An Evaluation of Seedbed Preparation Methods for Growing Irrigated Cotton in Grey Clays

by

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Preface

I certify that the substance of this thesis has not already been submitted for any degree and is not currently being submitted for any other degree.

I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

[redacted]

Patrick Joseph Hulme

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As I have typed the thesis, drawn the sketches, plotted the graphs and set out the tables I accept full responsibility for the imperfections in it. However I wish to thank Phil Jones for providing me with the computer and software on which much of the thesis was typed, and Richard Luck for loaning me his computer so the final version could be printed on a high quality printer.

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Abbreviations used

Greek letters

Δx	dry height of layer being sampled
ΔX	fully swollen height of layer being sampled
ε_a	air filled porosity
$\gamma(h)$	semivariance
ν	specific volume
θ_g	gravimetric water content
θ_v	volumetric water content
ρ_b	field bulk density (field volume / oven dry mass)
ρ_{ba}	field bulk density of soil sampled between cracks
$\rho_{b_{min}}$	field bulk density of fully swollen soil
ρ_s	particle density
σ^2	population variance
ψ_e	soil water air entry potential
ψ_m	soil water matric potential
ψ_Ω	soil water overburden potential
ψ_p	soil water pressure potential

Latin letters

1D	subscript meaning; corrected for unidimensional shrinkage
3D	subscript meaning; corrected for three dimensional shrinkage
a	coefficient from curve fitting
ANOVA	analysis of variance
AWC	available water content
b	coefficient from curve fitting
c	neutron counts
CEC	cation exchange capacity
CNSD	conditional, negative, semidefinite
DAI	days after irrigation
e	void ratio
EC	electrical conductivity
ESP	exchangeable sodium percentage
ET_o	evapotranspiration from a reference crop
H	hydraulic gradient
K_{sat}	saturated hydraulic conductivity
LPL	lower plastic limit
m	material coordinate
MANOVA	multivariate analysis of variance

MRE	mean relative error
m_s	mass of solids for each depth interval
M(z)	mass coordinate
n	count rate ratio, also used to indicate the number of samples
NLWR	non-limiting water range
OFD	oxygen flux density
P.	probability
PAWC	plant available water content
PVC	polyvinyl chloride
r	correlation coefficient
r^2	coefficient of determination
SAR	sodium adsorption ratio
s^2	sample variance
sd	sample standard deviation
$se_{y.x}$	standard error of estimate of Y for fixed X
TSS	total soluble salts
UPL	upper plastic limit
x	conventional scale of physical length
Z	depth

Abstract

Declining cotton yields led to doubts about the long term viability of irrigated cotton growing in the lower Macquarie Valley, N.S.W., only 10 years after the industry was established. Soil limitations to cotton growth were implicated as the main reason for the yield decline in the absence of insect and disease outbreaks. Following unsuccessful screening for soil chemical deficiencies, soil physical conditions were studied. A series of experiments have since shown that poor soil physical conditions in Macquarie Valley vertisols can be improved by using crops to dry the soil, deep tillage and gypsum.

The next step, which this project addresses, is to study soil management systems which minimize degradation of soil physical conditions. Aims of this project were to:

i) Assess the viability of the permanent bed system for irrigated cotton production in which the hills on which cotton is grown are left in the same place for a number of years. This was done by comparing soil physical properties and cotton growth on areas prepared using conventional seedbed preparation in which the hills are knocked down and reformed each year with areas of cotton under permanent beds.

ii) Study cotton growth in response to a range of soil physical conditions created by different tillage systems, and the relationship between cotton growth and some measures of soil physical condition. From these relationships, we should gain a clearer picture of how deep tillage ameliorates poor soil structure, and also how it can cause the yield depression observed in some prior experiments.

iii) Combine information from this project with other, similar, projects, to establish guidelines to predict which soil management practices are best suited to a given situation.

The main part of the project was a field experiment, monitored over two and a half years. Three tillage treatments, ripping to 0·45 m, chisel ploughing to 0·25 m, and a permanent bed system were imposed in a randomized complete block design with three blocks (replicates) at the start of the trial in May, 1984. Cotton, wheat, and maize crops were grown over the next two years, then deep tillage treatments were reimposed prior to a second cotton crop.

Soil swelling, and neutron moisture meter and gamma density meter calibrations

Because of the importance of swelling to the physical behaviour of vertisols and weaknesses in the current methods of accounting for swelling, an experiment was undertaken to examine the nature of swelling in the field, and its relation ship to swelling in the laboratory. Field shrinkage measured at 0·2 and 0·3 m using swelling pins was much less than expected from extrapolation from laboratory results. Field shrinkage measurements indicate that the errors introduced to water content measurement by ignoring swelling are no greater than those introduced by sources such as relocation error in placement of the neutron moisture meter source in the access tube. Consequently, little accuracy (3·5% error only) would be lost at this site by ignoring swelling in neutron moisture meter calibrations. Errors in the measurement of soil water and air filled porosity introduced by swelling increase with depth, especially beyond the depths monitored closely in this experiment. However, the importance of these errors is reduced by the decreasing range of water content measured with increasing depth.

As the neutron moisture meter was widely used in measurement of soil water in the current study, a neutron moisture meter was calibrated at the experimental site. The use of corrections for changes in density did not improve the precision of the neutron moisture meter calibration, and led to

only a small increase in accuracy. The use of shrinkage models was only beneficial when applied to specific situations such as the determination of air filled porosity. It was thus recommended that the calibration of neutron count rate ratio on volumetric water content be used to predict soil water content in preference to calibrations using shrinkage models.

Prediction of air filled porosity was improved by the use of the 3-dimensional shrinkage model. The simplest means of determining air filled porosity corrected for 3-dimensional shrinkage (ε_{a3D}) was from the gravimetric water content calibration rather than a separate ε_{a3D} calibration, and should be used.

A gamma density meter was also calibrated at the experimental site. The gamma density meter was a poor predictor of soil field bulk density. The neutron moisture meter provided a more precise density calibration, and should be sufficiently accurate if measurements are taken at each field site to check the calibration.

Crop growth and soil physical conditions in the 1984/85 cotton season

In the 1984/85 season, no yield penalty was suffered by planting cotton into permanent beds formed by direct listing compared to the two alternative seedbed preparation methods where beds were knocked down and reformed.

The few statistically significant differences between treatments detected in this season differences indicated better soil conditions in the ripped than direct listed plots. However, under the prevailing climatic and management regimes, cotton plants did not appear to exploit the more favourable soil conditions in the ripped plots.

Improvements in methods of evaluating soil conditions over those used in the 1984/85 season were needed to quantify differences between tillage treatments. To estimate the degree and duration of waterlogging, increased emphasis should be given to conditions soon after irrigation.

Effectiveness of sampling techniques used in the first cotton season was tested using geostatistical techniques and classical statistics. The geostatistical analysis showed small variability across the field, which means that neutron moisture meter access tubes need not be any further apart than the separation distance used in the analysis (26 m) while, because of the strong correlation of volumetric water content between depths, readings should be separated by at least 0·2 m depth. Classical statistics showed that only one neutron moisture meter reading need be taken per depth unless very high precision is required. Subject to the constraints imposed by the design of this experiment, the sensitivity of penetration resistance in detecting treatment differences would be increased by making insertions much further than 1 m apart, whilst remaining sufficiently close to access tubes to obtain associated moisture measurements.

Evaluation of methods for measurement of soil physical properties in vertisols

The few differences in soil properties detected in the 1984/85 season suggested a need to test whether differences in soil properties affecting cotton growth could be better identified by using additional indicators or better use of current indicators. Two studies, the first of which aimed to asses the effect of wheel passage at different water contents on soil structure, were undertaken between harvest of the 1984/85 cotton crop and planting of the 1986/87 crop. In the first study, penetration resistance, but

not field bulk density, proved to be a useful indicator of structural degradation in response to picker and header wheelings. The small response of bulk density was attributed to aggregate deformation rather than volume change being the main form of structural degradation in vertisols.

The critical subsurface soil water content for structural degradation in response to header or picker wheeling in this soil lies between 0·14 and 0·21 kg kg^{-1}. This is drier than 0·23 kg kg^{-1}, the lower plastic limit of the soil.

In the second study, a number of indicators of soil physical condition were used to monitor changes in soil physical condition over a 12 day period after irrigation of a cotton crop planted to evaluate three rotation practices-safflower and wheat crops, and a bare fallow in which weeds were controlled by disc ploughing. The indicators of soil physical condition used were: measurement of air filled porosity and oxygen flux density in core samples; measurement of an *in situ* water retention curve with tensiometers; assessing pore continuity with a dye infiltration technique; penetration resistance as an indicator of soil strength; and water content.

Apart from water content, all indicators of soil structure used in this study were able to differentiate between fallow, wheat and safflower treatments to a depth of 0·25 m. Of the techniques used, a combination of core sampling to measure air filled porosity together with the penetrometer was best able to define structural conditions relevant to root growth down the profile. This conclusion was supported by the greater sensitivity of penetration resistance than bulk density measurement as an indicator of structural degradation caused by wheel passage. The dye infiltration technique provided consistent data, but was more laborious. Tensiometers provided a useful adjunct to other methods of characterizing soil physical properties, although their value is limited by large demands on time, and sensitivity to installation and maintenance.

Suspicions of extended periods of waterlogging following irrigation in the 1984/85 season were confirmed by the results of this experiment. However, the observed waterlogging did not appear to markedly restrict water uptake.

It was concluded that techniques to measure aeration status described here would be used in the 1986/87 growing season. Tensiometers would also be installed despite their drawbacks, as they would enable the determination of hydraulic gradients, hence give information on the direction of water flow in the soil. Rhodamine dye infiltration has provided information on the effects of structural degradation on water flow, and would be used on a limited scale.

Crop growth and soil physical conditions 1985 to 1986/87 cotton season

Selective measurements taken during the wheat crop grown between the two cotton crops. All tillage treatments had similarly low wheat yields, which were attributed to moisture deficit and nitrogen deficiency stress. Due to the lack of data and the absence of comparative treatments, no partitioning of the yield depression between these two factors was possible.

Permanent beds established using direct listing were the highest yielding plots in the 1986/87 season. There is little doubt that this form of permanent beds is viable for at least four years after the beds are established, provided the direct listing is carried out under a favourable moisture regime.

Waterlogging, and not high soil strength, was the main soil physical constraint to cotton growth in this experiment. Yield depression in the ripped areas was attributed to a longer duration of waterlogging compared to chiselled or direct listed areas.

The measures of physical properties used in the 1986/87 season were able to account for the yield differences between tillage treatments. The next step in differentiating the physical properties of vertisols subjected to a range of tillage treatments is to assess the plant available water capacity of these soils. The practice of watering the whole experiment when one plot shows signs of water deficit stress needs to be abandoned in favour of separating the experiment into at least two groups for irrigation scheduling.

Conclusions

The project has shown that permanent beds formed by direct listing are a viable means of cotton production. Other research has shown that good soil structure, essential to the longevity of permanent beds, can be maintained by avoiding traffic on wet soil, and utilizing the ability of plants to ameliorate structural degradation as they crack the soil by drying it.

Deep tillage increases soil porosity and disrupts the continuity of impermeable layers near the soil surface. Deep tillage will improve cotton production if it disrupts these layers, and subsequent management protects the porosity created by deep tillage, and utilizes the improved plant available water content of the deep tilled soil. As no impermeable layers were present near the soil surface in the present experiment, deep tillage did not improve cotton production.

Waterlogging is the main soil physical limitation to cotton production in vertisols. Measurement of soil physical differences between imposed treatments in irrigated vertisols must include an assessment of the degree and duration of waterlogging in the treatments. In addition, the non-limiting water range of treatments should be fully assessed, by measuring the extent to which plants can dry soil before soil strength restricts root extension or water potential reduces water supply to the level where plants suffer water deficit stress.