.

(4) Parallelepipedal: referring to the shape of the parellelepiped or solid skewed-paralellogram. Code PLL.

(5) Platy: referring to a solid form with horizontal faces well developed and vertical faces ill-defined and of a smaller dimension. Code PL.

(6) Spheroidal: referring to the form of a sphere. Subdivided into a solid sphere (code SSPH) and a sphere with visible voids (code VSPH).

Size of Peds.

This is given simply in inches and fractions thereof. For geometric forms having unequal dimensions, such as the prism, both dimensions are given, e.g., APR 1" x 3". In using the code the size specifications must always be followed by the inch abbreviation (") or the figures may be confused with force values.

Breakdown of Primary Peds

The usual description of structure refers to the largest peds which the soil material can produce. But in many soil materials these primary peds will break down readily to a second population of smaller peds, and these may be of a different form from the primary peds. This property of a soil material is worth including in a description, and as the primary peds can frequently be manipulated in the hand, some estimate of the force involved in the breakdown can be given.

Examples of the Code for Structure

The accepted form for the code is:—

III (ABL2")

with the structure grade placed first, and in parenthesis the ped form followed by the dimension of the ped. In the case of apedal materials the code "A" completes the statement as far as structure is concerned; the following consistence description will provide all further information needed. Where the breakdown of peds is described it follows the normal structure statement, preceded by the relevant force designations, viz.:—

III (APR 3" x 8"), 1, ABL ½", 2, ABL ¼"

Consistence

As mentioned above the points to be evaluated in describing the consistence of a soil material are the strength of cohesion and the reaction to a minimal amount of work done. The procedure adopted is to take a piece of undisturbed soil material of about ¾" size and, holding it between thumb and fingers, apply a compressive-shearing force of just sufficient magnitude to cause the piece to deform or break. This force is expressed in the scale of forces set out above, and it is the first value sought for the consistence description.

The work to be done on the soil material to obtain the second value is the application of this same force by a rotary movement of thumb and fingers for two seconds. It will be seen that the amount of work to be done is not the same for all soils; it is adjusted to the cohesive strength of each sample, and is the minimum amount that will give a reaction (bending or breaking) during the two seconds of application. When work is done on soil materials the result may be either to break them down to smaller and smaller pieces until finally the ultimate soil particles are separated, or alternatively, the final result may be a coherent, plastic mass. In the latter case the material may have the plastic property at the commencement of working, or it may only appear after passing through a friable state. These manifestations are the bases of the descriptive system, and their expression is vested in the concepts and scales of *pulverescence* and *coalescence*.

Pulverescence

The consideration of pulverescence is applicable to soil materials which break into smaller and smaller pieces as a result of work being done on them. The significant characteristic is the manner of breaking, whether into a population of peds, or into an unsorted assembly of fragments and/or ultimate soil particles. The introduction of the ped concept into consistency considerations has been mentioned earlier in this paper. The occurrence of peds on the microscale has a strong influence on the force of cohesion. A mass of soil material which is strongly pedal has a much lower cohesion than a mass of soil of the same texture which is apedal.

The soil material which does not break into peds will break into fragments and/or ultimate particles. This material, not being predisposed to break into pieces of any particular size and shape, must be bonded uniformly. It would seem to follow that whether it breaks down to fragments in one case, or to ultimate particles in another, there is no essential difference in the kind of cohesion, but only in the effectiveness of the applied work. It is concluded from this argument that there is no justification for distinguishing the fragments from the ultimate particles in assessing pulverescence.*

A scale of pulverescence has been adopted which depends on the amount of peds in relation to fragments and/or ultimate particles in the hand sample after it has worked as defined above:—

Pulverescence 1: less than one-tenth of the material occurs in the form of irregular fragments and/or ultimate particles. Code P1. Pulverescence zero may be used if the material consists entirely of peds.

Pulverescence 2: between one-tenth and one-third of the material occurs as fragments and particles. Code P2.

Pulverescence 3: between one-third and two-thirds of the material occurs as fragments and particles. Code P3.

Pulverescence 4: between two-thirds and nine-tenths of the material occurs as fragments and particles. Code P4.

Pulverescence 5: more than nine-tenths of the material occurs as fragments and particles. Code P5.

Coalescence

The consideration of coalescence is applicable to soil materials which have plastic properties or else develop plastic properties as a result of work being done on them. The essential aspect of the plastic state is that the material deforms or bends, as distinct from breaking. The ideal plastic material bends without any associated breaking, but very rarely is this state found in undisturbed soil materials: they usually require that work be done on them before this state is developed. In soil materials there is more or less of breaking and crumbling, and, as work is continued, the material then coalesces into the plastic state.

A scale of coalescence has been adopted which depends on the proportion of the hand sample which has coalesced into the plastic form after work has been done on it as defined above. The amount of initial breaking is also taken into account.

Coalescence 1: less than one-tenth of the material occurs as plastic rods or balls. Code. C1. Coalescence zero may be used for material giving no coalesced portion.

Coalescence 2: from one-tenth to a half of the material occurs in the form of plastic balls. Code C2.

Coalescence 3: from one-half to nine-tenths of the material occurs in the form of plastic balls. Code 3.

For C1, C2 and C3 there is always a clear development of the friable state during working, and this is followed by a variable amount of coalescence by the time working stops. For C4, C5 and C6 there is no significant amount of un-coalesced material at the completion of working, and the differentiating factor is the amount of preliminary fracture which occurs.

Coalescence 4: more than nine-tenths of the material occurs in the coalesced form, and subdivision of the primary pieces results from work. Code C.4

Coalescence 5: all of the material occurs in the coalesced form and there is no subdivision of the primary piece, but some fracturing can be seen at the commencement of working. Code C5.

Coalescence 6: as for C5 but there is no preliminary fracturing to be seen. Code C6.

Soil materials with a high coalescence are very prone to change to the coalesced form when handled. Their reaction to the soil auger or spade during removal of the sample should be carefully noted and the piece selected for description taken only from the uncoalesced portion.

*Some field workers prefer to consider them separately, confining the term pulverescence for the tendency to go to ultimate particles, and using "fragmentariness" for the tendency to go to fragments

General Descriptive Terms for Consistence

A statement of the appropriate pulverescence and/or coalescence values will specifically describe the soil material, but there is some use for more general, descriptive terms. Those adopted, and their specifications, are shown in Figure 1. The words crumbly (code CR), brittle (code BR), labile (code LA) and plastic (code PL) are each used with a special meaning, which is not, however, in conflict with their meaning as given in the Oxford Dictionary.

The Full Statement of Consistence

It is proposed that the full statement of soil consistence should include the following:—

(1) Moisture stage.
(2) The force of cohesion (yield point) of the $\frac{3}{4}$" piece.
(3) The general descriptive term of consistence.
(4) The size of the smallest peds to be seen during working.
(5) Statement of pulverescence and coalescence.

The proposed form for writing the code is

M2 (2 LA, $\frac{1}{16}$") P2, C3

with the first term being the moisture stage, the first inside the parenthesis the yield point, the second the general descriptive term of consistence, the third the smallest size of ped, and after the parenthesis first the pulverescence value and then the coalescence value.

Discussion

The method set out above is intended merely to describe soil materials; the measurements involved are not sufficiently rigorous for the examination to amount to an analysis in the scientific sense. Its chief value is that it involves a closer and more detailed examination of the soil than is usually given, and it provides a language and a system for talking about some of the physical properties of soils. It is in this light that the diagrams in the later part of this paper should be read

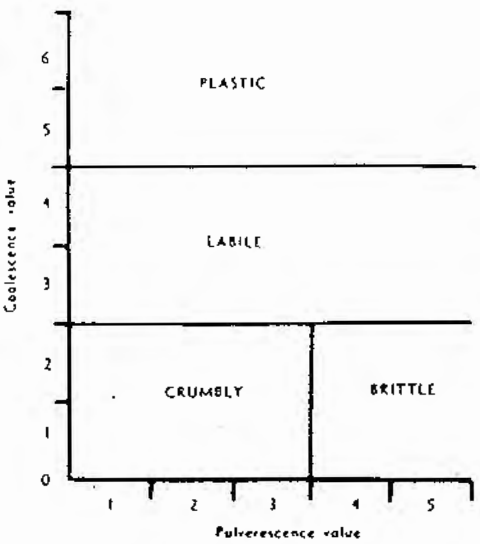

Figure 1.

Showing the general consistence categories in terms of pulverescence and coalescence.

The Force 5 and Beyond

Materials with a cohesive force of 5 or more need some comment. The assessment of forces beyond 5 has not been allowed for in this system, and some expedient such as striking with a hammer (U.S.D.A. 1951, p.234) may be resorted to. In actual fact soil materials, other than stones concretions and hardpans, rarely suggest the need for a force greatly in excess of 5 if the $\frac{3}{4}$" lump specification is adhered to. But even so it is sometimes difficult to determine the kind of consistence for these materials and they can be merely described as "5", e.g., D1(5). Since consistence descriptions for several moisture stages are needed to characterise a soil material, the moister consistence descriptions will help to throw light on the significance of the drier one.

Cemented and Sticky Consistence

The omission of cemented and sticky consistences from the present system may require some comment. In regard to cemented consistences, their chief feature, apart from high forces of cohesion, is that the kind and magnitude of cohesion varies very little or not at all with changes of moistness. Since the descriptive system as proposed above can convey these features it has not seemed necessary to create a special category for them.

The need for consideration of sticky consistences has not emerged in the region where this consistency descriptive system was developed. It seems that stickiness over and above that due to mere wetness is confined to coalesced materials, and as the description applies to soil materials before coalescence, attention has not been given to it. Nevertheless it may be a useful criterion for distinguishing one soil material from another, and its incorporation in a descriptive system thereby vindicated. The case may be met by adopting the standards of stickiness—slightly sticky, sticky and very sticky—defined in the Soil Survey Manual (U.S.D.A. 1951, p.232).

Consistence in Relation to Texture

The greatest significance of consistence properties is gained by considering them in relation to texture. Each texture class has a "normal" range of consistence properties, with the properties changing according to the moistness of the sample. For example a "normal" heavy clay has a cohesion of force 5 when dry, and this falls to about 3½ or 4 in the moist stage; at about moderately moist 2, plastic properties begin to appear and these increase to coalescence 5 at moist 3. However there is a great diversity of consistence properties of clays, and it may be said that, for clays, these vary all the way to those of sands. The range of consistence properties is less for clay-loams than for clays, and for loams less than for clay-loams. Sands alone have a very narrow range of consistence properties. In the ensuing discussion it will be most illuminating therefore to give particular attention to clays, though the same principles apply to lesser degrees, to the less clayey textures.

Texture of soil materials, as determined in the field, is based on consistence properties of the material when kneaded for 20 seconds or so between thumb and fingers at a specific moisture stage (usually M3). According to the cohesion and plasticity of the material under these conditions, and the "feel" of the coarser grain sizes, it is classified as clay, loam, sand, etc. But *before* being kneaded the cohesion, plasticity, etc. (i.e., the consistence) of the material may be quite otherwise; and it is the change in properties which kneading may make which is the basis of the distinction between texture and consistence. In some soil materials kneading, or doing work on it, causes no change in properties, whilst in other materials it causes a profound change. These data may be related to the discussion under the heading of peds at the beginning of this paper. Soil materials may have a specific organisation in the arrangement of their particles, and this expresses itself as modifications of the consistence properties as more and more work is done on them. In this paper the examples of the "normal" texture class are those which show minimal consistency changes as work is done on them.

In some soil materials there are not only consistency differences between the hand sample as kneaded in texturing, compared with the consistence as determined above, but there is also a progressive change as manipulation is continued for a long period up to 15 minutes. This indicates a fabric, or specific organisation of particles, of considerable stability and probably also of complexity.

The "light" heavy clays of Taylor & Hooper (1938, p.70-75) and the "friable" clays of Butler et al. (1942, p.37) are examples of clays which have consistence properties greatly at variance from those of the "normal" clays. These clays have the consistence properties of gravels.

sands or loams; indeed the farmers refer to them as gravels and in their influence on drainage they seem to behave as gravels. During the manipulation of field texturing their apparent clayiness increases progressively until, at the end of five minutes, it fully corroborates the mechanical analysis figures (*vide loc. cit.*) for heavy clay. Less striking examples of the discrepancies between consistence and texture are common, and the usefulness of consistency studies in following these changes with respect to moisture stage is brought out in Figures 2, 3 and 4.

The soil materials which have consistency properties suggesting less clay than they actually contain are designated as "sub-plastic". In contrast to these are the "super-plastic" clays which show diminishing apparent clayiness as manipulation is continued. Local experience to date associates super-plastic soil materials with old, buried soils, which seem to have much in common with gumbotil (Hseung et al, 1949), however the association may not be exclusive. A useful expedient for assessing these super and sub-plastic materials in the field is to quote two textures, one for the first apparent texture and the second for the final texture after manipulation has been continued to the point where no change occurs. During this process more water will need to be added to maintain the moisture stage at M3 as the breakdown of the fabric has the effect of drying out the sample. However, this method of assessment is known to be unreliable as the 'first' texture is influenced by the moisture stage at the time texturing is commenced.

Figure 2 illustrates the changes in the force of cohesion of a number of heavy clays as work is done on them. This data is based on soil materials which are at moisture stage M3 and kept at that moistness throughout the trial by the addition of more water as needed. The work done is manipulation between thumb and fingers.

Figure 3 shows the variation in the force of cohesion of various soil materials throughout the moisture range. It will be noticed that there is a general tendency for cohesion to decrease with increasing moistness except in the cemented materials. Though cohesion increases with clay content—as indicated by the graphs for "sand", "normal clay-loam" and "normal clay", individual clays may occur in almost any situation. Thus the self-mulching clay could barely be dis-

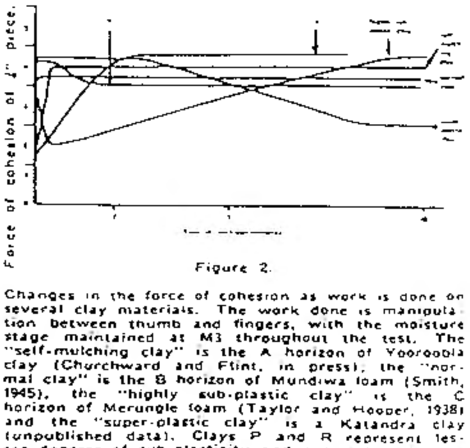

Figure 2.

Changes in the force of cohesion as work is done on several clay materials. The work done is manipulation between thumb and fingers, with the moisture stage maintained at M3 throughout the test. The "self-mulching clay" is the A horizon of Yooroobla clay (Churchward and Flint, in press), the "normal clay" is the B horizon of Mundiwa loam (Smith, 1945), the "highly sub-plastic clay" is the C horizon of Merungle loam (Taylor and Hooper, 1938) and the "super-plastic clay" is a Katandra clay (unpublished data). Clays P and R represent lesser degrees of sub-plasticity and super-plasticity respectively.

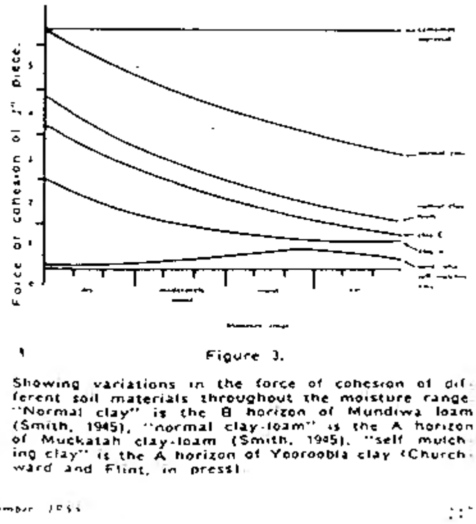

Figure 3.

Showing variations in the force of cohesion of different soil materials throughout the moisture range. "Normal clay" is the B horizon of Mundiwa loam (Smith, 1945), "normal clay-loam" is the A horizon of Muckatah clay-loam (Smith, 1945), "self mulching clay" is the A horizon of Yooroobla clay (Churchward and Flint, in press).

tinguished from a sand—unless it was coalesced (see Figure 2). Other deviations from the "normal clay" are indicated by clays A and C.

Figure 4 shows the diversity of plastic properties of different clays with changes of moistness. Coalescence value is taken as a measure of plasticity. The cnrve for "normal clay" may be compared with a self-mulching clay, and with a highly sub-plastic clay. Clays D and E show intermediate degrees of sub-plasticity. It will be noted that not only the maguitude of the plasticity value, but also the shape of the curve, is quite variable among different clays. This makes it impossible to select auy one moisture stage for characterising the plastic properties of soil materials.

Figure 5 shows the variations iu pulverescence values of a selection of soil materials with changes in moisture content. There seems to be no general or "normal" relatioaship between pulverescence value and texture, except that the very sandy textures always have a high value. The pulverescence value would bear an inverse relationship to what the field agronomist would call fineness of tilth as produced by tillage. However this statement would not apply to sands which may be regarded as giving a high grade of tilth though they would not have a low pulverescence value. Generally the pulverescence value falls with increasing moistness up to field capacity, then it increases rapidly again. In this moisture stage the pulverised material immediately coalesces. These data are all relevant to the characterisation of the soil material, and to the agronomist's selection of the best moisture stage for tillage. Soils A and B in Figure 5 present these characteristics. Soil D, the A horizou of a humic gley soil, contrasts with these in having a uniformly low pulverescence at all moisture stages. Soil E, the A horizon of Riverina clay (Johnston, 1953), a solodised solentz, has a uniformly high pulverescence at all moisture stages. Soil E, a self-mulching clay, does not show the initial decline in pulverescence value, but, beyond moist 2, a remarkable increase.

Laboratory Correlations

The descriptive system has been developed without specific regard to the possibility of correlations with precise laboratory technique. And it is quite possible that any such techniques will need to develop an approach quite different from the expedients adopted in the field description method. Marshall and Quirk (1950) have studied the break-down of dry soil materials. They found that when dry soil was dropped

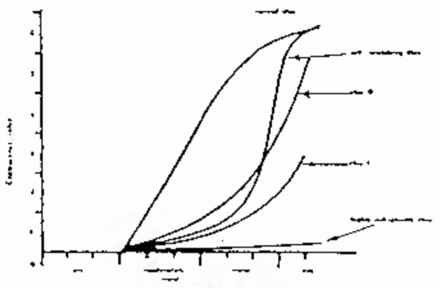

Figure 4.

Showing variations of plastic properties of different clay materials throughout the moisture range. "Normal clay" is the B horizon of Mundiwa loam (Smith, 1945), "self-mulching clay" is the A horizon of Yooroobla clay (Churchward and Flint, in press), and "highly sub-plastic clay" is the C horizon of Merungle loam (Taylor and Hooper, 1938)

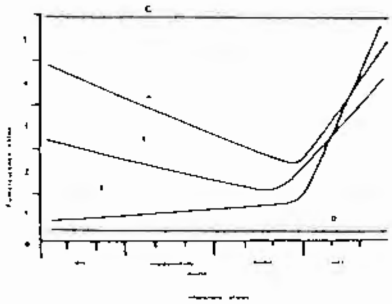

Figure 5

Showing variations in the pulverescence value of different soil materials throughout the moisture range onto a hard surface, the product of the height of drop and the number of drops gave an index of the amount of breakdown. For example, 8 drops from a height of 60 cm. gave much the same result as 4 from 120 cm. Hence the breakdown of dry soil depends on the amount of work done on it, not on a certain yield point being exceeded. This conclusion does not, however, destroy the reality of the yield point in regard to the initial break of the piece before work is done on it.

The study of soil materials in the moist state will inevitably lead to their study as plastic substances, and for this the current elaboration of rheological techniques should offer a number of opportunities. The study of structure or fabric in soil materials by the physicist may well be based on a comparative study of physical properties before and after the fabric is destroyed, and the amount of work done in its destruction. The study of puddling in soils (Bodman & Rubin, 1949) may be a step in this direction.

Acknowledgment

The descriptive method presented here was developed over a period of about nine years, and many of the author's colleagues have materially contributed toward its present form. Among these the author is pleased to mention Dr. T. J. Marshall, Messrs. E. J. Johnston, R. Brewer, C. Hawkins, S. Flint and M. Churchward. The author is indebted to Dr. C. G. Stephens for reading the manuscript.

References

Anon (1948)—Report of the sub-committee on soil structure and soil consistence. National Soil Survey Committee Meeting at Guelph (Canada). Mimeo.

Bodman, G. B. and Rubin, J. (1949)—Soil puddling. *Soil Sci. Soc. Amer. Proc.* 13: 27-36.

Butler, B. E., Baldwin, J. G., Penman, F. and Downes, R. G. (1942)—Soil survey of part of county Moira, Victoria. C.S.I.R. Bul. No. 152.

Churchward, H. M. and Flint, S. F. (in press)—Jernago extension of the Berriquin Irrigation District, N.S.W. C.S.I.R.O. Division of Soils and Land Use Series No. 17.

Hseung, Y., Marshall, C. E. and Krusekopf, H. N. (1949)—The origin of gumbotil. *Soil Sci. Soc. Amer. Proc.*, 14: 311.

Hubble, G. D. (1948)—Soil survey notation. C.S.I.R.O. Division of Soils, Adelaide. Mimeo.

Johnston, E. J. (1953)—Pedology of the Deniboota irrigation district, N.S.W. C.S.I.R.O. Soil Pub. No. 1.

Marshall, T. J. and Quirk, J. P. (1950)—Stability of structural aggregates of dry soil. *Aust. Jour. Agric. Res.* 1: 266-75.

Nikiforoff, C. C. (1941)—Morphological classification of soil structure. *Soil Sci.* 52: 193.

Northcote, K. H., Russell, J. S. and Wells, C. B. (1954)—Soils and land use in the Barossa district, S.A., Zone I. C.S.I.R.O. Division of Soils, Soils and Land Use Series No. 13.

Russell, E. W. (1938)—Soil structure. Imp. Bur. Soil Sci. Tech. Com. 37.

Smith, R. (1945)—Soils of the Berriquin irrigation district, N.S.W. C.S.I.R. Bull. 189.

Smith, R. M. and Cernuda, C. F. (1952)—Some characteristics of the macrostructure of tropical soils in Puerto Rico. *Soil Sci.* 73: (3), 183-92.

Templin, E. H., et al. (1945)—Inspectors' committee on soil structure and soil consistence. *Soil Sci. Soc. Amer. Proc.* 10: 479-81.

Taylor, J. K. and Hooper P. D. (1938)—Soil survey of the horticultural soils in the Murrumbidgee irrigation areas, N.S.W. C.S.I.R. Bull. No. 118.

U.S.D.A. (1951)—Soil survey manual. U.S. Dept. Agric. Handbook No. 18.

Yoder, R. E. (1937)—Significance of soil structure in relation to the tilth problem. *Soil Sci. Soc. Amer. Proc.* 2: 21.

Zakharov, S. A. (1927)—Achievements of Russian science in the morphology of soils. Acad. Sci. U.S.S.R. (Leningrad) Russ. Ped. Invest. No. 2, 47.

(*Received for publication July 25, 1955.*)

MAIL TO	*Original to Client*

Department of Agriculture New South Wales

SOIL SAMPLE INFORMATION

CEREALS & OILSEEDS *30/6/86*

Chemistry Branch,
Department of Agriculture,
Rydalmere, N.S.W. 2116

PHYSICAL

BCRI FILE:

Please follow sampling instructions on back of last copy.

Date sampled *6/6/86*
Map grid ref. *555-560*
Map sheet *8837-N*
B.C.R.I. file

Regional Supervisor/O.I.C.,
Department of Agriculture,
P.O. Box *148*
Narrabri Postcode *2390*

Attention:
District Agronomist ☑
Research Agronomist ☐

Client's name and address *~~MR D ANTHONY~~ Auscott Narrabri P.O Box 303 Narrabri*

PRESS HARD FOR LEGIBLE COPIES

SAMPLE AND SOIL INFORMATION * see instructions overleaf — CROP AND FERTILIZER INFORMATION

Laboratory number	Sample* number	Hectares in field	Topography*: Ridges	Topography*: Slopes	Topography*: Flats	Rock* type	Soil* colour	Texture*	Drainage*	Is area irrigated?	No. of years since pasture	Year crop last grown	Fertilizer applied for last crop kg/ha: N	P	K	S	Other	Next crop to be grown	Farmer identification
C86-3251	1	153			✓	Bas	Grey	Clay	Good	Yes	—	Cotton 85-86	80					Saff	F15-15
B86-2994	2	"			"	"	"	"	"	"		"	80					"	F15-30
B86-2995	3	"			"	"	"	"	"	"		"	"					"	F15-45
B86-2996	4	"			"	"	"	"	"	"		"	"					"	F15-60
B86-2997	5	"			"	"	"	"	"	"		"	"					"	F15-75
C86-3252	6	78			"	"	"	"	"	"		"	"					"	F20T-15
B86-2998	7	"			"	"	"	"	"	"		"	"					"	F20T-30
B86-2999	8	"			"	"	"	"	"	"		"	"					"	F20T-45
B86-3000	9	"			"	"	"	"	"	"		"	"					"	F20T-60
B86-3001	10	"			"	"	"	"	"	"		"	"					"	F20T-75

(written vertically across rows 5–10:) *[illegible] near Tail Block*

SKETCH FIELDS SAMPLED

Continues over

N / W / E / S

Note Soil too wet for Nitrate N

Fill in as completely as you can

DESCRIBE SPECIAL PROBLEMS *Test for N, P and exchangeable bases. Tests for gypsum response. Auscott working with David McKenzie so please contact Dave regarding these samples.*
Only Test Samples F15-15, F20T-15, F20T-15 (ie 1, 6 and 11) for N P, as others are from deep soil profile. The last digits refer to sampling depth - 15 cm, 30 cm, 45 cm, 60 cm, 75 cm SEE NEXT SHEET.

Send top two copies to laboratory with sample

Yellow copy — Agronomist | Pink copy — Laboratory | White copy — Landholder

APPENDIX II

MAIL TO

Original to client

Department of Agriculture New South Wales

SOIL SAMPLE INFORMATION

CEREALS & OILSEEDS

Chemistry Branch, Department of Agriculture, Rydalmere, N.S.W. 2116. MR. D. ANTHONY,

30-6-86

X PHYSICAL

BCRI FILE:

Please follow sampling instructions on back of last copy.

Date sampled 6/6/86

Metric grid ref. 555-560

Map sheet 8837-N

B.C.R.I. file

Regional Supervisor/O.I.C., Department of Agriculture

P.O. Box 148

NARRABRI Postcode 2390

Attention: District Agronomist ☐ Research Agronomist ☐

Client's name and address: AUSCOTT NARRABRI, P.O. BOX 303, NARRABRI

PRESS HARD FOR LEGIBLE COPIES

SAMPLE AND SOIL INFORMATION

* see instructions overleaf

CROP AND FERTILIZER INFORMATION

Laboratory number*	Sample* number	Hectares in field	TOPOGRAPHY* Ridges	Slopes	Flats	Rock* type	Soil* colour	Texture*	Drainage*	Is area irrigated?	No. of years since pasture	Year crop last grown	Fertilizer applied for last crop kg/ha N	P	K	S	Other	Next crop to be grown	Farmer identification
C86-3253	1	[illegible]			✓	Bas	Grey	Clay	Good	Yes	–	Cotton 85-86	80					Safflower	F20T?
B86-3002	2	[illegible]			✓	"	"	"	"	"	–	–	"					0-15	F20H-
B86-3003	3	[illegible]	(20		✓	"	"	"	"	"	–	–	"					15-30	F20H-
B86-3004	4	[illegible]			✓	"	"	"	"	"	–	–	"					30-45	F20H-
B86-3005	6	[illegible]			✓	"	"	"	"	"	–	–	"					–	F20T-
	6																		
	7																		
	8																		
	9																		
	10																		

Fill in as completely as you can

SKETCH FIELDS SAMPLED

N / W / E / S

DESCRIBE SPECIAL PROBLEMS

Discussed with Dave Anthony of Auscott Ltd., Narrabri. Poor cotton yield in Field 20 (3.7 bales/ha) cf. [illegible] F15 (6.45 bales/ha). Soil moister below 20 cm in F20 than F15 indicating less root activity. Want to identify reasons for poor growth in F20

Department of Agriculture New South Wales

Soil Analysis Report 85-86/2591

HORTICULTURE
IRRIGATION SUITABILITY

Chemistry Branch, B.C.R.I., Rydalmere 2116

For interpretation see over

Laboratory number	Sample number	pH 1:2 $CaCl_2$ 0.01M	pH 1:2 water	E.C. 1:2 mS/cm	Approx. EC_e (25°C) mS/cm	Bray 1P ppm	Exchangeable cations m.e./100 g: Ca	Mg	K	Na	Al	Exch. Na %	Exch.Ca / Exch.Mg	Free lime
C86/3251	1	7.0		0.10		17	24	15	1.5	1.3		3.0	1.6	0
686/2994	2	7.2		0.09			24	15	1.4	1.8		4.2	1.6	0
686/2995	3	7.5		0.12			23	15	0.87	2.4		5.8	1.5	0
686/2996	4	7.7		0.14			25	15	1.0	4.4		9.8	1.7	0
686/2997	5	7.7		0.21			22	15	1.1	4.9		12	1.5	0
C86/3252	6	7.0		0.11		23	22	12	1.4	1.7		4.6	1.8	0
686/2998	7	7.3		0.10			22	12	1.2	1.9		5.2	1.8	0
686/2999	8	7.1		0.10			21	12	0.81	2.3		6.3	1.8	0
686/3000	9	7.5		0.11			22	12	0.78	3.0		7.9	1.8	1
686/3001	10	7.5		0.10			21	12	0.77	3.4		9.1	1.8	0

Laboratory number	Sample number	Texture *	Bulk density when air-dry g/cm3	Saturated hydraulic conductivity cm/h	Clay dispersion %	Crusting test: Crust strength MPa	Lateral shrinkage %	Aggregate analysis (% particles in suspension): 0-50 µm	0-20 µm	0-2 µm	Organic matter %	Colour (moist)
C/3251	1	MC					F15 – 0-15	23.8	10.4	1.9	1.3	wdgy
6/2994	2	MC			3.0							wdgy
2995	3	MC			4.4							wdgy
2996	4	MC			11.2							wdgb
2997	5	MC			14.8							wdgy
C/3252	6	MC					F20T 0-15	21.9	10.2	2.1	1.1	wdy
6/2998	7	MC			4.2							dgb
2999	8	MC			4.7							dgb
3000	9	LMC			5.3							db
3001	10	LMC			8.3							dgb

* C Clay(ey), FS Fine sand(y), G Gravel(ly), H Heavy, L Loam(y) (exceptions: LC Light clay, LMC Light medium clay), M Medium, S Sand(y), Si Silt(y).

Laboratory comments: The higher yielding soil F15, is sodic, with high clay dispersion, at 60 and 75 cm depth but not above 60 cm. The F20T soil is similar, in fact not quite as sodic at 60 and 75 cm. However the F20H soil is sodic throughout. Not only does the topsoil break down in water much more strongly than the other two topsoils (aggregate analysis results), but also sodicity and clay dispersion are considerably higher at 45 cm. The neutron probe data are consistent with this, in that they show that little water is being extracted from 40 - 50 cm depth in the poor soil, presumably because roots have difficulty penetrating this layer.

Signed: .... for Director

(CONTINUED NEXT PAGE)

Date / /

Department of Agriculture New South Wales

Soil Analysis Report 85-86/2592

HORTICULTURE

IRRIGATION SUITABILITY

Chemistry Branch, B.C.R.I., Rydalmere 2116

For interpretation see over

Laboratory number	Sample number	pH 1:2 $CaCl_2$ 0.01M	pH 1:2 water	E.C. 1:5 mS/cm	Approx. EC_e (25°C) mS/cm	Bray 1P ppm	Exchangeable cations m.e./100 g: Ca	Mg	K	Na	Al	Exch.Na %	Exch.Ca / Exch.Mg
C86/3253	1	7.7	F20-T	0.42	4	19	24	11	0.71	5.9		14	2.2
B86/3002	2	7.9	F20-H	0.26	2½		27	12	0.75	5.1		12	2.3
B86/3003	3	7.7	"	0.28	2		30	14	0.64	5.1		10	2.1
B86/3004	4	7.8	"	0.29	2½		29	13	0.64	6.0		12	2.2
B86/3005	5	7.4	F20-T	0.18	1½		29	13	1.0	3.0		6.4	2.2
	6												
	7												
	8												
	9												
	10												

Laboratory number	Sample number	Texture *	Bulk density when air-dry g/cm3	Saturated hydraulic conductivity cm/h	Clay dispersion %	Crusting test: Crust strength MPa	Lateral shrinkage %	Aggregate analysis (% particles in suspension): 0-50 µm	0-20 µm	0-2 µm	ORGANIC MATTER %	Co… (…
C/3253	1	LMC					F20-H	57.3	21.3	5.7	0.7	dy
B/3002	2	LMC			6.3							dy
B/3003	3	MC			10.5							Ua
B/3004	4	LMC			14.3							dy
B/3005	5	LMC			3.6							dy
	6											
	7											
	8											
	9											
	10											

* C Clay(ey), FS Fine sand(y), G Gravel(ly), H Heavy, L Loam(y) (exceptions: LC Light clay, LMC Light medium clay), M Medium, S Sand(y), Sl Silt(y)

Laboratory comments: I would expect that F20H is the dominant soil in Field 20.
Deep rooted plants should help but I would also like to see some gypsum tried on Field 20, particularly to treat the topsoil and the 40-50 cm layer.

Signed: J. Abbott for Director

Date 1 / 8 / 86

White copy – Landholder