SUGAR RESEARCH AND DEVELOPMENT CORPORATION

FINAL REPORT

Project Title: *Increasing sugar cane yields by improvements in soil structure*.

Project Code: NSWA1S

Organisations: NSW Agriculture (NSWAg)
University of Queensland (UQ)
NSW Sugar Milling Co-op. (NSWSMC)

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NSW Agriculture provided salaries for Hughes and Hirst as well as equipment, facilities, offices, laboratories, libraries, computers and administrative and technical support.

UQ provided salaries for A/Prof. So and Dr Schafer, laboratory and office space for the student as well as a range of other facilities needed for the project.

NSWSMC provided salaries for Nielsen and technical staff, except for 10% of Nielsen's salary paid for by SRDC, and laboratory facilities at Broadwater Mill.

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Abstract

A project to increase sugar cane yields by improvements in soil structure was conducted at Broadwater, NSW. It was instigated in response to the poor physical structure of many cane soils and poor root development in many sugar cane crops resulting in low cane yields. A number of alternative management practices were tested and cane and sugar yield as well as appropriate soil parameters were measured.

The main findings were that ridging had the biggest effects on cane and sugar yields and on soil bulk density, soil moisture (drier in the top 30 cm and wetter at depth), and a leaching of Cl, Na and S when in excess amounts. Ridging also resulted in a stable inter-row and hence far less damage during wet harvests. Intensity of tillage had some small effect on yields and soil structure; it is not clear if these would have increased over a longer period of time. The main effect of soybean production during the fallow period was due to nitrogen input. There were some small but positive effects on subsequent cane root growth soil organic carbon and soil bulk density. Mole drains and deep ripping provided no clear advantage over laser levelling alone.

Non-technical Summary

This project was developed to investigate alternative management practices upon soil structure and crop yield. The context of the project was the poor physical structure of many cane soils and poor root development in many sugar cane crops resulting in low cane yields.

The alternative management practices tested included two drainage systems, two fallow treatments, and a range of tillage treatments that varied tillage intensity and soil profile in the row. Cane and sugar yield as well as appropriate soil parameters were measured.

The main findings from this project have been:

- Ridging had the biggest effects on cane and sugar yields and on soil bulk density, soil moisture (drier in the top 30 cm and wetter at depth), and a leaching of Cl, Na and S when in excess amounts. These effects were measured when rainfall was low for most of the life of the crop even though the treatment was designed to improve soil drainage and structure under wet conditions.

- Ridging also resulted in a stable inter-row and hence far less damage during wet harvests.

- Intensity of tillage had some small effect on yields and soil structure; it is not clear if these would have increased over a longer period of time.

- The main effect of soybean production during the fallow period was due to nitrogen input. There were some small but positive effects on subsequent cane root growth, soil organic carbon and soil bulk density.

- Mole drains and deep ripping provided no clear advantage over laser levelling alone.

1. INTRODUCTION

The poor physical structure of many cane soils is suspected to be the major cause of poor root development in many sugar cane crops. The structural degradation of cane soils is associated with the implementation of conventional tillage practices and the passage of heavy machinery at high soil moisture contents. Yield losses on structurally degraded soils are most pronounced following extraordinarily wet seasons. Yield losses on a mill area basis, following very wet seasons have been as high as 22%. If very wet conditions occur soon after planting then up to 10% of new plantings fail and require replanting. The effect of alternative management practices upon soil structure, and crop yield is not well understood. The BW trial was conducted on a sodic vertisol soil at Banks Estate, Broadwater between 1992 and 1996 to quantify the effect of management on soil structure and sugarcane yield, and thereby identify superior management systems.

2. MATERIALS AND METHODS

2.1 Field Trial Design And Management

Broadwater has a subtropical climate with an annual average rainfall of 1480mm spread relatively evenly throughout the year. As Broadwater is near the southern extremity of the northern wet season during summer months, and also the northern extremity of the southern wet season during winter months, it often experiences two "wet-seasons" annually. September and December are the only months in which floods have not been recorded in the Broadwater region (Maynard 1982). Mean monthly maximum and minimum temperatures range from 29-20^{o}C and 19-7^{o}C respectively. The BW site was under a pasture fallow for 5 years previous to the commencement of experimentation.

Management treatments in the Broadwater trial (BW) were:

(1) 3 tillage intensities: conventional tillage (CT), minimum tillage (MT), no-tillage (NT)

(2) 2 soil bed profiles: ridge tillage (Ridge), flat tillage (Flat)

(3) 2 drainage techniques: Laser- levelling only (Laser), Laser-levelling deep ripping + mole drains (Mole)

(4) 2 fallow treatments: bare fallow (Bare), soybean rotation (Soybean)

Prior to cultivation, the entire site was laser-leveled to a uniform slope of less than 1%. Following leveling, mole drains were installed in half the plots of each replicate block at a depth of 40cm. Moles were pulled up and down the slope, spaced 1.2m apart, intersecting a sub-surface drain at one end. This drain essentially consisted of a trench, back-filled with sand and gravel, containing a slotted PVC pipe which ran perpendicular to the direction of the mole drains and conveyed water to a nearby canal. Surface drainage was achieved through a series of shallow table drains at the down-slope end of each experimental block. Complex drainage structures isolated individual plots from run-off and drainage effects.

Primary tillage on CT and MT treatments consisted of moldboard ploughing to a depth of 20cm. Secondary tillage on CT and MT treatments utilised a disk plough and rotary hoe. Prior to the pre-cane fallow of 1992, ridges approximately 50cm high were constructed in half the NT treatments using a conventional ridging implement. Aside from the initial leveling, ripping and ridging operations NT treatments were never disturbed by tillage (see Figure 1).

		CT Flat	NT Flat	MT Flat	NT Ridge	MT Ridge
1992	July	Rotary Hoe	Spray	Rotary Hoe	Spray	Rotary Hoe
		Deep Rip •				•
	Aug-Oct	4 Ploughings		4 Ploughings	Form Ridge	4 Ploughings
	Nov					
	Dec	Plant Legume •				•
1993	May	Destroy Legume •				•
	May-Aug	4 Ploughings		4 Ploughings		3 Ploughings
						Form Ridge
	Sept	Plant Cane •				•
	Oct	Ploughing	Spray •			•
	Nov	Ploughing				
	Dec	Ploughing+Fertilizer	Fertilizer •			•
1994	Jan	2 Cultivations	Spray •			•
	Feb	Spray •				•
	Oct	Harvest as 1 yr				
	Nov	Rotary Hoe + Cultiv	Spray •			•
	Dec	Ploughing+Fertilizer	Fertilizer •			•
1995	Jan	Spray •				•
1996	Sept	Harvest as 2 yr •				•
Number Ploughings		17	0	9	0	9

Figure 1: Management of the Broadwater field trial.

Soybeans (*Glycine max* c.v. Manta) were planted in half the experimental plots in December 1992. Grain was not harvested and all the senesced material broken up with a slasher and then was either ploughed in (CT and MT treatments) or left on the soil surface (NT treatment). Following destruction of the soybean cover crop, and secondary tillage operations, ridges were constructed on half of the MT treatments. The sugarcane was planted in October 1993 using a conventional planter. Weeds were controlled in reduced tillage treatments with herbicides, and Endosulphan® was used to control insect pests. In October 1994 the first sugarcane crop (plant-cane) was harvested green. Under average conditions the crop would have been burnt prior to harvest, however extremely dry and windy conditions prohibited burning at this time. As a relatively lightweight harvester used to harvest the crop the load of heavier and more conventional machinery was simulated with a single pass of a wheeled vehicle, weighing 14 tonnes, over the entire site. Following the harvest of the plant-cane, the sugarcane was ratooned, or regrown without replanting, for 2 years (ratoon-cane) before the final harvest in August 1996.

Treatments were implemented within 60 field plots measuring 15m x 15m, arranged in a split-plot design with 3 replications of 20 unique treatment combinations. (see Figure 2). Drainage was the main plot factors; bed preparation, fallow- and tillage management were subplot factors.

spoon drain

Rep	Drainage										
REP 1	Laser	1 CT flat soybean	2 NT ridge soybean	3 NT flat soybean	4 MT flat soybean	5 NT flat fallow	6 CT flat fallow	7 MT ridge soybean	8 MT ridge fallow	9 MT flat fallow	10 NT ridge fallow
	spoon drain										
	Laser & Mole	11 MT ridge soybean	12 NT ridge fallow	13 NT ridge soybean	14 CT flat soybean	15 MT ridge fallow	16 NT flat soybean	17 MT flat soybean	18 MT flat fallow	19 CT flat fallow	20 NT flat fallow

spoon drain

Rep	Drainage										
REP 2	Laser & Mole	21 CT flat soybean	22 MT flat soybean	23 MT ridge soybean	24 NT ridge soybean	25 NT ridge fallow	26 NT flat soybean	27 NT flat fallow	28 MT ridge fallow	29 CT flat fallow	30 MT flat fallow
	spoon drain										
	Laser & Mole	31 MT flat fallow	32 MT ridge soybean	33 CT flat soybean	34 CT flat fallow	35 NT flat soybean	36 NT flat fallow	37 MT ridge fallow	38 NT ridge soybean	39 MT flat soybean	40 NT ridge fallow

spoon drain

Rep	Drainage										
REP 3	Laser & Mole	41 CT flat soybean	42 NT flat fallow	43 MT flat soybean	44 MT ridge fallow	45 CT flat fallow	46 MT ridge soybean	47 NT ridge soybean	48 NT flat soybean	49 MT flat fallow	50 NT ridge fallow
	spoon drain										
	Laser & Mole	51 CT flat fallow	52 CT flat soybean	53 MT flat fallow	54 NT ridge soybean	55 MT flat soybean	56 NT ridge fallow	57 MT ridge fallow	58 NT flat soybean	59 MT ridge soybean	60 NT flat fallow

spoon drain

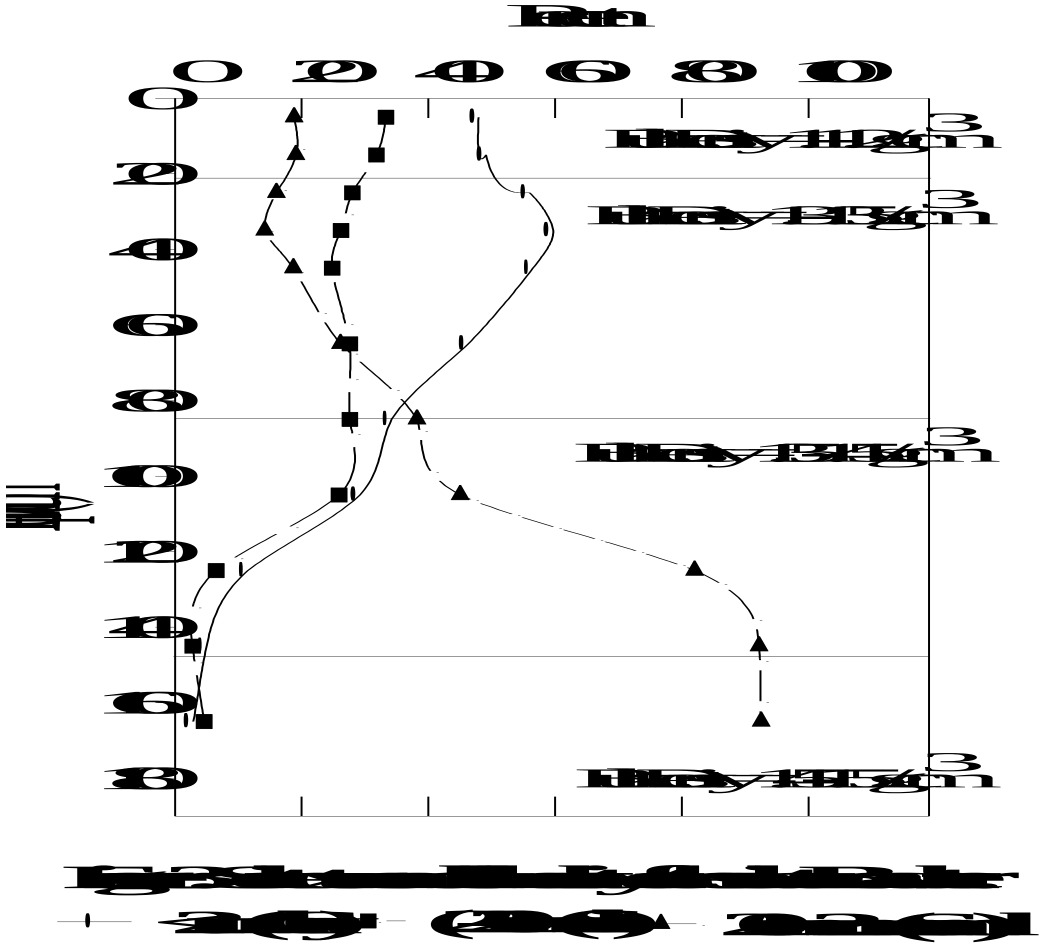
Figure 2: Design of the Broadwater surface management.

2.2 Soil Characteristics

The poorly drained sodic Vertisol at the BW site cracked to a depth of around 60cm on drying. The surface soil was a blocky, medium clay that graded abruptly into a massive clay horizon at the base of the plough zone (see Figure 3). Particles with an equivalent spherical diameter of greater than 2mm comprised less than 5% of the bulk soil. Soil bulk density increased from 1.1-1.2g/cm3 at the surface to 1.3-1.35g/cm3 at depth. Increased bulk density reduced saturated hydraulic conductivity from of 6mm/hr at the surface to <1mm/hr at depth. Soil clay content increased from 48% in the top 10 cm to 60% at 30 – 40 cm depth. At 60 cm beneath the surface the sand content of the profile began to increase slightly, and at approximately 120cm beneath the surface the profile graded abruptly to a perennially saturated sand layer.

The most abundant of the exchangeable cations present was magnesium, comprising around 50%, and 60% of the total exchangeable cations present surface– and sub- soil respectively (see Table 1). The sodicity of BW soil was also high, increasing from 6% in the surface soil, to 16% in subsoil, to 25% at below 120cm depth. Despite the high sodicity, soil electrical conductivity was far less than that which is thought to suppress yields (0.28dS/m).

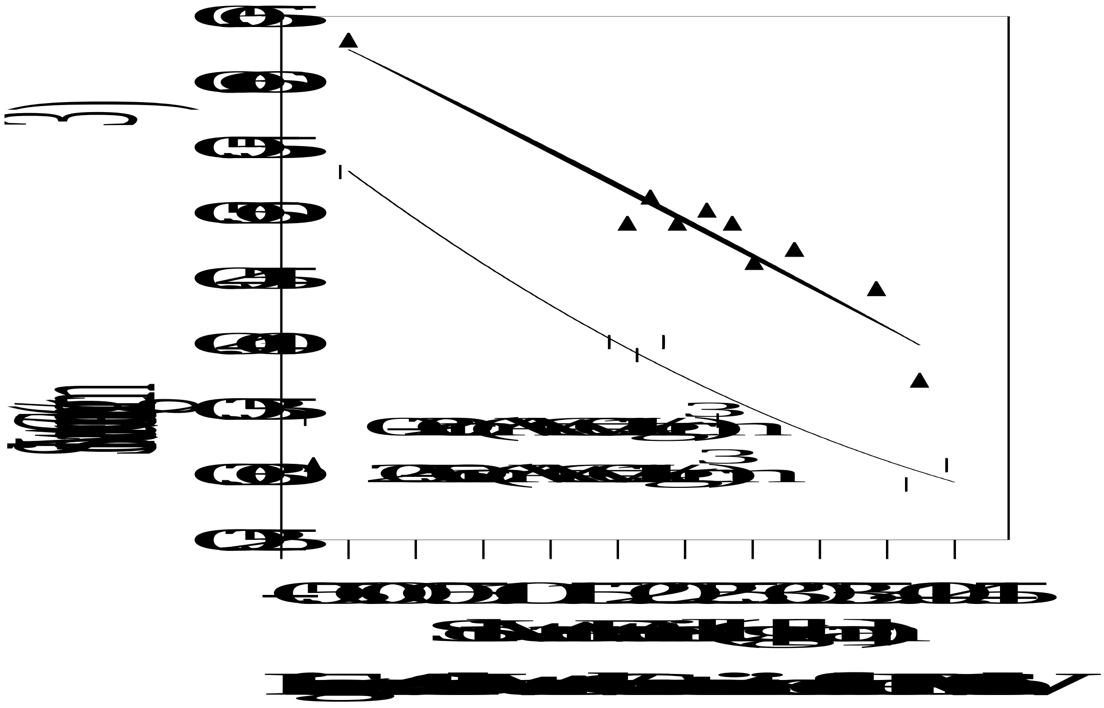
High exchangeable Na, and Mg were consistent with moderate dispersibility. Both Na and Mg were lower at 20 – 40 cm in the ridged plots than in the flat plots and this was probably due to a higher proportion of top soil in the ridges. Approximately 24% of the total silt + clay, and 12.5% of the total clay content of the surface soil was readily dispersable. The dispersable silt and clay of the subsoil, was greater than that of the surface soil. Despite moderate to high soil acidity, soil analysis indicated that crop yields were unlikely to be limited by the availability of the macro- and micro-nutrients examined. Aluminium toxicity is also unlikely to adversely effect crop performance.



The plant available soil water holding capacity of the BW soil was around 0.11g/cm^3 for both the surface- and sub- soil (see Figure 4). As measurements of soil water content and crop water use indicated that the sugarcane crop extracted water to a depth of approximately 1m, the effective water holding capacity of the BW profile was approximately 110mm.

Table 1 : Chemical properties of soil at Broadwater March 1993.

	Flat			Ridge		
	0-20cm	20-40cm	40-60cm	0-20cm	20-40cm	40-60cm
pH_{CaCl2}	4.15	4.31	4.37	4.09	4.22	4.46
Organic Carbon (%)	2.05	1.14	0.53	1.90	1.50	0.55
Ca^{++} (cm^+/mg)	5.18	5.37	3.62	4.94	5.38	3.77
Mg^{++} (cm^+/mg)	11.6	17.6	18.3	11.5	14.0	17.3
K^+ (cm^+/mg)	0.33	0.25	0.24	0.37	0.27	0.21
Na^+ (cm^+/mg)	1.48	3.66	5.03	1.32	2.29	4.41
Al^{+++} (cm^+/mg)	4.09	3.49	2.48	4.22	4.01	2.48
P (mg/kg)	51.0	22.5	21.7	46.9	37.7	20.2



2.3 Meteorology.

Daily total rainfall, solar radiation, air and soil temperature were measured at the experimental site by a solar-powered automated weather station. Data was downloaded monthly. When equipment malfunction occurred, the records were supplemented with data from the Broadwater mill which is about 3 km east of the experimental site

2.4 Crop Production

Soybean establishment was estimated six weeks after planting and dry matter yields were measured six weeks after planting and at crop maturity. Establishment rates were determined by counting all individuals within two complete rows of each soybean plot. To determine dry matter yield, 2m sections were cut from each of the rows examined during the establishment counts. Soybean samples were placed in a paper bag, and dried in a fan forced oven at 40^0C for a week before weighing.

Stalk populations were estimated approximately 6 months after planting (25/4/1994) and ratooning (2/5/95) from 2 rows * 5m in each plot.

Stalk length to the first expanded dewlap was measured on 5 stems from each plot on a weekly basis for both the plant (20/12/1993 – 31/10/1994) and the first ratoon crop (16/1 – 10/9/1995). Measurements ceased when crop lodging prevented access.

Biomass components (node numbers, dry matter content, stalk proportion of above ground biomass, individual stalk dry weight and biomass) were estimated from a 15 stalk sample taken from 6 treatments i.e. 3 tillage (CT flat, NT flat and NT ridge) by 2 drainage (laser vs mole) (Muchow *et al*., 1993). Green leaf and millable stalk samples were analyzed for N, P, K, Ca, Mg and Na.

Leaf samples (blade only), from the middle 20 cm of the 3rd last fully emerged leaf, were taken 6 months after ratooning (2/5/1995). Samples were dried in a dehydrator at 60 ^{o}C, ground through a 2 mm screen and analyzed for N, P and K.

The root length density of the sugarcane crop was measured at the end of the first year of the ratoon. Two soil samples were extracted to a depth of 80cm from the row and the inter-row of the CT, and NT treatments using a hydraulically operated coring tool with an internal diameter of 95mm. These samples were divided into the following depth increments 0-5cm, 5-10cm, 10-15cm, 15-20cm, 20-30cm, 30-40cm, 40-50cm, 60-70cm, and 80-90cm. Each field-moist sample was weighed, and sub-sampled for gravimetric moisture content and root length density analysis. Roots were extracted from the soil using a wet separation process after samples had been soaked overnight in a dilute solution of de-ionised water, sodium hexametaphosphate, and sodium hydroxide.

Sugarcane yields were determined by weighing the cane harvested from 14m of each row in every plot. Freshly cut billets were directed from the mechanical harvester into a specialized “weighing” bin with an accuracy of +/- 0.10 tonne. Immediately prior to harvest 4-5 stems were collected from each plot to determine for moisture, and sugar content. After the fist year of the ratoon, 4m of row was cut from the center 4 rows of each plot by hand. The cut stalks were weighed using a balance capable of measuring to 1 +/- 0.05 tonne, and which was mounted in the tray of a utility vehicle.

2.5 Soil Bulk Density

A thin walled hydraulically operated coring tube with a 96mm cutting edge was used to collect bulk density samples to a depth of 90cm. Sampling depth, sampling intensity and the separation of samples into individual depth increments varied from sampling period to sampling period depending upon the number of treatments being included in the sampling and other physical constraints. Bulk density was sampled using the hydraulically operated coring tube on five separate occasions,

- at the start of the fallow (all treatments; 1 core/plot from the planting furrow to 50cm depth in 10cm increments)
- before and after cane planting (all treatments; 1 core/plot from the planting furrow to 50cm depth in 10cm increments)
- at the commencement of the ratoon (all treatments; 1 core/plot from the planting furrow and 1 core/plot from the inter-row to a depth of 50cm depth in 10cm increments)
- at yield sampling one year into ratoon.(CT, NT treatments only; 1 core/plot from the planting furrow and 1 core/plot from the inter-row row to 80cm depth in 5 and 10cm increments)

Once extracted, the samples were sealed in plastic bags to prevent the evaporative loss of soil water and transported to the laboratory. The field bulk density of these samples was determined from total sample weight and gravimetric moisture content as measured within 1 week of sampling. The remaining sample was then gently broken by hand into 20 to 40 mm fragments and air dried in a ventilated and temperature controlled glass house at approximately 35^{0}C.

Bulk density measurements were adjusted for linear shrinkage, and were corrected to an equivalent bulk density at a gravimetric soil moisture content of 35 % according to the following relationship.

2.6 Infiltration And Hydraulic Conductivity

The hydraulic conductivity of a soil represents relative soil permeability, or the ability of the soil to transmit water, and is determined by soil pore characteristics. Hydraulic conductivity may be defined as the rate of flow per unit area of soil.

Disk permeameters are commonly used to determine *in situ* hydraulic properties of field soils in Australia. Perroux and White (1988) and the CSIRO (1988) have published comprehensive reviews of disc permeameter design and operation. Due to high soil dispersibility, however, the disk permeameter could not be used to accurately measure soil hydraulic conductivity at Broadwater, and in its place, a Guelph borehole permeameter was used to measure in situ saturated hydraulic conductivity. Gallichand (1990) and Wu (1993) have provided details reviews of the design and operation of these apparatus. A single measurement was conducted in the planting row and inter-row of all the CT and NT treatments.

2.7 Crop Water Use

Crop water use was measured periodically using a moisture balance approach, that is,

$$\text{Crop Water Use} = \underset{\text{(Time 1)}}{\text{Profile Moisture Content}} - \underset{\text{(Time 2)}}{\text{Profile Moisture Content}} - \underset{\text{(Time 1 to 2)}}{\text{Rainfall}}$$

The soil moisture content in the surface 0.2m of the soil GFSB and BW profiles was determined gravimetrically at each sampling date. Soil samples were typically collected from the 0.0-0.1m and 0.1m-0.2m depth intervals using a small hand spade, or steel coring device 50mm in diameter that was driven into the soil using an electric jackhammer. Soil moisture contents between 0.2m, and 1.8 m were determined using the neutron probe. A single access tube was installed in each plot.

To facilitate the installation of access tubes a soil core at least 1.8 m long was extracted from the planting row of each plot using a hydraulic ram mounted upon a small tractor, and a stainless steel coring tool 49mm in diameter. Following the removal of the soil core, the hydraulic ram was used to force an aluminium access tube 50mmin diameter, into the hole produced by the coring tool. As the access tube were 2m long, they were then trimmed so that the opening of the access tube was exactly 10cm above the soil surface. Neutron probe readings were made at depths of 0.25m, 0.35m, 0.45m, 0.65m, 0.85m. 1.05m, 1.25m, 1.45m, and 1.65m.

The soil cores extracted during access tube installation were divided into 10cm intervals, transferred to sealed labeled plastic bags, and stored in a cool place. The water content of these samples was determined gravimetrically within a week of sampling to limit errors arising from the evaporative loss of soil moisture. To determine gravimetric soil water content (GWC), 100-200 grams of moist soil was transferred into a weighed container, and dried at 105^0C. After at least 2 days drying, the samples were removed from the oven and re-weighed. GWC was then calculated as:

$$GWC = [\text{Mass}_{\text{moist soil + container}} - \text{Mass}_{\text{dry soil + container}}] / [\text{Mass}_{\text{dry soil + container}} - \text{Mass}_{\text{container}}]$$

Sample GWC was multiplied by the relevant mean bulk density to determine volumetric soil water content (VWC). The neutron probe was partially calibrated by correlating probe count ratios measured immediately after access tube installation, against VWC. The probe count ratio used in these calibrations was the ratio of neutron probe counts in soil to counts in pure water. Water counts were measured in the laboratory by placing an access tube into 200L drum of deionised water.

To reliably calibrate the neutron probe it is necessary to measure count ratios across a wide range of soil moisture contents. To facilitate reliable calibration, the calibration procedure described above was conducted at planting and at the start of the ratoon. To extend probe calibration, soil water content was measured adjacent to the access tubes immediately prior to tube removal at the end of the "plant-cane". These samples were collected to 1.2m, using a steel corer 50mm in diameter and an electric jackhammer.

Crop water use was measured throughout the plant-cane crop, and during the first year of the ratoon. In the second year of the ratoon, lodging prevented access to the moisture meter access tubes, however a single soil moisture measurement was made after the ratoon crop had been burnt in preparation for harvest. Soil moisture measurements were on several occasions at regular intervals throughout the cropping cycles (see Figure 7).

2.8 Water Release Characteristics

The water release characteristics of the BW soil were determined using the filter paper technique of Fawcett and Collis-George (1967). It was difficult to accurately measure the water release characteristics using intact cores or clods due to the high swelling and severe slacking properties of the soil upon wetting. Whatman No.42 Filter papers were inserted into samples of field-moist soil, collected during the measurement of field bulk density, and allowed to equilibrate for one week within sealed plastic bags. After equilibration the filter papers were removed from the soil, dried at 40^0C overnight and the moisture content determined. From the pre-calibrated moisture release curve of the filter paper the equivalent soil moisture potential was then determined. These measurements were conducted on samples collected from a range of treatments after 3 separate sampling trips so incorporate a wide a range of moisture contents in the analysis. The near saturation moisture content of the soil was determined from soil clods which had been wetted to 0.001bar on a tension table.

2.9 Soil Particle Size Analysis

Samples obtained during the measurement of soil bulk density measurements were dry sieved to 2mm and used in the particle size analysis. Dispersion of the samples was achieved through a combination of chemical and physical techniques. To initiate chemical dispersion, 25 grams of air dry soil was combined with 10ml of 1N NaOH, 10ml of 10% sodium hexa-meta-phosphate, and 200ml of deionised water. The samples were then physically dispersed using an ultrasonic probe, set to output 2400 J/minute, for a period of 10 minutes. The energy requirement for complete sample dispersion was obtained through prior calibration of the ultrasonic technique for each of the soil types examined.

The dispersed samples were transferred to sedimentation cylinders along with enough deionised water to produce a total volume to one litre. The total clay (<2um) and silt (<20um) fractions were determined using the pipette technique (Coventry and Fett 1979). Fine (0.02-0.2mm) and coarse (0.2-2mm) sand fractions were separated using decantation and a 0.2mm mesh sieve.

2.10 Wet Sieving And Water Stable Aggregate Analysis

Air-dry samples were gently broken by hand and passed through a 20mm sieve. The sieved sample was then homogenised in a plastic bag, and a 40-45 gram sub-sample was randomly selected for wet sieving. The analysis followed procedure similar to that described by Kamper and Chepil (1965) incorporating an assemblage of nested sieves with mesh sizes of 9.5m, 5.1mm, 2.0mm, 1.0mm, 0.5mm, 0.25mm, and 0.12mm, and a sieving apparatus with a stroke length of 12mm and a stroke frequency of 12 strokes per minute.

The soil was immersion wetted in de-ionised water and sieved for 15minutes. Previous calibration had shown that no significant changes in aggregate size distribution occurred after 15minutes. After sieving the contents of each sieve was dried at 105^0C for 24 hours and weighed. From the results of the analysis, water-stable mean weight diameter (Kemper and Chepil 1965), and percent of water stable material greater than 0.25mm were calculated. Mean Weight diameter was calculated by,

$$MWD = sum\ [x_i\ (W_i - P_i)] / sum\ (W_i - P_i)$$

Where : x = mean diameter in size class i
W = Total mass soil material in size class i
P = Mass primary soil particles in size class I

Preliminary analyses indicated that primary particles comprised less than 4% of the total Broadwater soil. For this reason, and because the accurate measurement of primary particle sizes was laborious and time consuming, corrections for primary particle mass were omitted from the wet sieving analysis of the BW soil.

2.11 Dispersion

The relative dispersability of soils was assessed using the method described by Cook (1988). Fifty grams of air dry soil sieved to <2mm, was added to one litre of triple deionised water at 20^oC in a sedimentation cylinder with a total volume of 1425ml, leaving an air gap of approximately 105mm above the suspension. The solutions were then shaken end over end for 30minutes at 20 rotations per minute. When shaking was complete, suspensions were left to settle at 20^oC and the readily dispersed silt (<20um) and clay (<2um) were measured using the pipette technique. The results of the analysis were expressed as a proportion readily dispersible silt and clay relative of the total soil mass. These results can also be expressed relative to the total dispersible material, that is total silt or total clay, but there was no obvious benefit to expressing results in this way.

2.12 Clod Density

The volume of clods 3-5cm in diameter was assessed using a pycnometer and kerosene. Weighed air-dry clods 3-5cm in diameter were immersed in kerosene at 20^oC and kept under a continuous vacuum for at least 3-4 hours to ensure the complete evacuation of air from each clod. The low surface tension properties of kerosene ensure rapid clod saturation with minimal slacking, when compared to that which occurs when clods are immersed in deionised water. The kerosene-saturated clods were then transferred to a standard pycnometer containing kerosene at 20^oC, and the volume was measured. Clod density was then calculated as the ratio of clod mass to clod volume.

2.13Soil chemical analysis

Soil samples were taken after the final harvest using a thin walled coring tube with a cutting edge of 5cm diameter. Samples were taken to 5m cm from all clear fallow plots, air dried and then submitted to Incitec for analysis.

2.14Harvesting effects on soil profile

Soil profiles were investigated pre and post harvest of the ratoon crop when the soil was wet. The post harvest measurements were taken after the passage of the harvester, a small weigh bin and a full field bin. Soil in cane rows 3 and 4 were taken as zero. A straight bar was placed across the inter-row and the profile was measured every 15cm.

3. RESULTS

3.1 Meteorological records

Temperature patterns were similar in1993/94, 1994/95 and 1995/96 but rainfall patterns were different in each season (Figure 5). In 1993/94 rainfall was low in the first half of the season and high in March; the total (1188 mm) was 80% of the long term mean. 1994/95 was very dry (786 mm) with only 53% of the long term mean. The pattern in 1995/96 was closer to the typical pattern for this area and the total (1435) was close to the long term mean (1480).

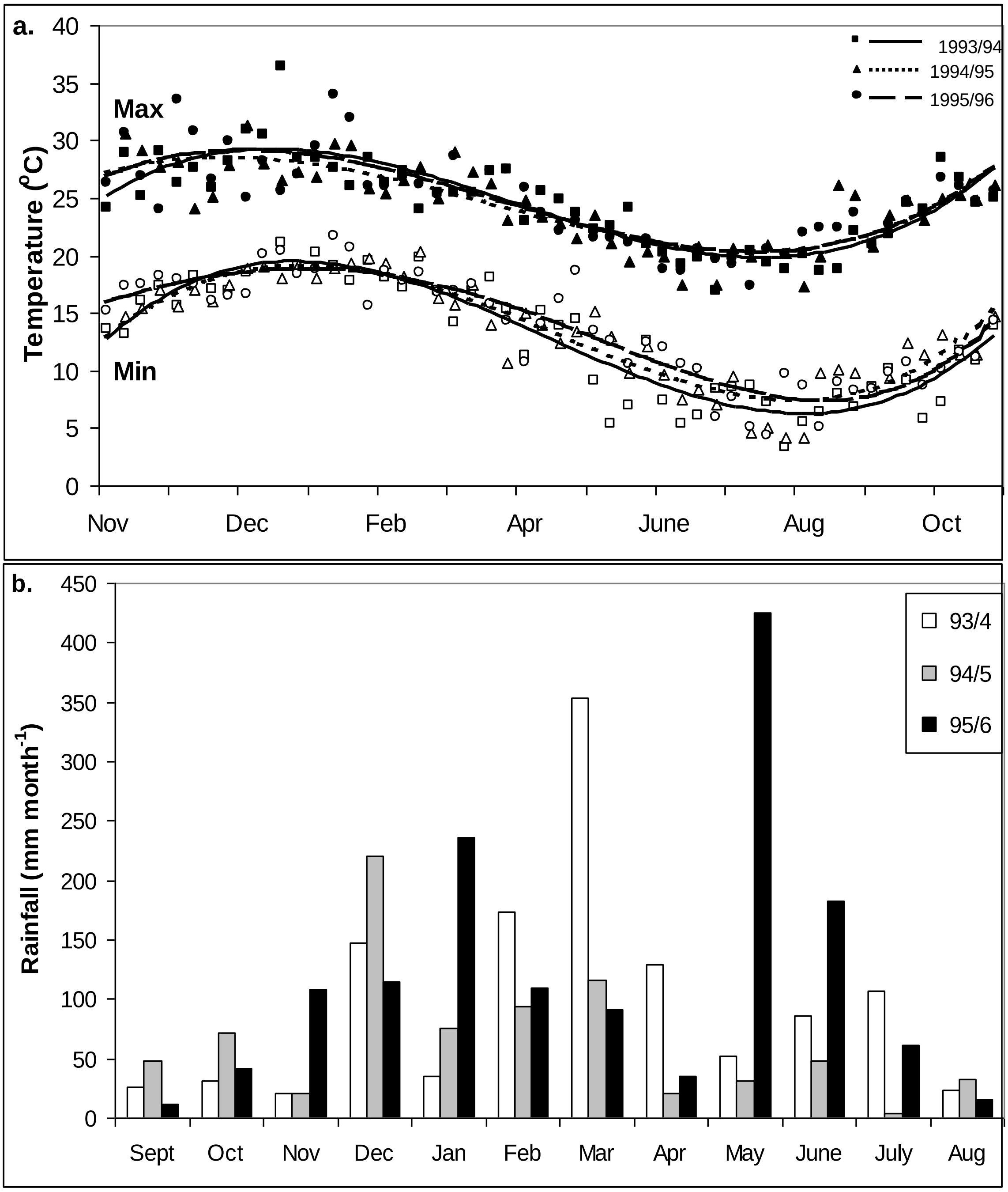


Figure 5. Temperature (a), and rainfall (b) during the growth of the plant crop (1993/94) and the first ratoon crop (1994/95 and 1995/96).

Solar radiation values in general were about 10% lower than those recorded at Harwood (Hughes and Muchow 1998) but significantly lower in September to December 1995 (Figure 6).

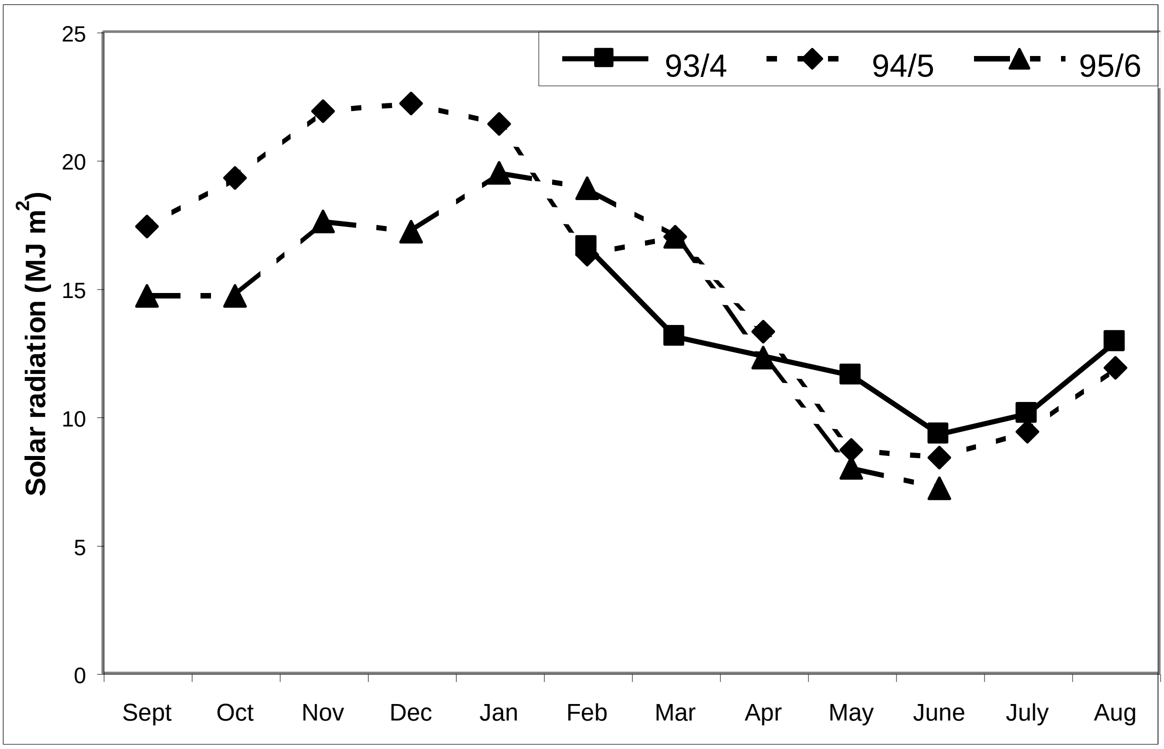


Figure 6. Solar radiation during the growth of the plant crop (1993/94) and the first ratoon crop (1994/95 and 1995/96).

3.2 Crop Performance

3.2.1 Soybean Rotation

Ridging of the NT treatments significantly (P#0.05) reduced the establishment and dry matter yields of the soybean fallow crop (Table 2). It is important to note that at this stage of the experimentation, ridging treatments were confined to the NT treatments. Ridges were not constructed within MT treatments until after the destruction of the soybean fallow. Neither the tillage or drainage techniques had a significant effect on the performance of soybeans during the fallow period. The establishment rates and dry matter yields of the CT, and MT-flat treatments also exceeded those of the NT ridges.

Table 2: Effect of ridging on performance of the soybean rotation.

Bed Form	Establishment Rate %	Dry Matter Yield 6 weeks after plant (t/ha)	Dry Matter yield at Maturity (t/ha)
CT-Flat	73.5	1.06	5.85
MT-Flat	78.8	1.44	6.04
NT-Flat	79.5	1.24	5.58
NT-Ridge	39.8	0.45	3.80
l.s.d. (p=0.05)			**1.24**

3.2.2 Sugarcane stalk populations.

Stalk populations were relatively uniform and the only significant differences were between flat and ridged treatments in the plant crop (Table 3.). The lower populations in the ridged treatment in the plant crop may have been due to lower soil water content (see section 3.4 Sugarcane Water Use, And Soil Profile Water Content). This lower population did not translate in lower yields.

Table 3. Sugarcane stalk populations in plant and first ratoon crops.

Treatment		**Plant crop (stalks m^{-2})**	**Ratoon crop (stalks m^{-2})**
Drainage	- Laser	7.45	7.71
	- Mole	7.71	7.63
		l.s.d. 0.02	*ns*
Tillage	CT	7.84	7.63
	MT flat	8.01	7.58
	MT ridge	7.04	7.79
	NT flat	7.69	7.50
	NT ridge	7.31	7.83
		l.s.d. 0.49	*ns*
Fallow	Soybeans	7.60	7.61
	Bare	7.56	7.72
		ns	*ns*

3.2.3 Sugarcane stalk growth

Mean daily growth rates from January to March were higher in 1995 than in 1994 due in part to an earlier stalk initiation in the ratoon crop and in part to a better soil moisture supply (Figure 7).

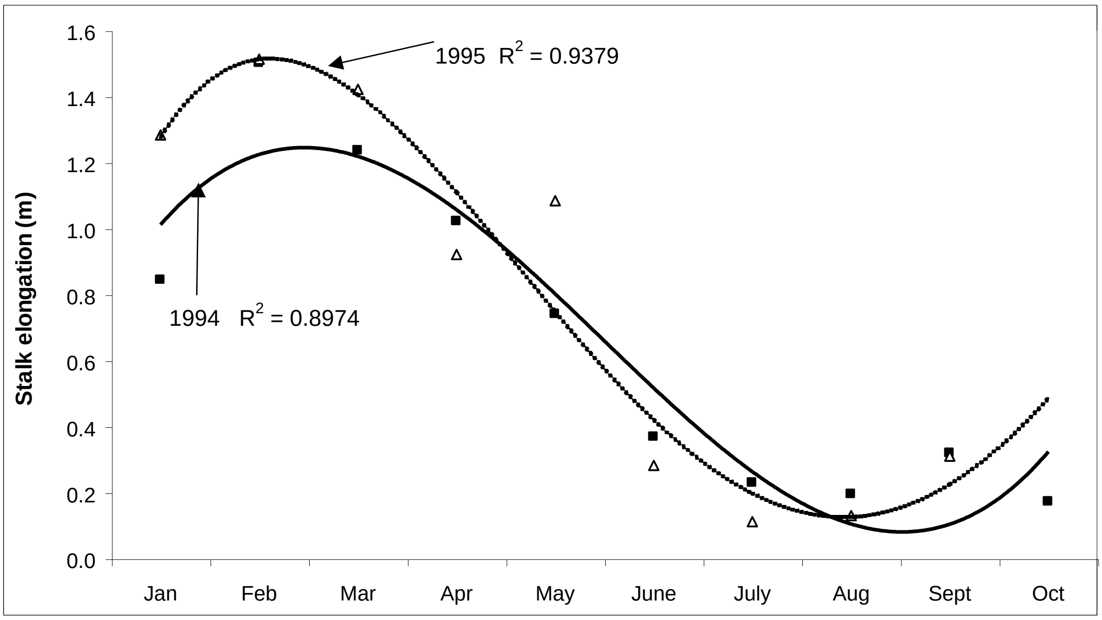


Figure 7. Mean monthly stalk elongation rates in the plant (1994) and ratoon (1995) crops.

In the plant crop (1993/94) there were no significant treatment effects on initial or final heights nor on growth over the 315 day period (Table 4). However there was a significant interaction between tillage and fallow treatments in that the production of soybeans during the fallow period resulted in less growth in the NT ridge treatment (Figure 8).

Table 4. Stalk heights to last visible dewlap on 20/12/1993 and 31/10/1994 plus total stalk growth during the measurement period.

		plant stalk height (m)			ratoon stalk height (m)		
		start 20/12/93	finish 31/10/94	growth (315 days)	start 16/1/95	finish 10/9/95	growth (237 days)
drain	laser	0.1626	2.154	1.991	0.4459	2.198	1.753
	mole	0.1581	2.197	2.039	0.4756	2.208	1.733
	lsd	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
till	CT	0.1642	2.160	1.996	0.3907	2.144	1.753
	MT flat	0.1668	2.187	2.020	0.4642	2.212	1.748
	MT ridge	0.1473	2.203	2.055	0.4728	2.214	1.741
	NT flat	0.1757	2.211	2.036	0.4915	2.239	1.747
	NT ridge	0.1477	2.117	1.970	0.4845	2.209	1.724
	lsd	*ns*	*ns*	*ns*	*0.0388*	*ns*	*ns*
fallow	fallow	0.1608	2.199	2.038	0.4612	2.227	1.765
	soy	0.1599	2.152	1.992	0.4603	2.180	1.720
	lsd	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

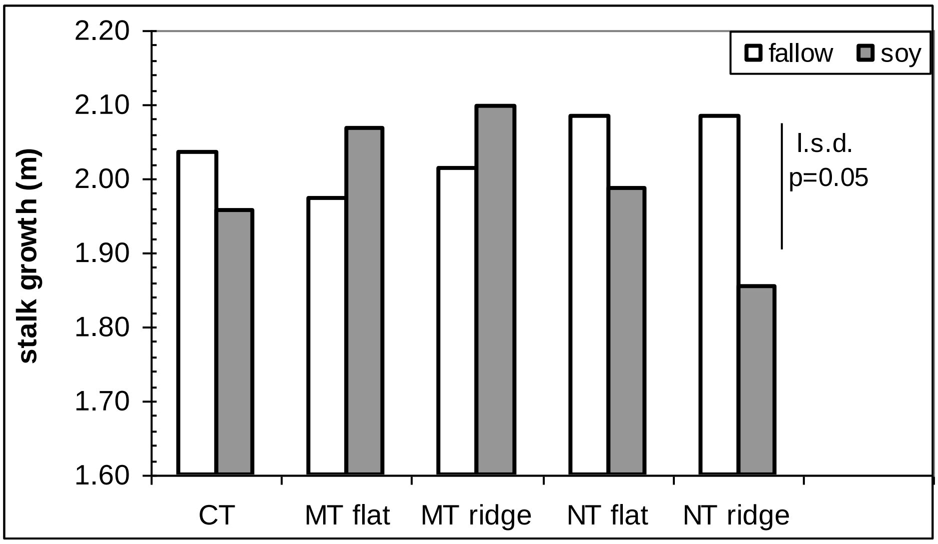


Figure 8. Interaction of tillage and fallow on stalk growth rates in the plant crop.

Tillage effects were significant for initial heights in the ratoon crop (1995), but this did not translate into differences in the final height nor in growth during the measurement period.

These stalk growth data indicate that, at least under the conditions of this experiment, soil management effects are greater during the germination to stalk initiation phase than subsequently. It remains to be seen if this still holds true under more extreme conditions like prolonged water logging.

3.2.4 Sugarcane stalk components

There were few significant differences between treatments with respect to component yield (Table 5.). Fresh weight of green leaf was higher in mole drained treatments than in laser treatments (F = 0.004) while the dry matter content of stalks in CT tilled plots was higher than that in NT ridged plots. There are no obvious reasons why the differences in green leaf fresh weight occurred. The lower dry matter content in the NT ridged plots probably is associated with better growing conditions which are associated with increased yields (measured cane yields at 12 months age were 87 t ha^{-1} and 93 t ha^{-1} for CT tilled and NT ridged treatments respectively).

Table 5. Stalk component data for the plant crop 30/8/1994.

Drainage	Tillage	INDMSTD	MOMST	PROPMST
L	**CT**	315.1 (*se = 24.3*)	0.295 (*se = 0.004*)	0.736 (*se = 0.014*)
M	**CT**	315.6 (*se = 28.5*)	0.280 (*se = 0.002*)	0.726 (*se = 0.007*)
L	**NTF**	330.0 (*se = 12.3*)	0.281 (*se = 0.004*)	0.715 (*se = 0.004*)
M	**NTF**	313.4 (*se = 6.3*)	0.284 (*se = 0.001*)	0.715 (*se = 0.001*)
L	**NTR**	322.4 (*se = 8.0*)	0.275 (*se = 0.004*)	0.716 (*se = 0.009*)
M	**NTR**	371.2 (*se = 17.2*)	0.277 (*se = 0.004*)	0.723 (*se = 0.002*)

INDMSTD = dry weight individual stalks, MOMST = dry matter content of millable stalks, PROPMST = millable stalk as proportion of aboveground biomass.

Tillage effects were highly significant (F=0.003) for Na content of millable stalks (Table 6) with values for NT ridged treatment nearly half that of the CT treatment. These large differences in stalk Na content due to tillage reflect changes in soil Na and may well be part of the reason for improved yields. N and Mg content were significantly higher in NT ridged treatments than in CT treatments (F=0.073 and 0.01 respectively). There were no significant differences in nutrient content in either green leaves or millable stalk due to drainage treatments nor in green leaves due to tillage treatments.

Table 6. Stalk component nutrient content for the plant crop 30/8/1994.

Plant Component	Treatment	Nutrient content N %	P %	K %	Ca %	Mg %	Na %
Green leaf	Laser	0.869	0.097	1.096	0.216	0.178	0.027
	Mole	0.880	0.098	1.091	0.216	0.187	0.031
	l.s.d.	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
	CT flat	0.862	0.098	1.118	0.207	0.178	0.030
	NC flat	0.868	0.098	1.067	0.217	0.185	0.029
	NT ridge	0.893	0.096	1.095	0.224	0.183	0.027
	l.s.d.	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Millable stalk	Laser	0.237	0.036	0.486	0.020	0.079	0.020
	Mole	0.253	0.036	0.503	0.019	0.083	0.020
	l.s.d.	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
	CT flat	0.225	0.034	0.490	0.018	0.070	0.026
	NC flat	0.247	0.039	0.488	0.018	0.081	0.020
	NT ridge	0.263	0.035	0.505	0.022	0.091	0.014
	l.s.d.	*0.025*	*ns*	*ns*	*ns*	*0.012*	*0.005*

3.2.5 Sugarcane leaf analysis

Growing soybeans during the fallow period resulted in higher leaf N and P (Table 7) and this was reflected in higher yields. The N effect would have been due to N fixation by the soybeans, although we were surprised that this effect was still present in the ratoon crop. The P effect was probably due residual fertiliser P from the soybean crop.

Table 7. Leaf analysis data for one-year ratoon cane (1995)

		%N	%P	%K
tillage	CT flat	1.262	0.140	1.001
	MT flat	1.273	0.144	1.013
	MT ridge	1.288	0.147	1.013
	NT flat	1.288	0.146	0.988
	NT ridge	1.293	0.145	0.990
	l.s.d.	*ns*	*ns*	*ns*
drainage	laser	1.292	0.1463	1.007
	mole	1.269	0.1423	0.995
	l.s.d.	*ns*	*ns*	*ns*
fallow	fallow	1.249	0.142	0.992
	soys	1.312	0.147	1.010
	l.s.d.	*0.034*	*0.004*	*ns*

3.2.6 Cane and sucrose yields.
3.2.6.1 Plant crop

Cane yield, CCS and sucrose yields were measured in the plant crop at 13 months of age (Table 8).

Table 8: Cane yields, CCS and sugar yields of the plant crop.

Treatments		Cane yield	CCS	Sugar yield
drainage	laser	78.1	14.43	11.26
	Laser + mole	79.1	14.51	11.46
	l.s.d. (P = 0.05)	*ns*	*0.064*	*ns*
	l.s.d. (P = 0.10)	*ns*		*ns*
tillage	CT flat	73.4	14.52	10.64
	MT flat	76.1	14.44	10.98
	MT ridge	82.6	14.41	11.90
	NT flat	76.9	14.51	11.16
	NT ridge	83.9	14.46	12.12
	l.s.d. (P = 0.05)		*ns*	
	l.s.d. (P = 0.10)	*7.25*	*ns*	*0.991*
		mtr, ntr > ct		*mtr, ntr > ct*
fallow	bare	76.2	14.52	11.05
	soybeans	81.0	14.42	11.67
	l.s.d. (P = 0.05)		*ns*	*ns*
	l.s.d. (P = 0.10)	*4.59*	*ns*	*ns*

There were no drainage effects on cane yield or on sucrose yield. There was a significant effect on CCS but this was so small as to be of no economic benefit. Tillage effects were significant for both cane (F = 0.092) and sugar yield (F = 0.079) (Figure 9).

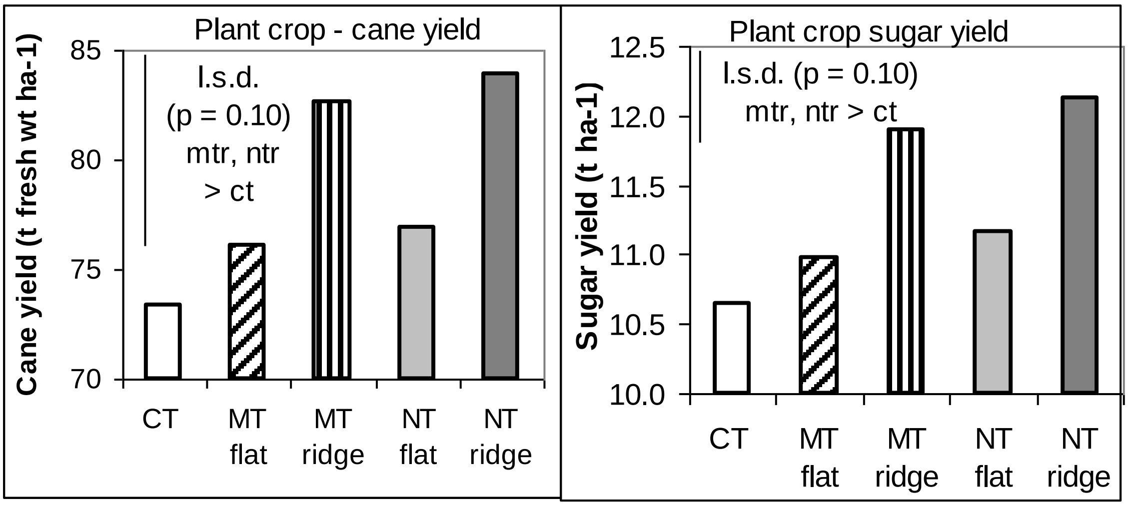


Figure 9. Effect of tillage on cane and sugar yield of the plant crop.

Fallow effects were significant for cane yield (F = 0.085),with the soybean fallow treatment out yielding the bare fallow treatment, but the differences were not significant for sucrose yield. There were no significant interactions between treatments.

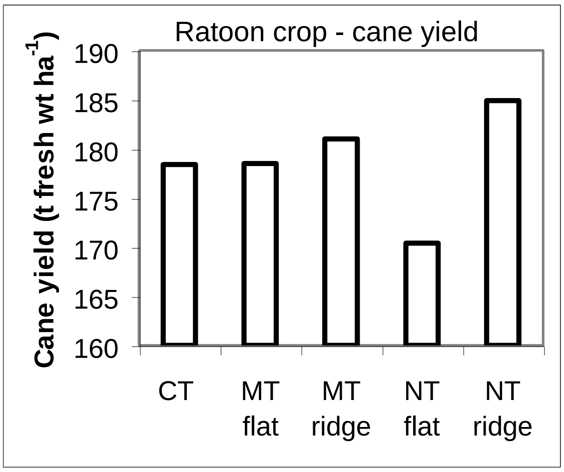
3.2.6.2 Ratoon crop

Cane yield, CCS and sucrose yields were measured in the ratoon crop at 23 months of age (Table 9).

Table 9. Cane yields, CCS and sugar yields of the ratoon crop.

Treatments		yield	ccs	Sugar
drainage	laser	178.2	14.09	25.10
	Laser + mole	179.1	13.82	24.73
	l.s.d. (P = 0.05)	*ns*	*ns*	*ns*
	l.s.d. (P = 0.10)	*ns*	*ns*	*ns*
tillage	CT flat	178.4	14.19	25.26
	MT flat	178.5	13.73	24.49
	MT ridge	181.0	14.19	25.68
	NT flat	170.4	13.82	23.59
	NT ridge	184.9	13.84	25.55
	l.s.d. (P = 0.05)	*ns*	*ns*	*ns*
	l.s.d. (P = 0.10)	*ns*	*ns*	*ns*
fallow	bare	177.5	13.80	24.46
	soybeans	179.8	14.12	25.37
	l.s.d. (P = 0.05)	*ns*	*0.33*	*ns*
	l.s.d. (P = 0.10)	*ns*	*0.27*	*ns*

There were no significant treatment effects or significant interactions between them. However the largest treatment differences were within the tillage set and these followed the same general pattern as in the plant crop (Figure 10).



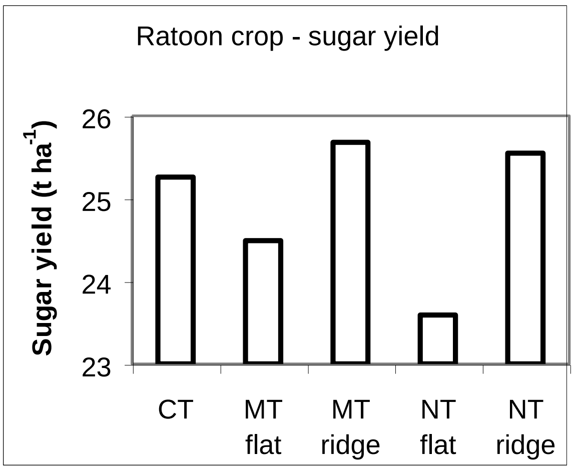


Figure 10. Effect of tillage on cane and sugar yield of the ratoon crop.

3.2.7
Discussion of Crop Performance Data.

The data indicates that ridging and the use of soybean rotations significantly improved cane and sugar yields and that these effects were present throughout both the plant and ratoon crops. Increased sugar yields were most frequently associated with increases in stalk yield rather than increased CCS.

In Australia, yield increases following the implementation of ridge tillage on poorly drained alfisols and vertisols is typically associated with improved soil aeration and drainage (Tisdall and Hodgson). Although ridge tillage is commonly used in a number of conventional farming systems (eg cotton) there has been limited research into its application within conventional sugarcane farming systems. Van Antwerpen et al (1991) assessed the viability of using ridge tillage on poorly drained duplex soils in South Africa. In 13 separate crops, grown on 5 individual field trials, they observed stalk yield increases ranging from 5 to 20 t/ha due to the use of ridge tillage. Van Antwerpen et al reported that ridges had consistently lower bulk density and were consistently drier than flat soil indicating that they were better drained. They also found that roots concentrated in the surface 20cm of the profile under flat cultivation, whereas they tended to be well distributed to a depth of 600mm within a ridge. Crop water use was therefore greater under ridging as water was extracted to a greater depth within the profile. Van Antwerpen et al also noted that ridge tillage reduced the incidence of compaction within the planting furrow as traffic was better controlled. In Australia, McMahon and Ham (1994) reported that ridge planting increased cane stalk yields on the heavy clay soils of the Burdekin irrigation area by upto 20 t/ha and attributed this to improved soil drainage based on qualitative observation.

As with ridge tillage there is very little published information available concerning the influence of legume rotations on sugar cane yields. Leguminous rotations might be expected to improve the yields of the subsequent cane crop through several mechanisms, the most obvious being the fixation of atmospheric nitrogen by symbiotic bacteria. However, rotations may also improve productivity by a range of other mechanisms including the reduction of pathogen populations, the stabilisation of soil structure through the addition of organic matter, and development of soil porosity through drilling by crop roots.

3.3 Soil Bulk Density

Soil bulk density is a measure of total soil porosity. The nature of soil porosity determines the hydraulic conductivity and water holding capacity of the soil. Soil bulk density is also associated with soil strength, with high bulk densities typically associated with increased soil strength and impedance to root growth.

3.3.1 Soil bulk density at the commencement of the fallow-soybean rotation (January 1993)

Soil bulk density was measured in the planting furrow at the start of the fallow-soybean rotation period in January 1993, which was prior to the formation of the ridges in the MT treatment. Significant treatment effects were drainage (P=0.063), depth (P=<0.001) and tillage (P=0.004) (Table 10).

Table 10: Soil bulk density in the planting furrow at the commencement of the fallow – soybean rotation (January 1993).

Treatments		**Bulk density ($g\ cm^{-3}$)**
mean		1.001
drainage	laser	1.024
	laser + mole	0.978
	l.s.d.	*0.053*
fallow	bare	1.004
	soy	0.998
		ns
tillage	CT	1.014
	MT flat	1.027
	NT flat	0.988
	NT ridge	0.976
	l.s.d.	*0.031*
depth (cm)	5	0.897
	15	0.972
	25	1.017
	35	1.054
	45	1.065
	l.s.d.	*0.034*

Significant interactions occurred between drainage and depth (p = 0.019), drainage and tillage (p = 0.068), as well as fallow and tillage (p = 0.019).

Mole drains appeared to have resulted in lower bulk density between 20 and 40 cm (Figure 11) which was presumably due the deep ripping action of the mole when the drains were formed. However this effect was significant for MT flat, NT flat and NT ridge but not for CT (Figure 12).

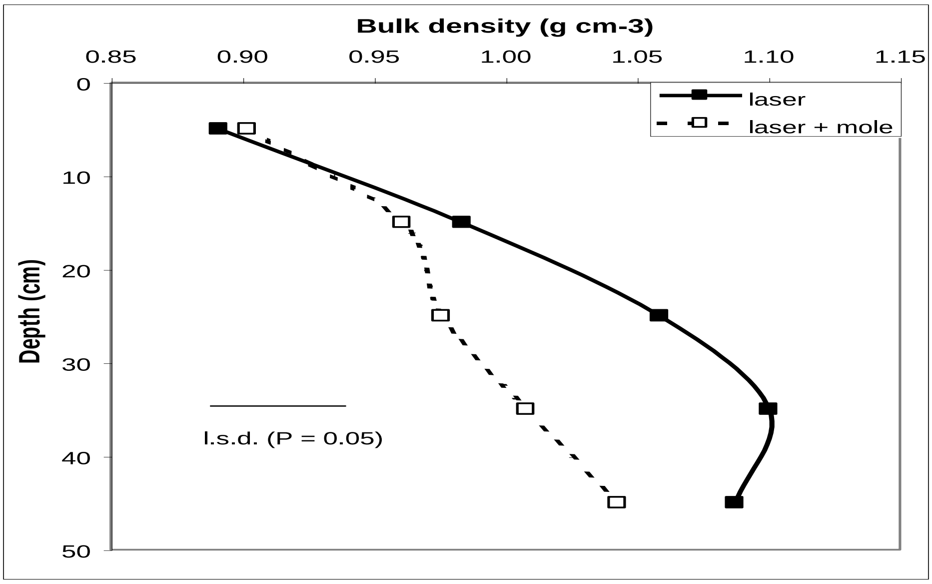


Figure 11. Effect of drainage treatments on soil bulk density at the commencement of the fallow period.

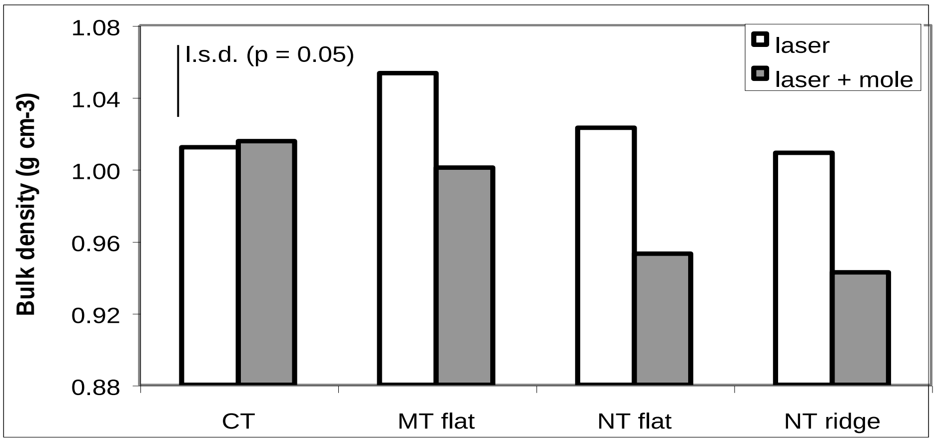


Figure 12. Interaction of tillage and drainage on soil bulk density in the fallow period.

Differences between tillage treatments were not significant following the bare fallow but the bulk density of both NT treatments was less than that of CT and MT flat following the soybean fallow (Figure 13).

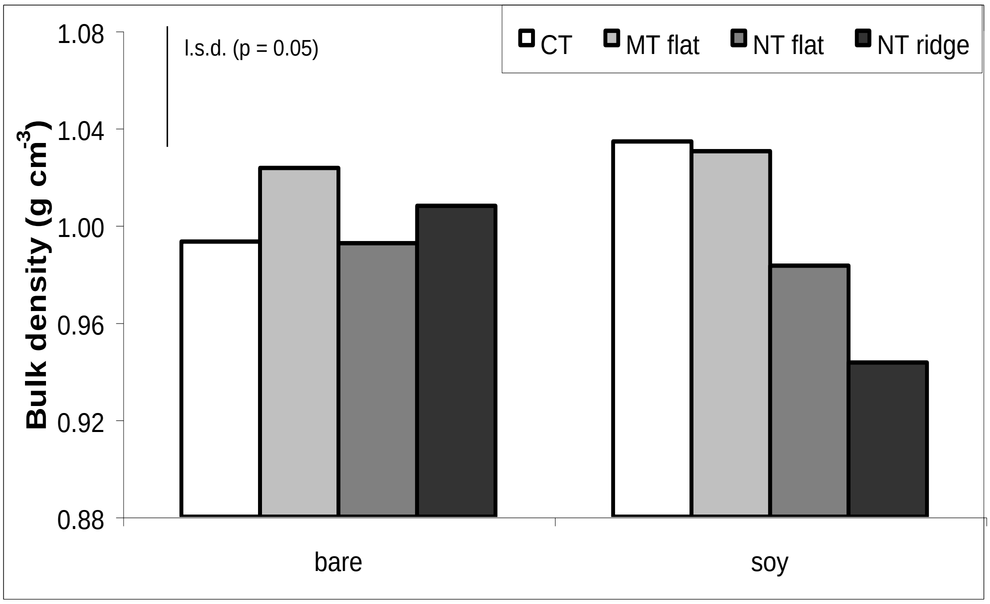


Figure 13. Interaction of tillage and fallow treatments on soil bulk density in the fallow period.

3.3.2 Soil bulk density at the commencement of the plant and ratoon crops (December 1993, January 1994 and January 1995).

Soil bulk density was measured in the planting furrow in December 1993 (two months after planting and before the final cultivation of the plant crop), in January 1994 after the final cultivation of the plant crop and in January 1995 after the final cultivation of the ratoon crop (Table 11).

Table 11.Soil bulk density in the planting furrow of the plant and ratoon crops (December 1993, January 1994 and January 1995).

Treatment		**Bulk density (g cm-3)**		
year		1993	1994	1995
mean		1.183	1.225	1.236
drainage	laser	1.178	1.238	1.246
	mole	1.188	1.212	1.227
	significance	*p = 0.048*	*ns*	*ns*
	l.s.d.	*0.009*		
fallow	bare	1.194	1.239	1.218
	soy	1.172	1.211	1.255
	significance	*ns*	*p = 0.001*	*p = <0.001*
	l.s.d.		*0.027*	*0.020*
tillage	CT	1.203	1.260	1.293
	MT flat	1.197	1.225	1.275
	MT ridge	1.175	1.201	1.167
	NT flat	1.148	1.221	1.224
	NT ridge	1.194	1.217	1.222
	significance	*p = 0.055*	*p <0.001*	*p <0.001*
	l.s.d.	*0.041*	*0.027*	*0.031*
depth	5	0.954	0.997	0.994
	15	1.139	1.146	1.203
	25	1.220	1.248	1.295
	35	1.315	1.320	1.343
	45	1.289	1.414	1.347
	significance	*p = 0.048*	*p <0.001*	*p <0.001*
	l.s.d.	*0.041*	*0.027*	*0.031*

Bulk density increased from the start of the fallow-soybean rotation period in January 1993 to the final cultivation of the plant crop in January 1994 but increased by only a small amount in the next year (Figure 14). As the increase in bulk density at 40 – 50 cm appears to be anomalous only data for 0 – 40 cm are included.

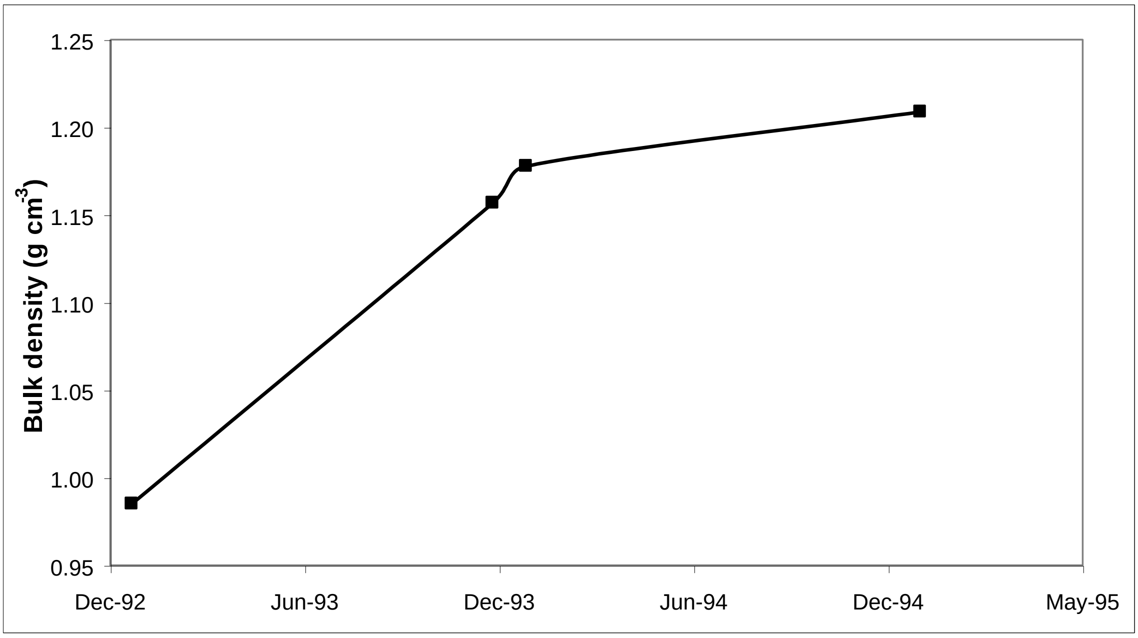


Figure 14. Changes in bulk density (mean of 0 – 40cm) from the commencement of the fallow-soybean rotation (January 1993) to early in the ratoon crop (January 1995).

The increases in bulk density over time were greater at depth than at the surface (Figure 15).

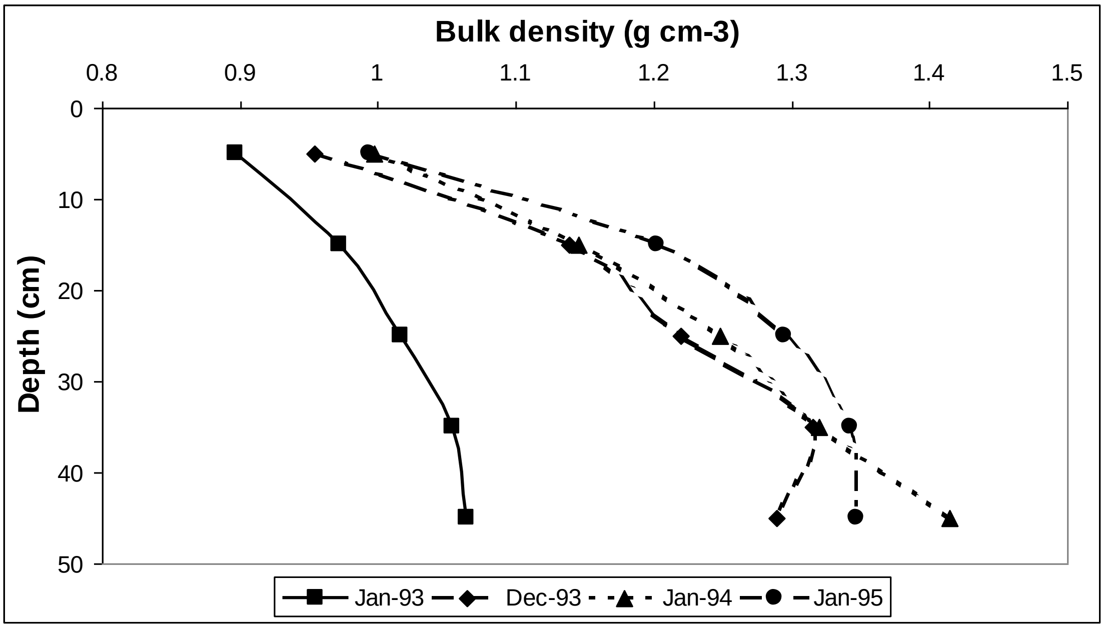


Figure 15. Changes in bulk density in the top 50cm from January 1993 to January 1995.

Drainage effects were small and were only significant in December 1993.

Fallow effects on soil bulk density were not significant in 1993. In 1994 bare fallow resulted in greater bulk density and differences were significant between 20 and 50 cm. In January 1995 bulk densities were greater following soybean fallow but this was only significant in the top 10 cm (Figure16).

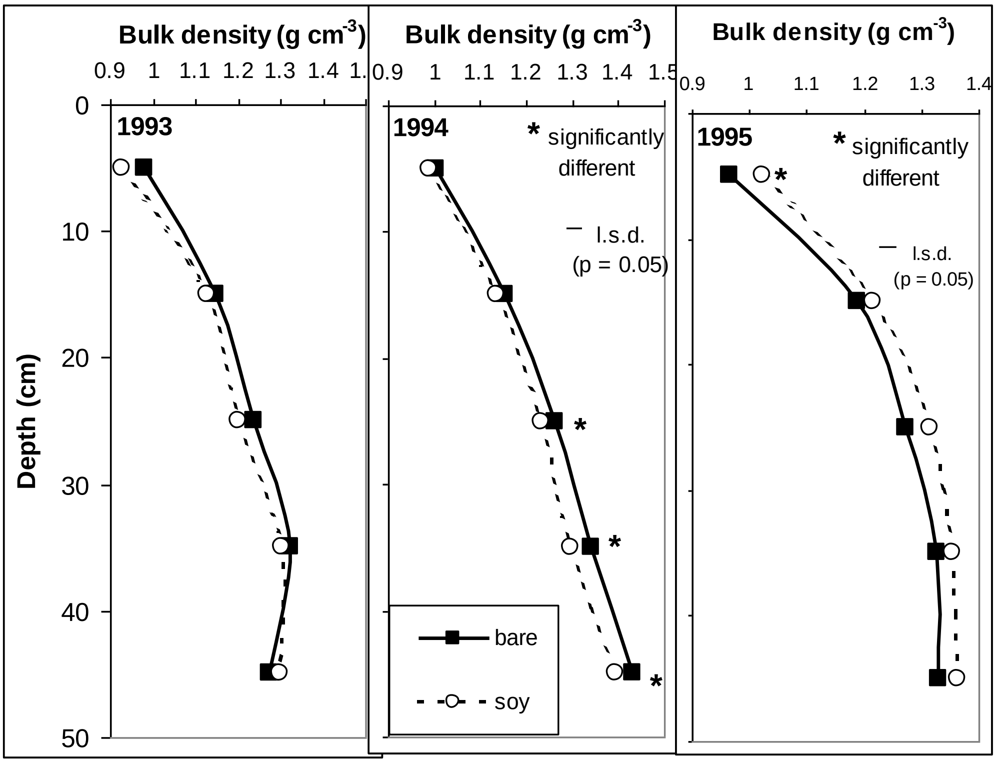


Figure 16. Fallow x depth effects on soil bulk density in 1993, 1994 and 1995.

Tillage effects were significant in all years and interacted with depth in 1993 and 1995 (Figure 17). Although the details of the interaction are complex (see Figure 14) there was a clear trend for the bulk density of the top 30cm in the ridged treatments to be less than that in the CT treatment. At the lower depths, interactions occurred that are statistically significant but are difficult to explain. This may be due to the variable depth to a sandy layer. In general this occurred at 80 to 100 cm but occasionally was as shallow as 40 cm.

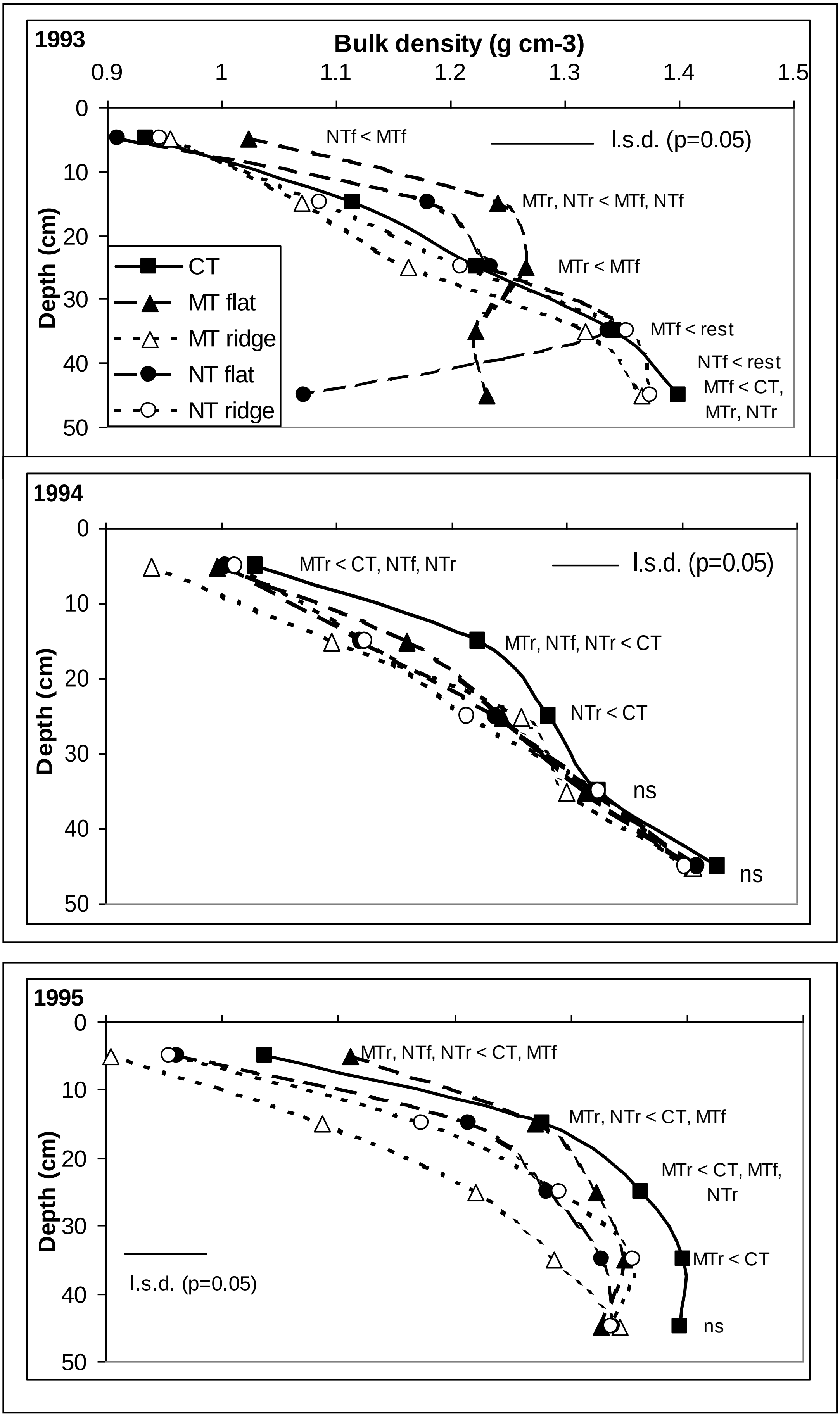


Figure 17. Tillage x depth effects on soil bulk density in 1993, 1994 and 1995.

There was an interaction between drainage and tillage in all years (F = 0.001 in 1993, 0.014 in 1994, and <0.001 in 1995 Figure 15). In 1993 the bulk density of the NT flat treatment in the laser drained plots was significantly lower than all other treatments in both laser drained and mole drained plots. As this was never repeated, it is probable that sampling errors were large in this treatment on this occasion. In the mole drained plots the bulk density in MT ridge was less than in MT flat and NT flat. This pattern was repeated in each year, although in 1994 the differences were not significant. The other consistent difference is the relatively higher bulk density in CT, especially in laser drained plots in 1994 and in mole drained plots in 1995.

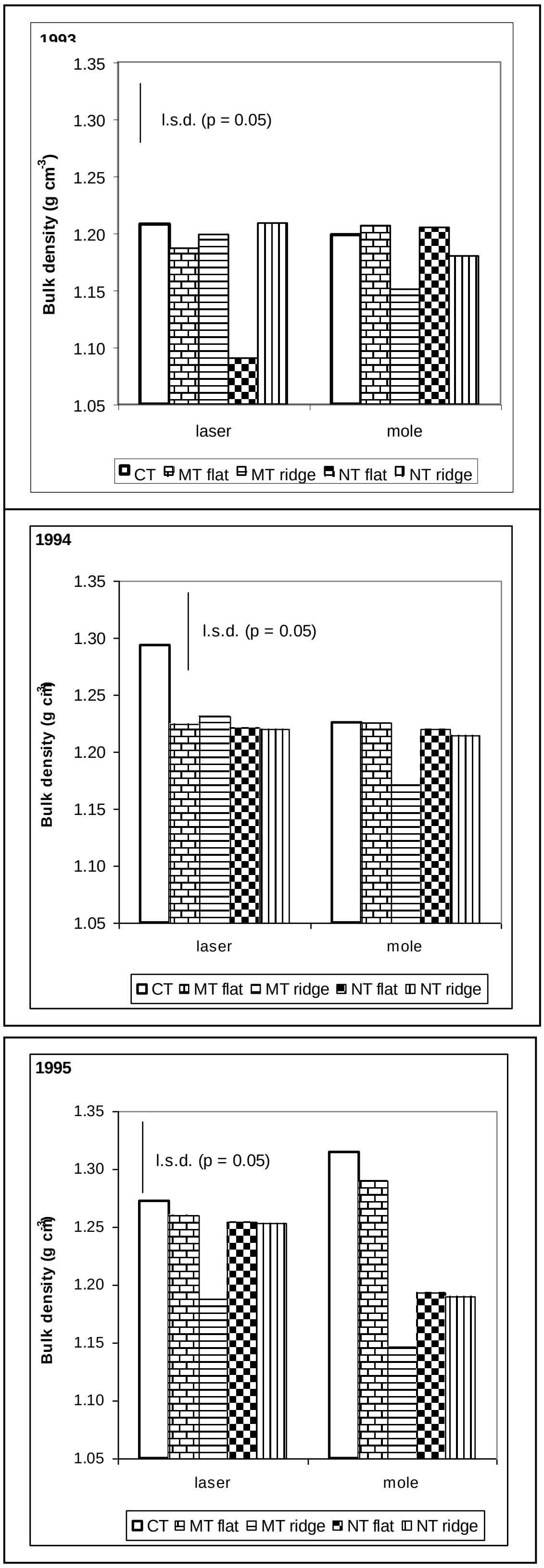


Figure 18. Drainage x Tillage effects on soil bulk density in 1993, 1994 and 1995.

3.3.3 Soil bulk density in the row and in the inter-row in the ratoon crop (January and October 1995).

Soil bulk density was measured in both the planting furrow and inter-row (Table 12) in January 1995 and again in October 1995. Drainage effects were not significant at either date, fallow effects were not significant in January but were highly significant in October. Tillage, row and depth effects were all significant at both dates.

Table 12 Soil bulk density in the planting furrow and in the inter-row in January and in October 1995).

Treatment			Bulk density (g cm^{-3})	
			January 1995	October 1995
Mean			1.2705	1.2440
Drainage	laser		1.2756	1.2449
	mole		1.2654	1.2431
	significance		*ns*	*ns*
	l.s.d.			
Fallow	Bare		1.2625	1.2537
	Soybeans		1.2786	1.2343
	significance		*ns*	*<.001*
	l.s.d.			*0.0112*
Tillage	CT		1.2925	1.2343
	MT flat		1.2973	
	MT ridge		1.2503	
	NT flat		1.2634	1.2428
	NT ridge		1.2492	1.2547
	significance		*0.006*	*0.0140*
	l.s.d.		*0.0333*	*0.0137*
Row	Interow		1.3191	1.2811
	Row		1.2219	1.2068
	significance		*<.001*	*<.001*
	l.s.d.		*0.0211*	*0.01121*
Depth (cm)		2.5		1.1257
		5	1.1045	
		7.5		1.1879
		12.5		1.1772
		15	1.2772	
		17.5		1.2092
		25	1.3222	1.2776
		35	1.3320	1.351
		45	1.3166	1.3792
	significance		*<.001*	*<.001*
	l.s.d.		*0.0333*	*0.021*

Bulk density in the inter–row was higher than in the row to a depth of 30 cm in January and to a depth of 20 cm in October (Figure 19). The data suggest that the self mulching properties of this soil resulted in a decrease in bulk density in the inter-row area to a depth of 20 cm.

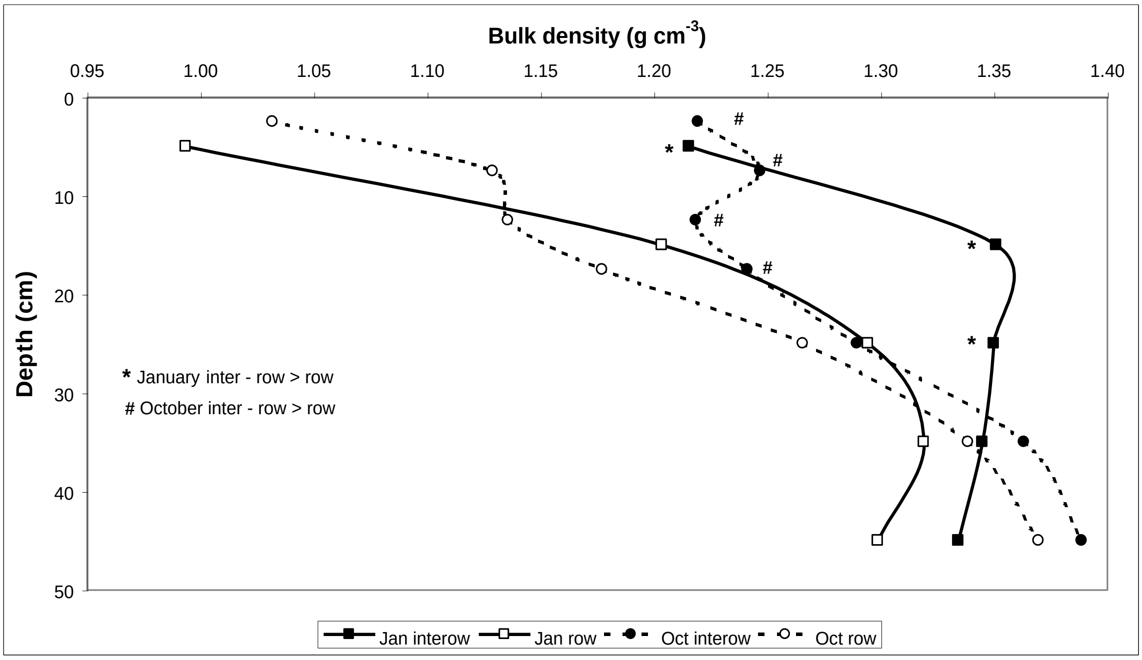


Figure 19. Differences in soil bulk density between rows and inter –rows in January and October 1995.

There was a significant interaction between tillage and row effects in January but not in October (Figure 20). In January bulk density in the inter-row was always greater than in the row except for MT flat where the difference was not significant. Differences between tillage treatment bulk density in the inter-row were not significant but in the row differences were significant in the order MT flat > NT flat > MT ridge, NT ridge.

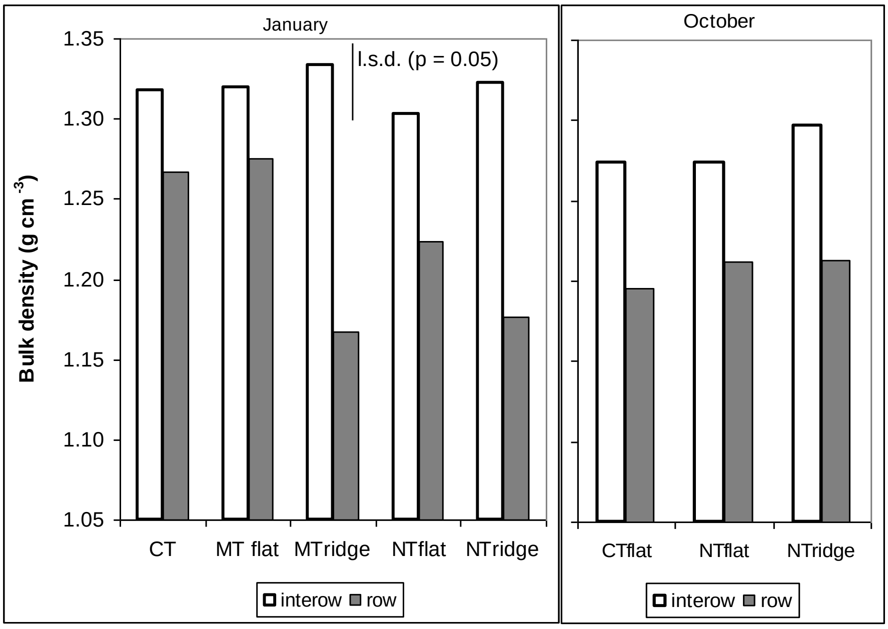


Figure 20. Interaction between row and tillage on soil bulk density in January and October 1995.

In January row effects were significant but fallow effects were not, nor were any interactions between these treatments significant. In October both row and fallow effects were significant, as was the interaction row * fallow * depth (Figure 21).

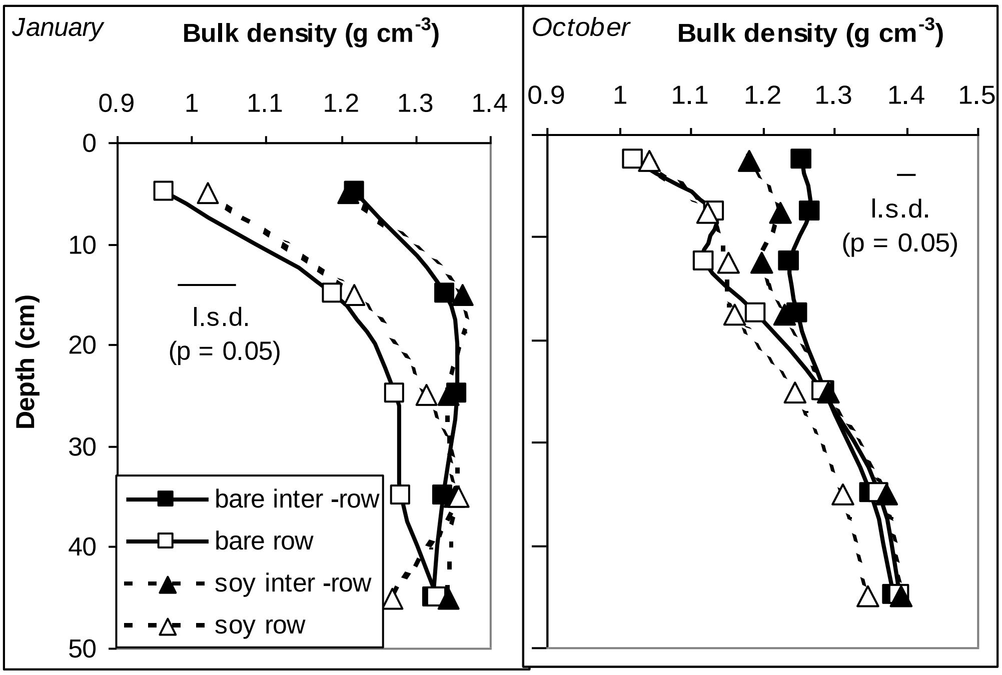


Figure 21. Interaction between row, fallow and depth on soil bulk density in January and October 1995.

3.3.4 Bulk Density in old CT and NT fields adjacent to the trial site.

Data collected from the planting furrow and inter-row of sugarcane fields adjacent to the trial site, indicate that, in the longer term, CT increases soil bulk density in both the row and the inter-row (Table 13 and Figure 22). The exception was that bulk densities in NT were higher than those in CT at 20 – 30 cm and similar at 10 to 20 cm. This was probably due to the long term effects of traffic.

Table 13. Soil bulk density in the planting furrow and in the inter-row in blocks that had been under conventional and no-tillage for several years.

Treatment		Bulk density (g cm^{-3})
mean		1.2390
tillage	CT	1.2880
	NT	1.1890
	significance	*<.001*
	l.s.d.	*0.0524*
row	interrow	1.2920
	row	1.1850
	significance	*<.001*
	l.s.d.	*0.0524*
depth	2.5	1.0180
	7.5	1.1970
	12.5	1.2160
	17.5	1.2560
	25	1.2930
	35	1.3400
	45	1.3510
	significance	**<.001**
	l.s.d.	**0.0980**

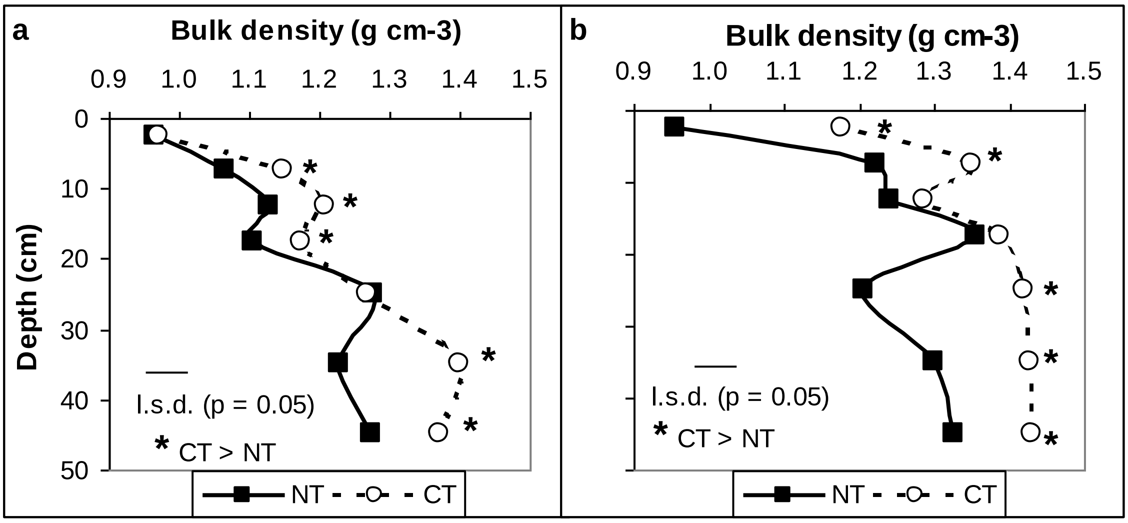


Figure 22. Effects of long term tillage on bulk density in a. rows and b. inter-rows.

3.4 Soil Hydraulic Conductivity

The saturated hydraulic conductivity (K_{sat}) of the surface 15cm of the soil, was measured with a bore-hole style Guelph permeameter at the end of the first year of the ratoon.

The low K_{sat} of the surface soil was expected given the relatively high sodicity and low structural stability of the Broadwater soil. K_{sat} was higher in the NT ridge plots than in NT flat and CT plots. Drainage and fallow treatments had no effect.

Table 14: Saturated hydraulic conductivity of the surface 15cm of the Profile.

Treatment		Hydraulic Conductivity Ksat (mm/hr) Mean	se of mean
Drainage	laser	3.80	0.35
	mole	3.68	0.34
Tillage	CT	3.40	0.35
	NT_Flat	3.40	0.40
	NT_Ridge	4.42	0.47
Fallow	bare	3.60	0.36
	soy	3.87	0.33

3.5 Soil Water Content.

3.5.1 Soil Water Content at during the Fallow-Soybean Rotation (January 1993).

Soil water content was measured when the soybean crop was about 8 weeks old. MT ridges had not been constructed at this point so only 4 tillage treatments (CT, MT flat, NT flat and NT ridge) were measured. Drainage had no effect but both tillage and fallow treatments were significant (Table 15).

Table 15: Volumetric soil moisture content in the planting furrow during the fallow-rotation period (January 1993)

Treatment		Soil water content ($g\ cm^{-3}$)
Mean		0.4110
Drainage	Laser	0.4145
	Mole	0.4106
	significance	*ns*
Tillage	CT	0.4262
	MT flat	0.3957
	NT flat	0.4308
	NT ridge	0.3974
	significance	*0.011*
	l.s.d.	*0.0281*
Fallow	bare	0.4323
	soy	0.3928
	significance	*<.001*
	l.s.d.	*0.0198*
Depth	5	0.2264
	15	0.3397
	25	0.4433
	35	0.5227
	45	0.5307
	significance	*<.001*
	l.s.d.	*0.0314*

CT and NT flat were significantly wetter than MT flat and NT ridge. However when tillage and depth are graphed, even though the interaction is not significant, the true nature of the differences can be seen (Figure 23). NT flat was clearly wetter than NT ridge between 10 and 40 cm. MT flat was slightly drier than NT flat between 10 and

30cm but much drier between 30 and 50cm. A close examination of the raw data showed that soil was much drier at 30 –50cm in two MT flat plots. If these data are assumed to be different due to factors other than treatment effects, perhaps due to a sand lens, and are removed then reanalysis only changes the tillage effects. Now MT flat is still drier than NT flat but not CT.

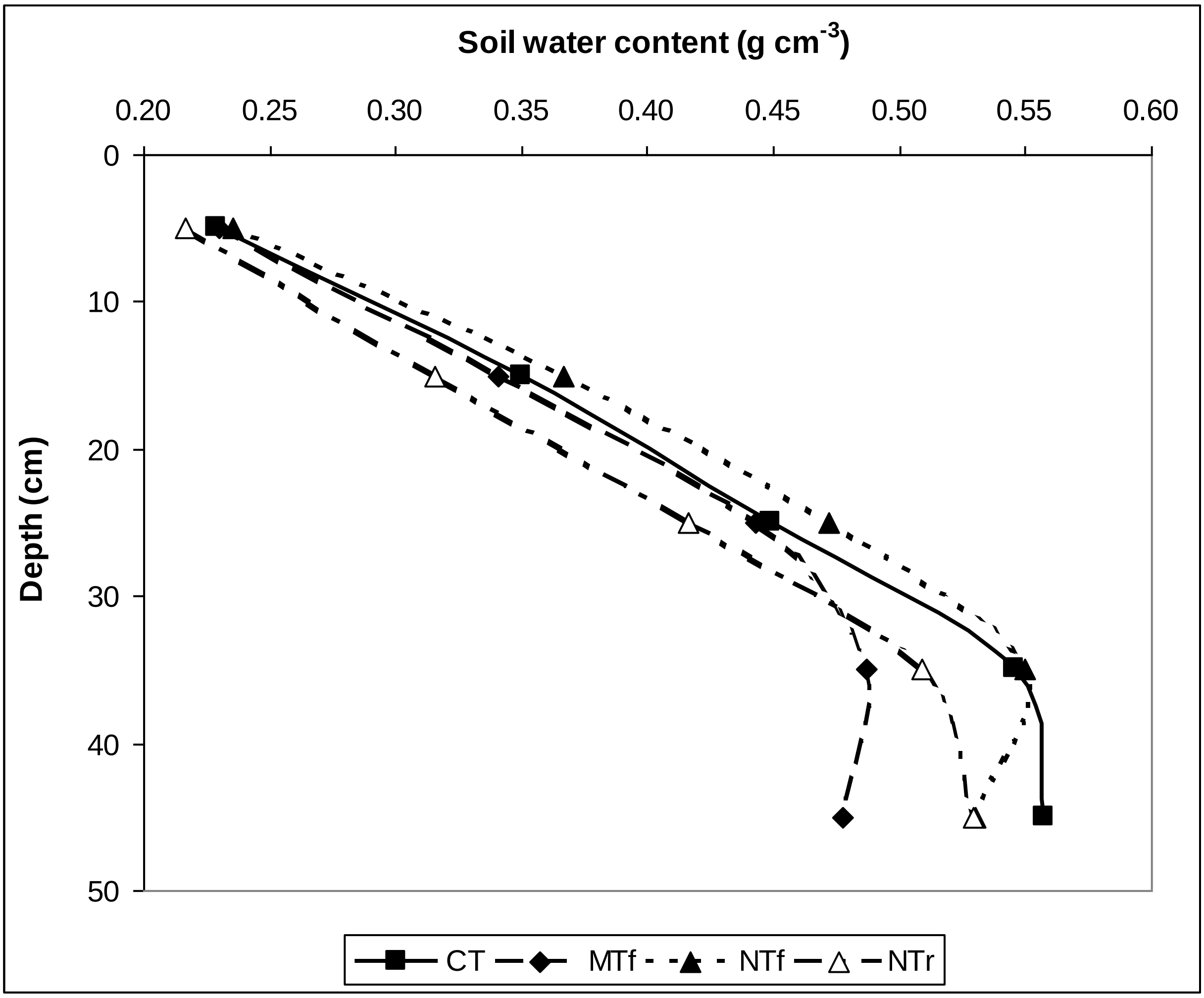


Figure 23. Tillage effects on soil water content during the fallow/soybean period (January 1993).

Soybeans, as expected, had a significant effect on soil water content form 0 to 50 cm (Figure 24). Corrections to MT flat data discussed above had only small, non significant effects on these data.

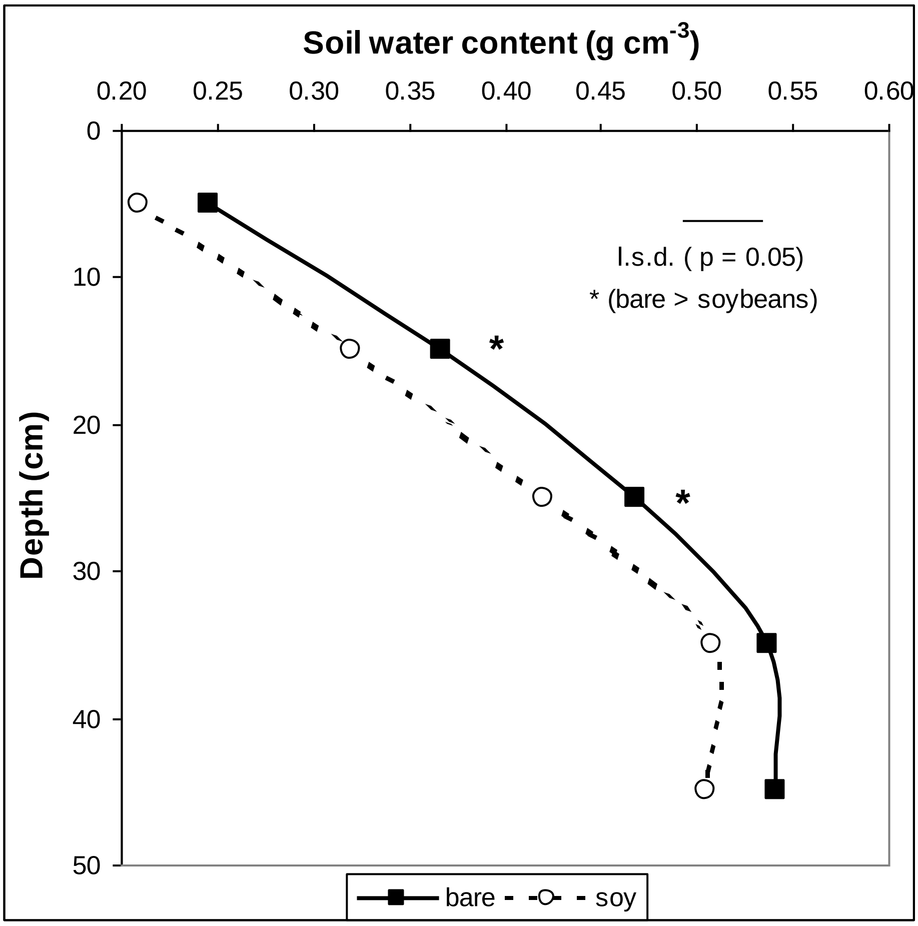


Figure 24. Fallow effects on soil water content during the fallow/soybean period (January 1993).

3.5.2 Soil Water Content at the Planting of the Sugarcane (October 1993)

Although soil bulk density was not measured at this time, soil water content was measured gravimetrically to a depth of 60 cm on the day the sugarcane crop was planted (Table 16). It is important to note that further tillage and soil ridging operations were conducted after the planting date. However, as cane performance is occasionally associated in the literature with soil water content at planting, these measurements were undertaken.

Neither drainage nor tillage had any effect on soil water content at this time, but fallow treatments did have a significant effect (Table 16).

Table 16: Gravimetric soil moisture content in the planting furrow on the day of planting the sugarcane crop (October 1993)

Treatment		Soil water content (g cm^{-3})
Mean		0.4042
Drainage	Laser	0.3975
	Mole	0.4109
	significance	*ns*
Tillage	CT	0.4031
	MT flat	0.4125
	MT ridge	0.3983
	NT flat	0.4003
	NT ridge	0.4067
	significance	*ns*
Fallow	bare	0.4117
	soybeans	0.3967
	significance	***0.038***
	l.s.d.	*0.0141*
depth	5	0.2666
	15	0.3797
	25	0.4576
	35	0.4832
	45	0.4409
	55	0.3972
	significance	*p = <.001*
	l.s.d.	*0.0053*

Although tillage did not have a direct effect, there was an interaction with depth (Figure 25); there was a trend for the ridged treatments to be drier in the top 30 cm but wetter from 40 – 60cm.

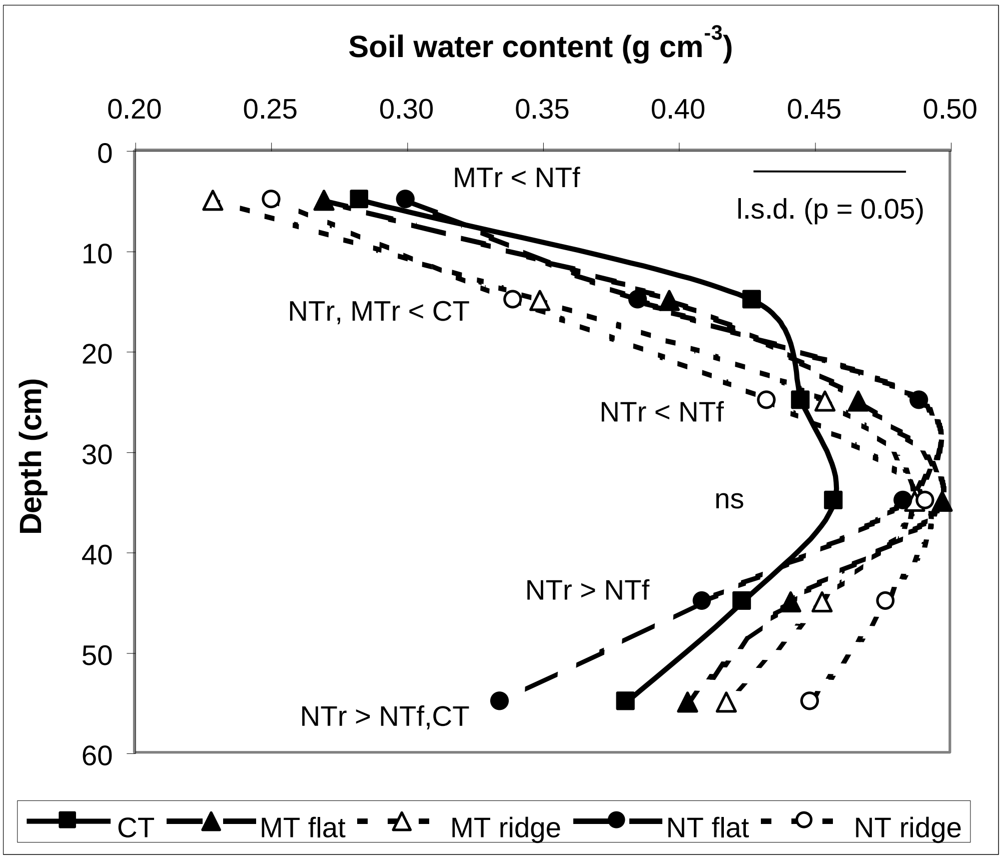


Figure 25. Tillage by depth interaction on soil water content at cane planting (October 1993).

3.5.3 Soil Water Content during the growth of the plant cane crop (December 1993 to November 1994).

Soil water content was measured on 7 occasions, (22/12/93; 7/1/94; 11/1/94; 14/2/94; 18/3/94; 7/8/94 and 2/11/94), during the life of the plant crop. Over this period drainage effects were not significant but all other main treatments (date, tillage, fallow and depth) were highly significant (Table 17).

Mean soil water content in the top 50cm of the profile was significantly different at each sampling date (Figure 26). Cane was growing actively between December 1993 and May 1994 and consequently soil water content reflected rainfall. Low temperatures inhibited growth from June to September, resulting in little water use. Increasing temperatures and active growth from October on resulted in declining soil water content.

Table 17: Volumetric soil moisture content in the planting furrow during the life of the plant sugarcane crop.

Treatment		Soil water content ($g\ cm^{-3}$)
Mean		0.4082
Drainage	Laser	0.4109
	Mole	0.4055
	significance	*ns*
Date	29/12/1993	0.4382
	7/01/1994	0.3743
	11/01/1994	0.3617
	14/02/1994	0.3442
	18/03/1994	0.4476
	7/08/1994	0.4830
	2/11/1994	0.4084
	significance	*p = <.001*
	l.s.d.	*0.0053*
Tillage	CT	0.4185
	MT flat	0.4124
	MT ridge	0.3945
	NT flat	0.4188
	NT ridge	0.3968
	significance	*p = <0.001*
	l.s.d.	*0.0045*
Fallow	bare	0.4124
	soybeans	0.4039
	significance	*p = <.001*
	l.s.d.	*0.0028*
depth	5	0.2467
	15	0.3190
	25	0.4687
	35	0.5015
	45	0.5051
	significance	*p = <.001*
	l.s.d.	*0.0053*

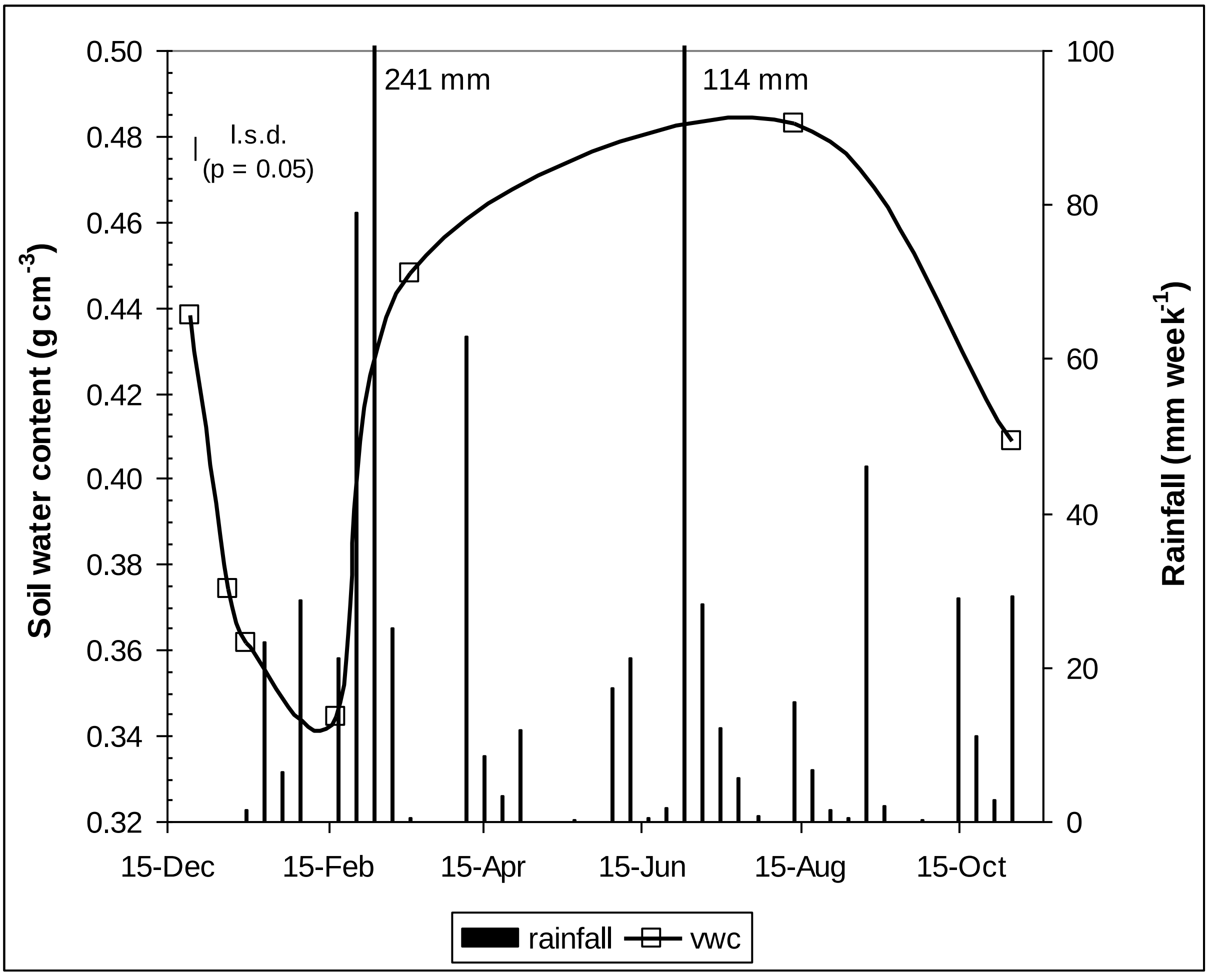


Figure 26. Mean soil water content (0-50 cm) for 7 sampling dates, and weekly rainfall, over the life of the plant crop.

Tillage treatments were significant with CT and NT flat being significantly wetter than MT flat while the ridged treatments were significantly drier. There was a significant interaction between tillage and depth (Figure 27). However the important result is that, at each sampling depth, soil water content in the top 30 cm of the ridged treatments was less than that in all other treatments.

Tillage also interacted with drainage ($p = <0.001$) and with fallow ($p = <0.001$) treatments. In both cases ridged treatments were drier than the other treatments; the interaction was due to variations between CT, MT flat and NT flat. The tillage * date interaction was also significant ($p = 0.015$); again the ridged treatments were always drier than the other treatments but the differences were not always significant.

An interaction was noted between fallow treatments and depths where soil water content following a soybean fallow was less than that following a bare fallow between 10 and 40 cm (Figure 28). There was no significant difference at 0 – 10 cm nor at 40 – 50 cm.

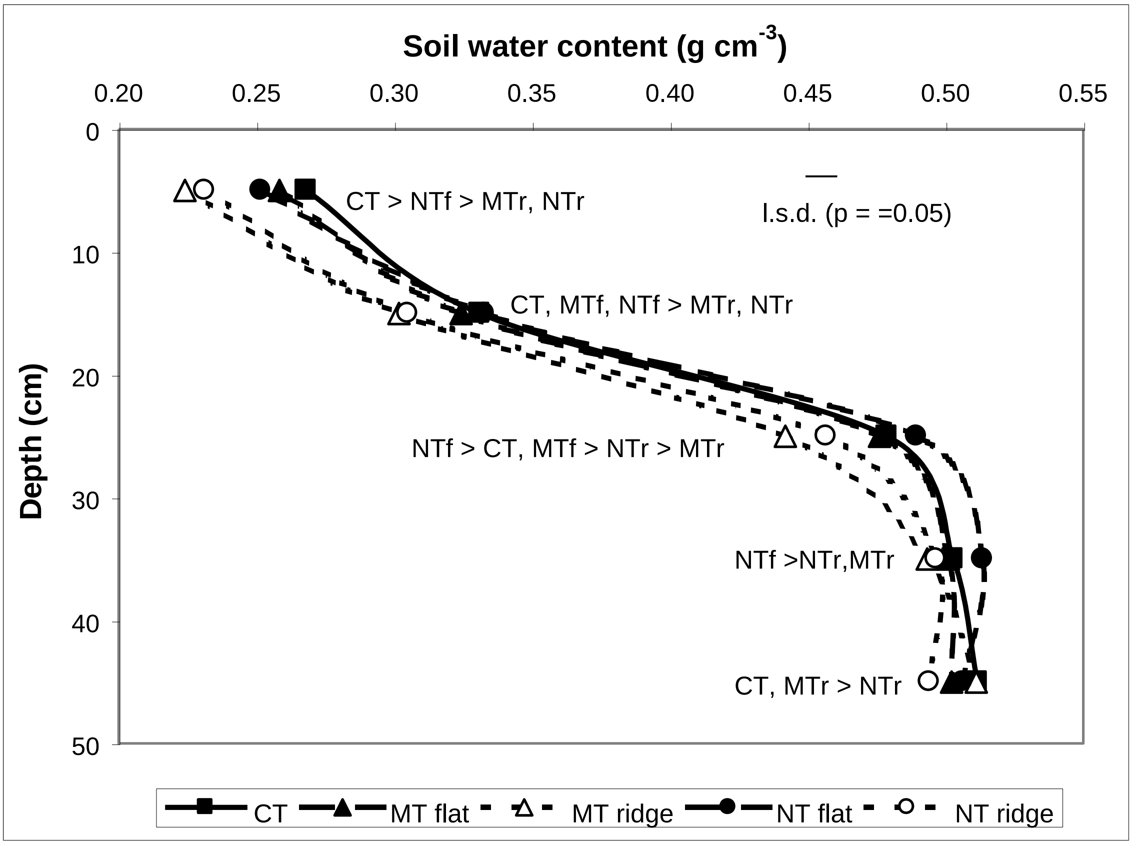


Figure 27. Interaction between tillage treatments and depth on soil water content under the plant cane crop.

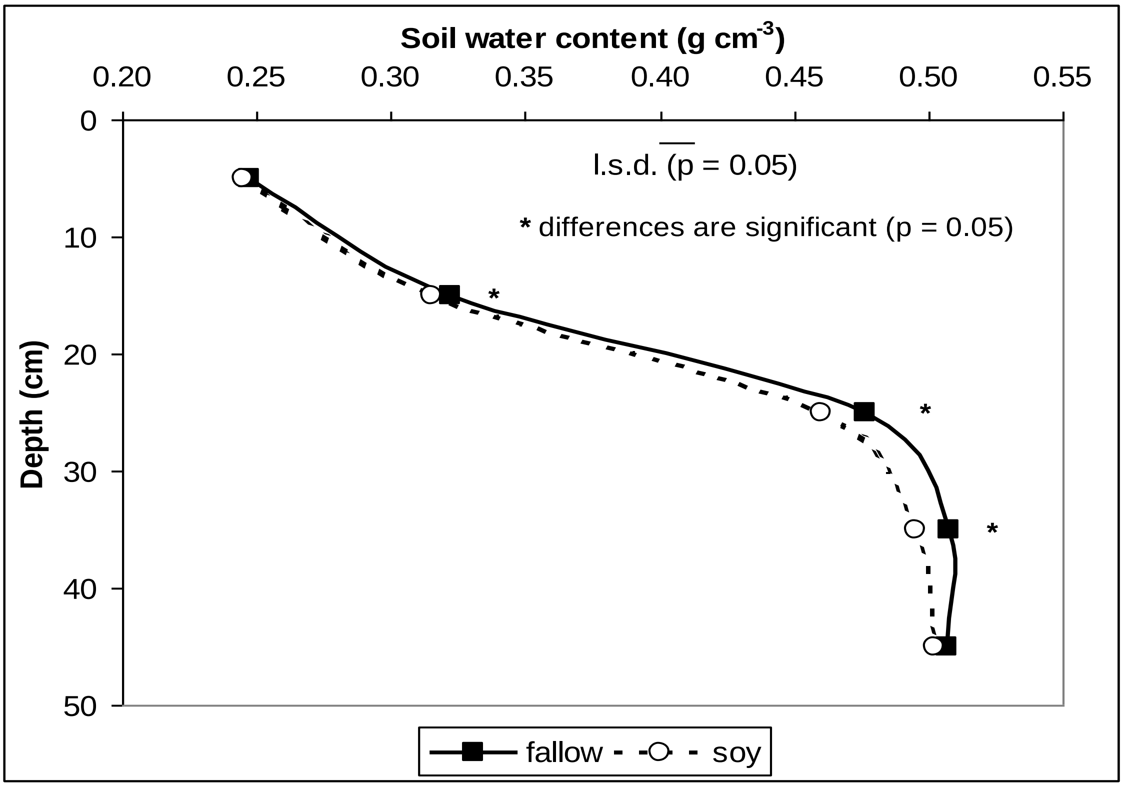


Figure 28. Interaction between fallow treatments and depth on soil water content under the plant cane crop.

3.5.4. Soil Water Content during the first year of growth of the ratoon cane crop (November 1994 to November 1995).

Soil water content was measured 9 times over the first 13 months of the ratoon crop and over this period the effects of drainage and fallow treatments were not significant but dates, tillage and depth were highly significant (Table 18).

Mean soil water content in the top 50cm of the profile was significantly different at each sampling date (Figure 29).

Soil water content increased between ratooning (2/11/94) and the first sampling (12/01/95) despite relatively low rainfall. This was probably because the cane was small and so water use was restricted. Crop water use is high during the January to May period due to high growth rates (Hughes and Muchow pers com) but in this case rainfall was sufficient to maintain high soil water content during summer and autumn (14/1/95 – 24/6/95). Low rainfall was received in winter and spring of 1995 so soil water content declined even though crop water use at this time is relatively low.

Differences between tillage treatments were significant (Figure 30), with both ridged treatments having significantly lower soil water than flat treatments. This effect is consistent for the top 40cm ($F = <0.001$) (Figure 31) and remains across all sampling dates ($F = <0.001$) although differences are not always significant (Figure 32).

Table 18: Volumetric soil moisture content in the planting furrow during the first thirteen months of the ratoon sugarcane crop.

Treatment		Soil water content ($g\ cm^{-3}$)
Mean		0.4149
Drainage	Laser	0.4195
	Mole	0.4102
	significance	*ns*
Date	2/11/1994	0.4065
	12/01/1995	0.4589
	22/03/1995	0.4425
	12/04/1995	0.4122
	21/06/1995	0.4659
	7/08/1995	0.3800
	25/09/1995	0.3521
	12/11/1995	0.3760
	28/11/1995	0.4399
	significance	*<0.001*
	l.s.d.	*0.0061*
Tillage	CT	0.4226
	MT flat	0.4167
	MT ridge	0.4052
	NT flat	0.4227
	NT ridge	0.4071
	significance	*<0.001*
	l.s.d.	*0.0045*
Fallow	bare	0.4180
	soybeans	0.4117
	significance	*<0.001*
	l.s.d.	*0.0029*
depth	5	0.2829
	15	0.3798
	25	0.4533
	35	0.4783
	45	0.4799
	significance	*<.001*
	l.s.d.	*0.0045*

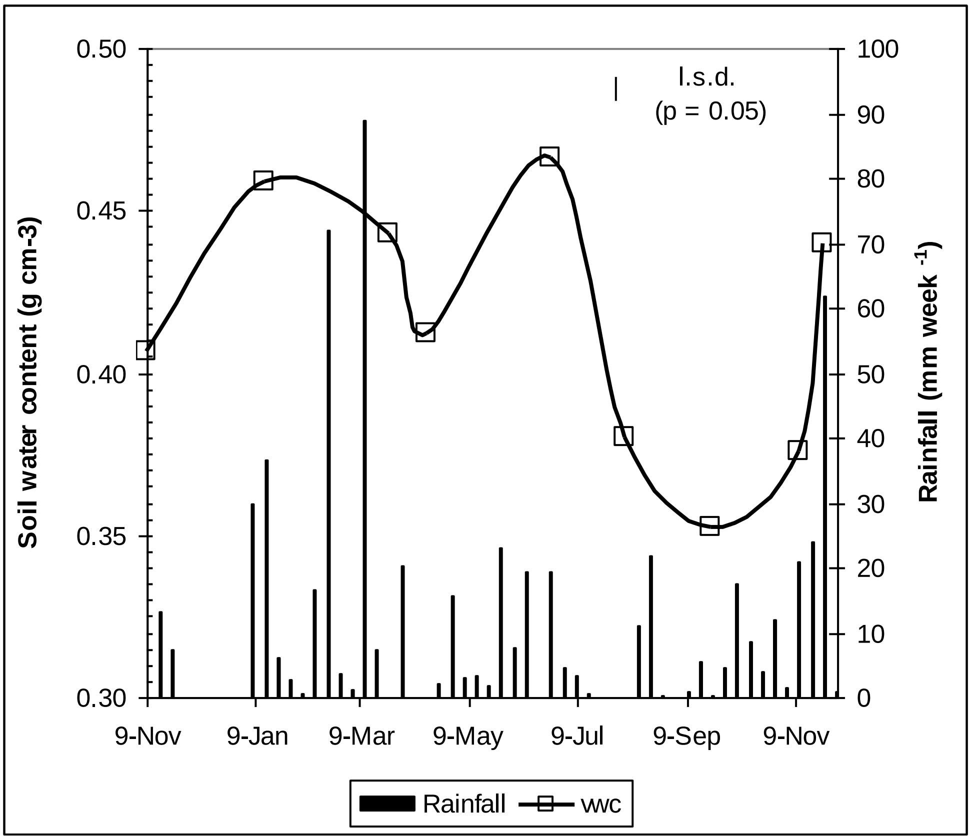


Figure 29. Mean soil water content (0-50 cm) for 9 sampling dates, and weekly rainfall, over the life of the ratoon crop.

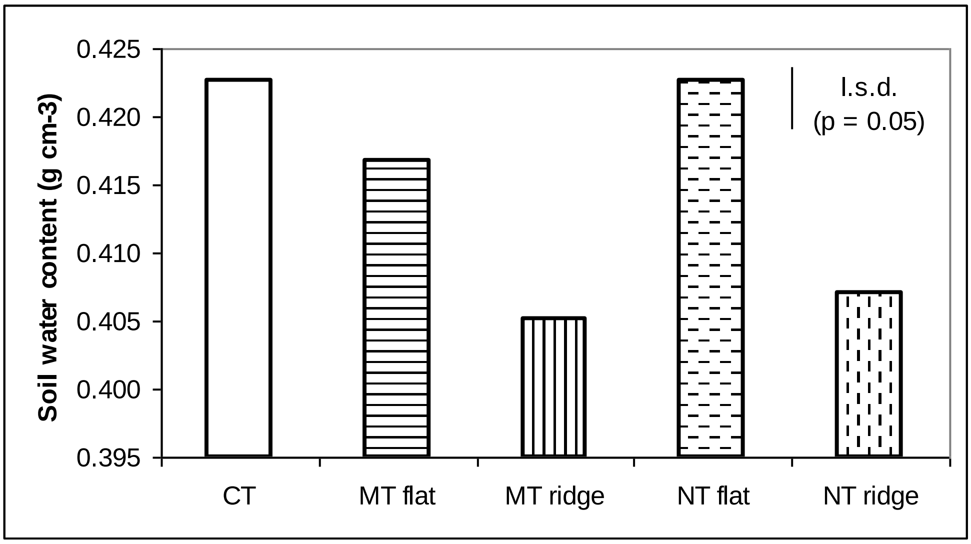


Figure 30. Tillage effects on soil water content (0-50 cm) in the ratoon crop.

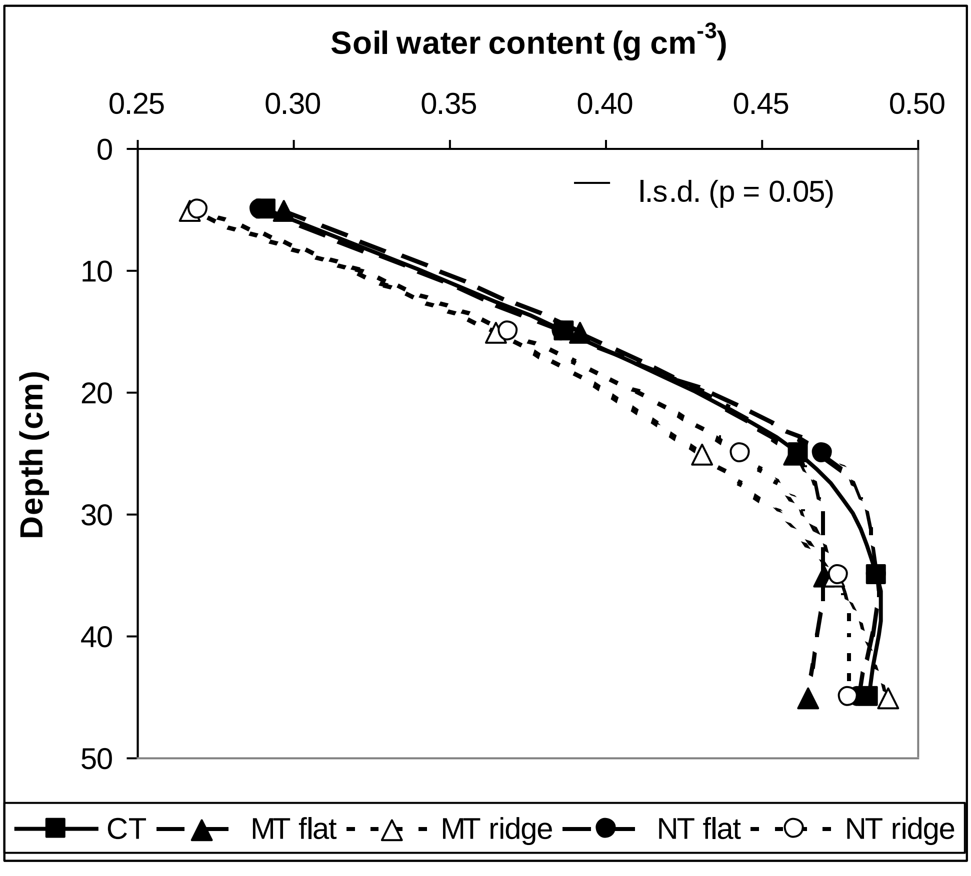


Figure 31. Tillage x depth interaction on soil water content (0-50 cm) in the ratoon crop.

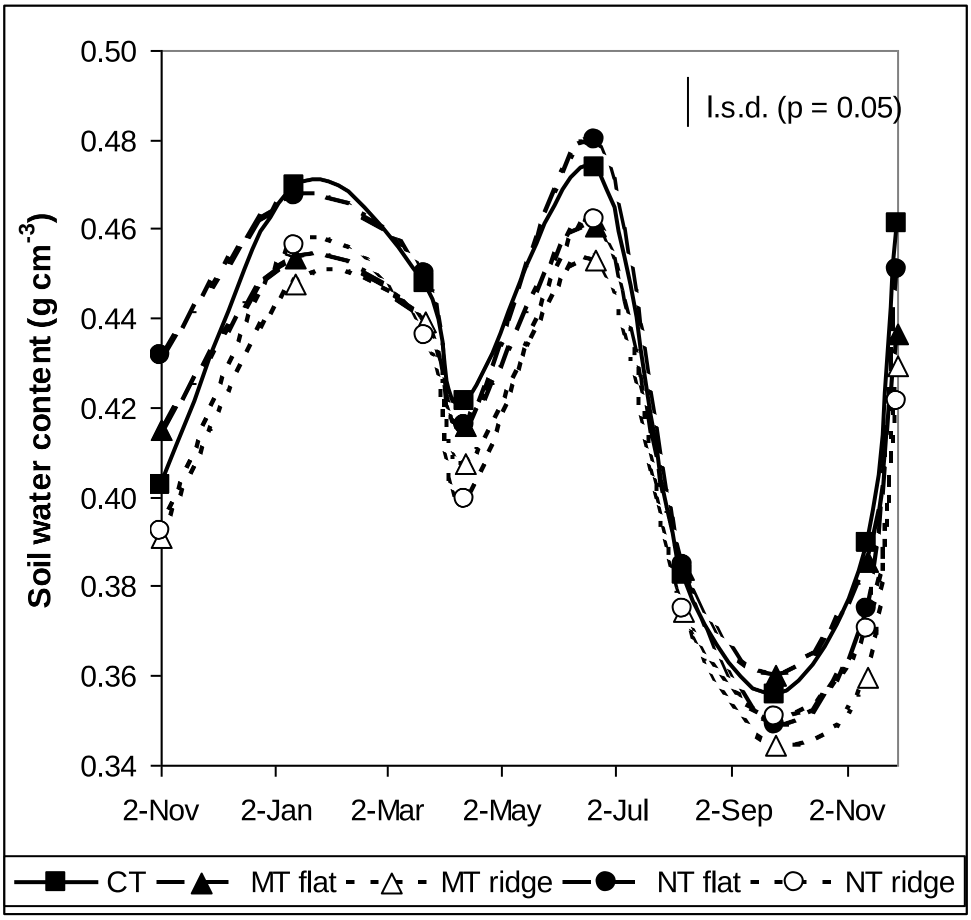


Figure 32. Tillage x date interaction on soil water content (0-50 cm) in the ratoon crop.

Tillage also interacted with fallow treatments in that bare fallowed CT, MT flat and NT flat had higher soil contents than did soybean fallowed CT, MT flat and NT flat, but there was no difference between ridged treatments (Figure 33.)

The tillage by drainage interaction resulted in there being no difference between flat and ridge treatments when laser drained but ridged treatments were drier following laser plus mole drainage (Figure 34).

The fallow by drainage interaction is illustrated in Figure 35; drainage had no effect following a bare fallow but there was a significant reduction in soil water content in laser & mole drainage compared to laser only drainage following a soybean fallow.

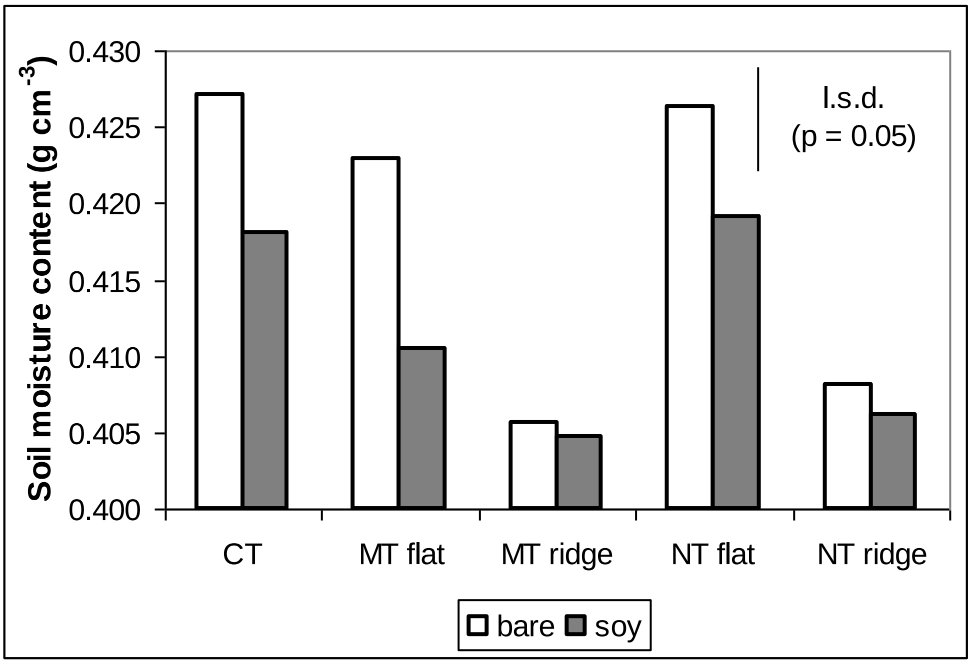


Figure 33. Tillage x fallow interaction on soil water content (0-50 cm) in the ratoon crop.

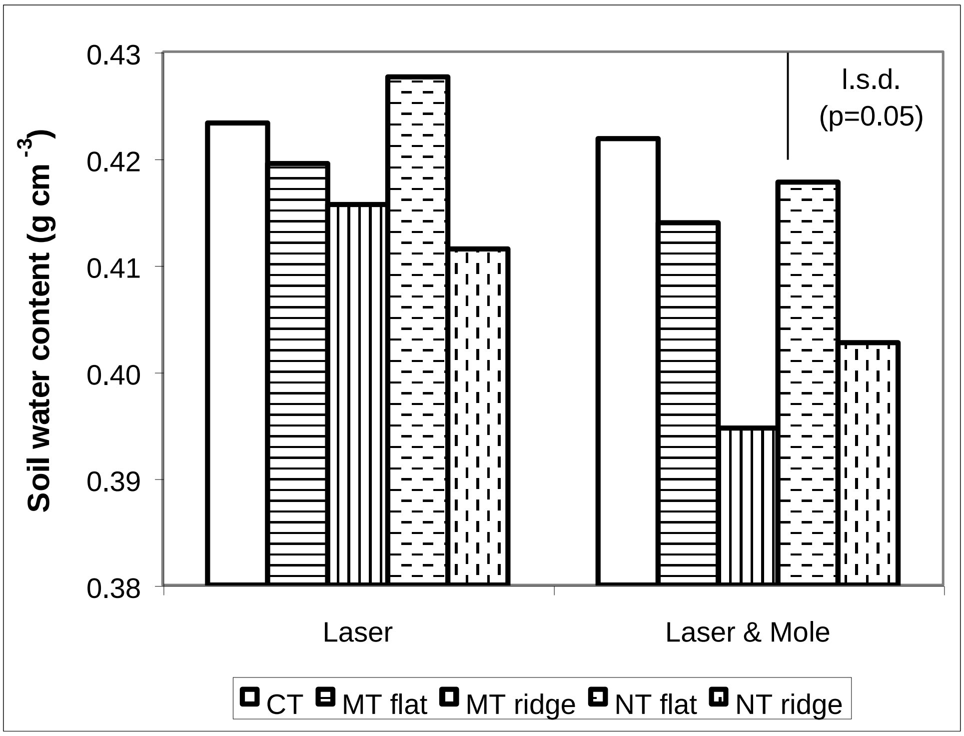


Figure 34. Tillage x drainage interaction on soil water content (0-50 cm) in the ratoon crop.

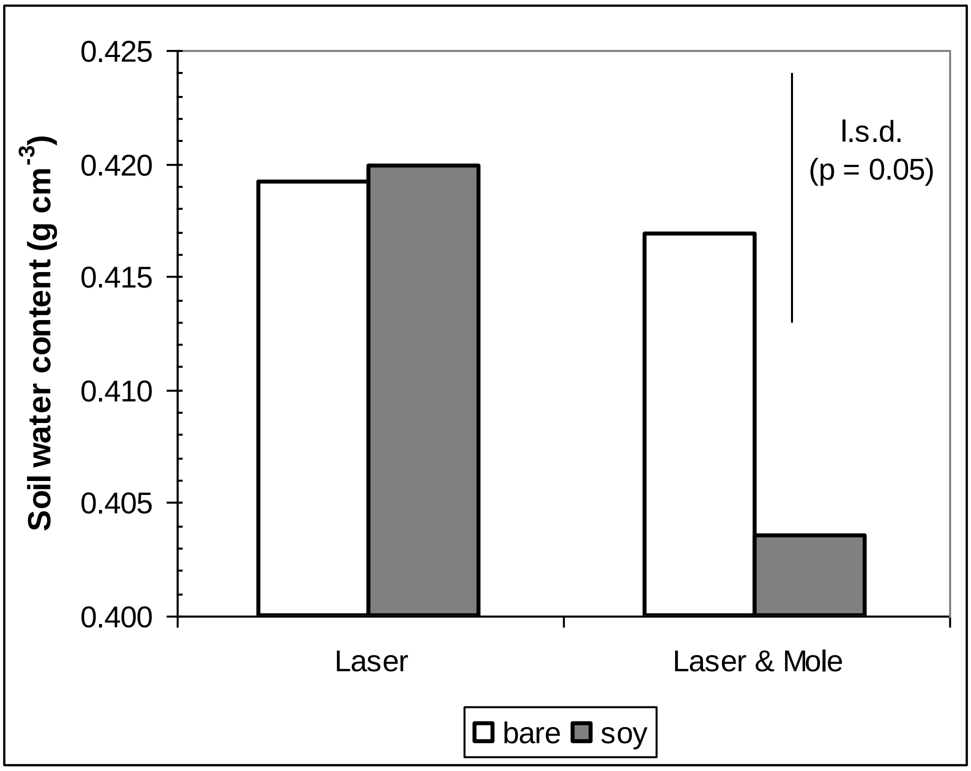


Figure 35. Fallow x drainage interaction on soil water content (0-50 cm) in the ratoon crop.

3.5.4 Discussion of Soil Water Content Data.

When all samplings, from planting through to the end of the ratoon crop, are included in one analysis, it becomes clear that tillage had a greater and more consistent effect on soil moisture content than did any other treatment and this reflects differences in cane and sugar yields. Although there were interactions between tillage and some other treatments (drainage and fallow), these did not alter the main pattern and tended to be statistically but not biologically significant.

3.6 Root Length Density in one year old Ratoon.

The root length density (RLD) of the sugarcane was measured in the planting furrow and inter-row at the end of the first year of the ratoon crop (see Table 19). RLD was very low in the inter-row and but much larger in the intra-row (Figure 36). Consequently the data were separated into two data sets and analysed separately. Drainage treatments were not significantly different either intra or inter-row. Tillage treatments were not significantly different intra-row but root length density was greater for NT flat than for CT in the inter-row. Fallow treatments were significantly different in both the inter and intra-row with root length density always greater following a soybean fallow than following a bare fallow.

Interactions occurred between tillage and fallow treatments in both intra and inter-row. In the intra-row RLD following a soybean fallow was significantly greater than following a bare fallow down to 10cm (Figure 37). In the inter-row the differences were significantly only in the top 2.5 cm. In the inter-row there were significant interactions between tillage and depth (Figure 38) and fallow and depth (Figure 37) but these only occurred at the surface.

Table 19: Root length density in the intra- and inter-row of the ratoon sugarcane crop after 12 months growth.

Treatment			Root length density	
			row	inter-row
Mean			24.4	15.0
Drainage	Laser		24.3	14.3
	Mole		24.4	15.6
	significance		*ns*	*ns*
Tillage	CT		22.6	13.4
	NT flat		24.8	16.5
	NT ridge		25.8	15.0
	significance		*ns*	*0.046*
	l.s.d.			*2.41*
Fallow	bare		20.3	13.6
	soybeans		28.5	16.4
	significance		*<0.001*	*0.006*
	l.s.d.		*4.0*	*1.97*
Depth		2.5	69.3	31.2
		7.5	30.5	14.9
		12.5	25.6	12.5
		17.5	16.3	10.5
		25	17.6	14.0
		35	13.9	12.4
		45	15.3	14.2
	significance		*<.001*	*<.002*
	l.s.d.		*8.48*	*4.18*

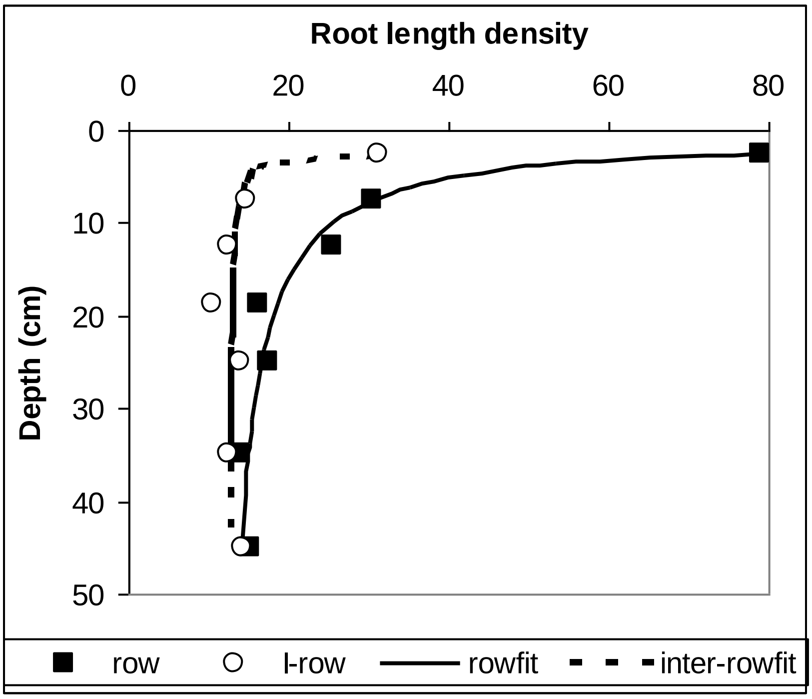


Figure 36. Root length density (0-50 cm) in the inter-row and the intra-row when the ratoon crop was 12 months old.

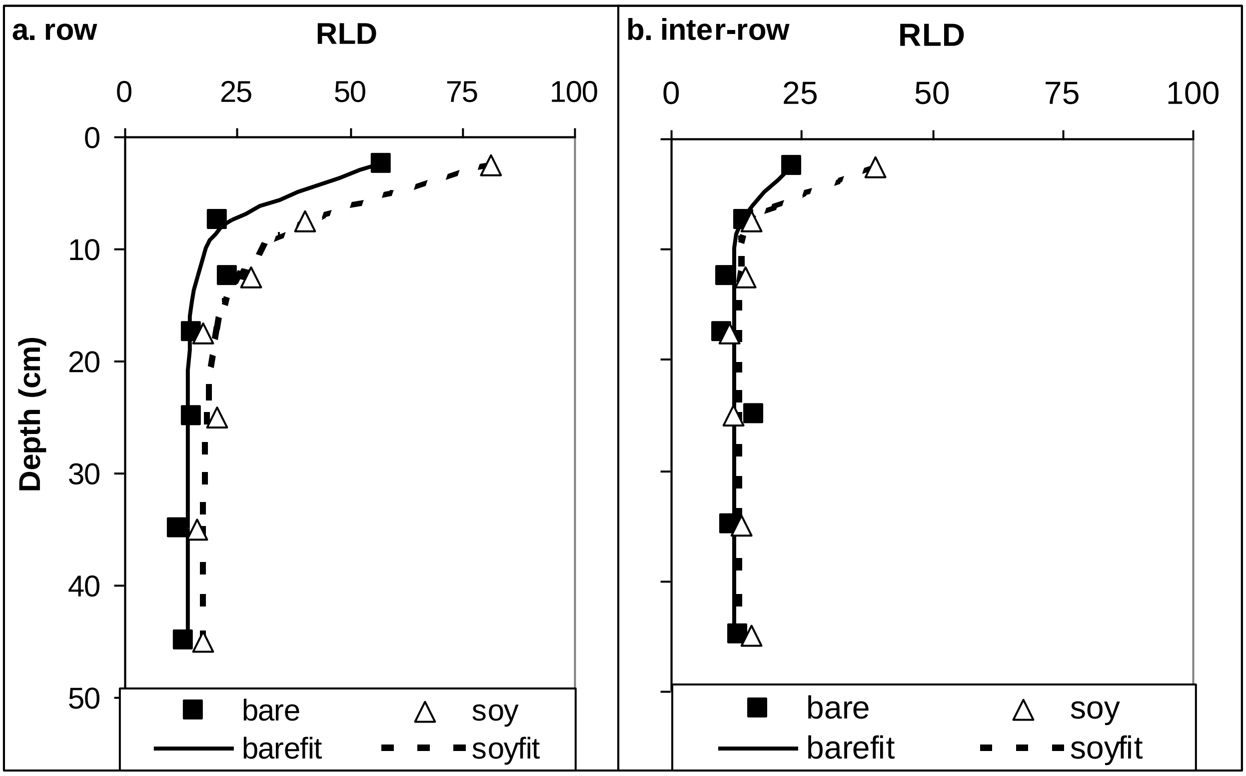


Figure 37. Fallow treatment effects on root length density (0-50 cm) in the intra-row (a) and the inter-row (b) when the ratoon crop was 12 months old.

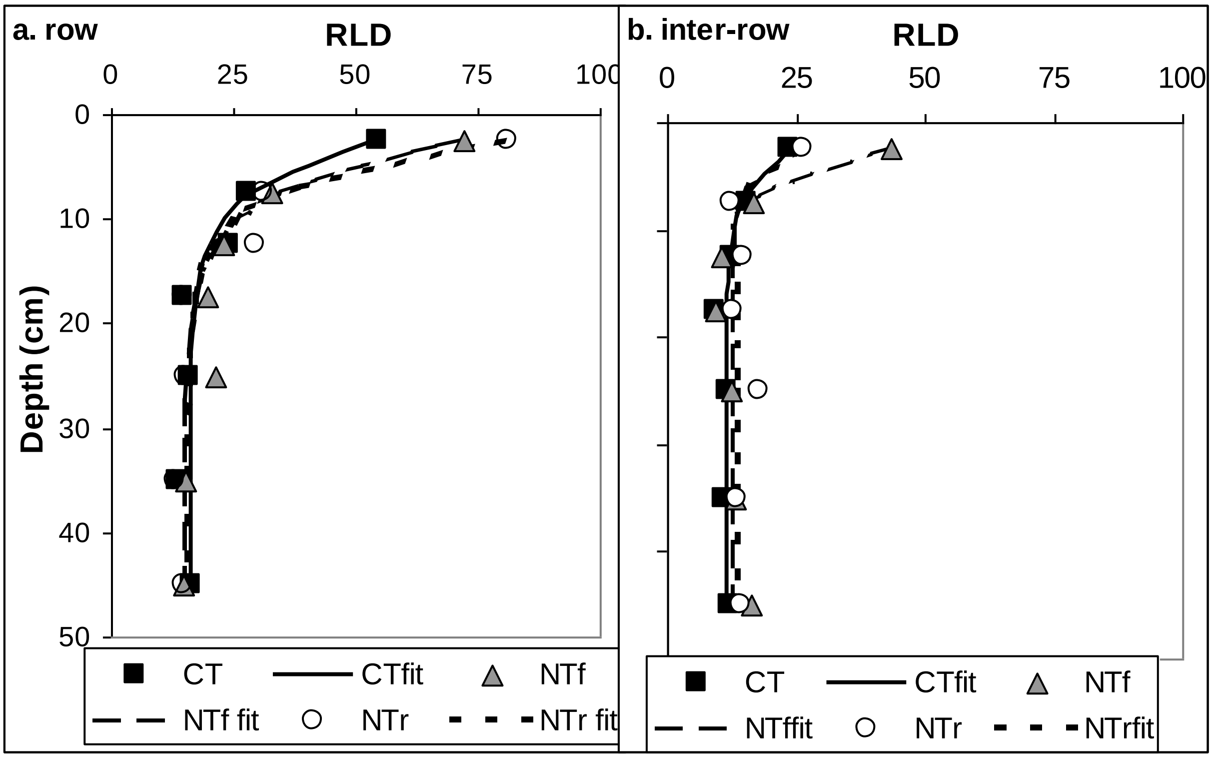


Figure 38. Tillage treatment effects on root length density (0-50 cm) in the intra-row (a) and the inter-row (b) when the ratoon crop was 12 months old.

3.7 Structural stability - Mean Weight Diameter

The mean weight diameter (MWD) within the surface 10cm of the profile was measured at various times during the trial (Table 20). Due to the influence of factors such as soil water content at sampling, aggregate stability can fluctuate greatly within single growing seasons, and hence, it is inappropriate to compare data collected at different sampling dates.

Table 20: Mean Weight Diameter in the surface 10cm of the soil profile.

		Jan-93	Oct-93	Jan-94	Jan-95	Oct-95	Jun-96
drainage	laser	2.41	4.52	2.34	4.12	2.18	1.72
	mole	1.96	3.22	2.21	4.02	2.59	1.68
	significance	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
fallow	bare	2.33	3.47	2.23	4.14	1.89	1.64
	soy	2.04	4.26	2.32	4.00	2.88	1.76
	significance	*ns*	*ns*	*ns*	*ns*	*0.02*	*ns*
till	ct	2.64	3.94	2.07	4.16	2.06	1.49
	mtflat	2.28	3.32	2.10			1.70
	mtr	2.43					1.78
	ntflat	1.89	4.34	2.65	3.98	2.71	1.74
	ntr	1.68					1.77
	significance	*0.035*	*ns*	*0.031*	*ns*	*ns*	*ns*
	lsd	*0.66*		*0.47*			
		ct>ntf, ntr		*ntf>ct,mtf*			

These data are limited in extent, are variable and don't give any insights into what is happening. At no stage were there any significant differences due to drainage. Soybean fallow had a significantly higher mwd in October 95. However, although there was a similar trend in October 93, January 94 and July 96, there was a reverse trend in January 93 and January 95.

3.8 Soil Organic Carbon Content

The organic carbon (OC) content of the surface 10cm of the profile was measured at various times during the trial on the CT and NT flat treatments only (Table 20).

Table 21. Soil Organic Carbon in the Surface 10cm of the Soil Profile.

Treatment			Organic carbon (%)
Mean			2.396
Drainage	Laser		2.31
	Mole		2.49
	significance		*p = 0.012*
	l.s.d.		*0.088*
Tillage	CT		2.29
	NT flat		2.50
	significance		*ns*
Fallow	bare		2.25
	soybeans		2.54
	significance		*p = 0.015*
	l.s.d.		*0.23*
Date		Jan-93	2.74
		Jan-94	2.13
		Jan-95	2.53
		Oct-95	2.29
		Jul-96	2.29
	significance		*p = 0.012*
	l.s.d.		*0.37*

Both drainage and fallow treatments interacted with dates and in both cases the major differences between treatments occurred on January 93 (Figures 39 and 40). It is not clear why OC was higher in the laser plus mole drained treatment compared to the laser drained treatment in January 93. It does appear that soybeans contributed to the OC pool although the crop was only 2 months old at this stage.

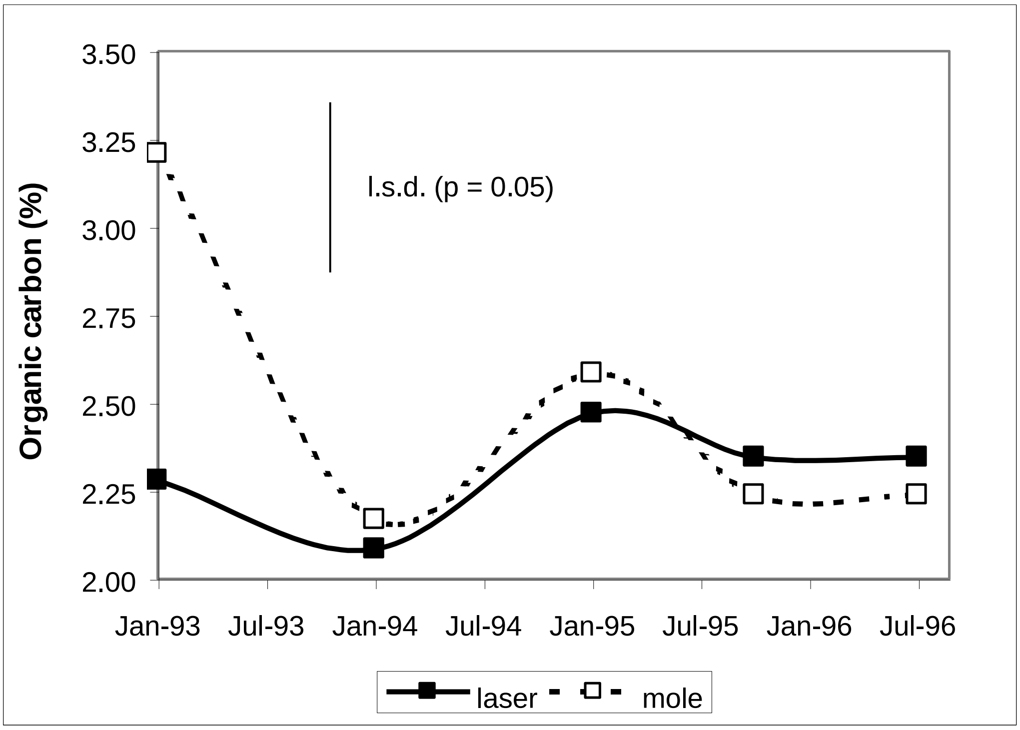


Figure 39. Effect of drainage treatments on soil organic carbon over 5 sampling dates.

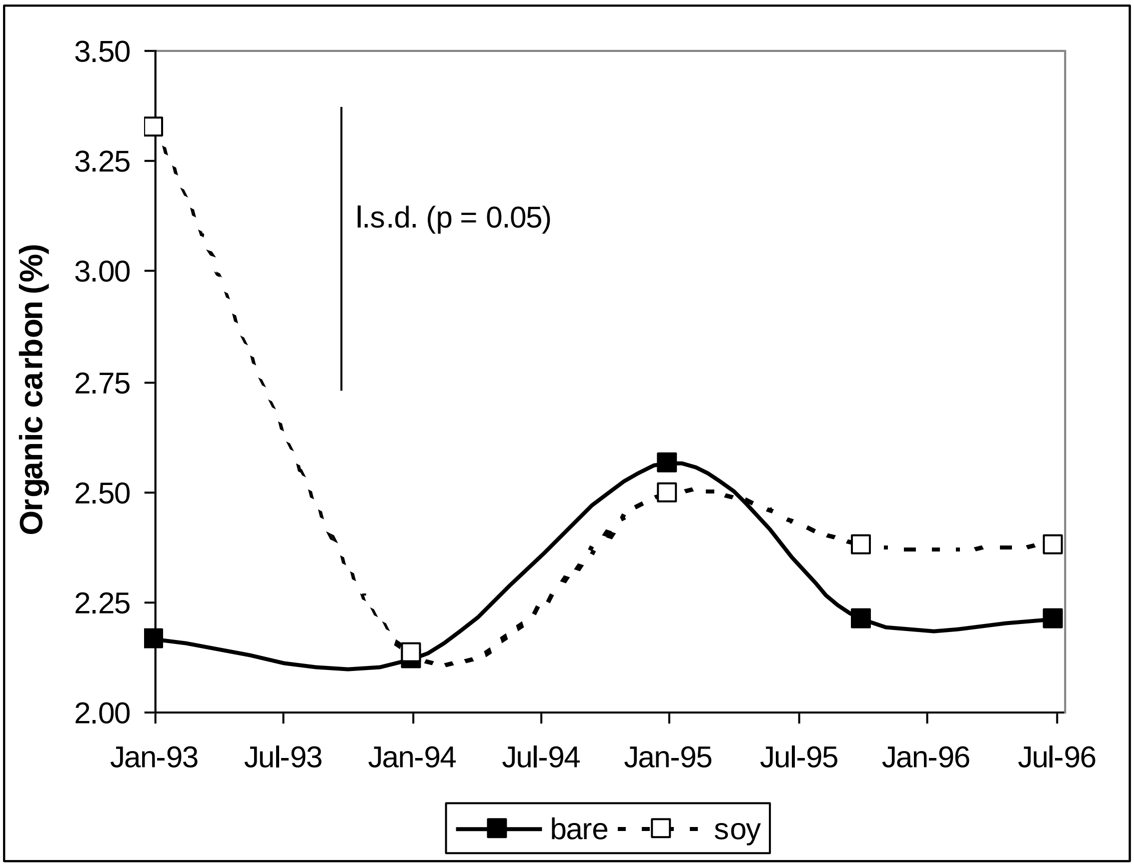


Figure 40. Effect of fallow treatments on soil organic carbon over 5 sampling dates.

3.8 Soil Chemical Analysis

The mean data for each depth (Table 22) indicate that K, P, Ca, Organic Carbon and pH were all at acceptable levels for sugarcane production.

Table 22. Mean soil chemical data for three depths.

Element	Depth		
	0 –10 (cm)	10 – 20 (cm)	30 – 50 (cm)
Exchangeable K (meq)	0.33	0.27	0.33
Plant available P (mg kg-1)	54.2	44.4	22.4
Exchangeable Ca (meq)	6.24	6.54	5.64
Exchangeable Mg (meq)	8.13	8.92	14.13
Exchangeable Na (meq)	0.81	1.49	3.92
Al (mg kg^{-1})	333	310	242
EC (dS m-1)	0.031	0.040	0.096
OC (%)	2.66	2.45	1.26
PH (CaCl2)	4.14	4.21	4.32
Cl (mg kg^{-1})	20.7	26.7	65.3
S (mg kg^{-1})	2.9	2.9	13.0

Depth effects were significant for all elements but proportional changes were considerably greater for Cl, EC, Na, and S than for the other elements. It is also these 4 elements that show most clearly a separation of CT from MTf and NTf from MTr and NTr (Figure 41).

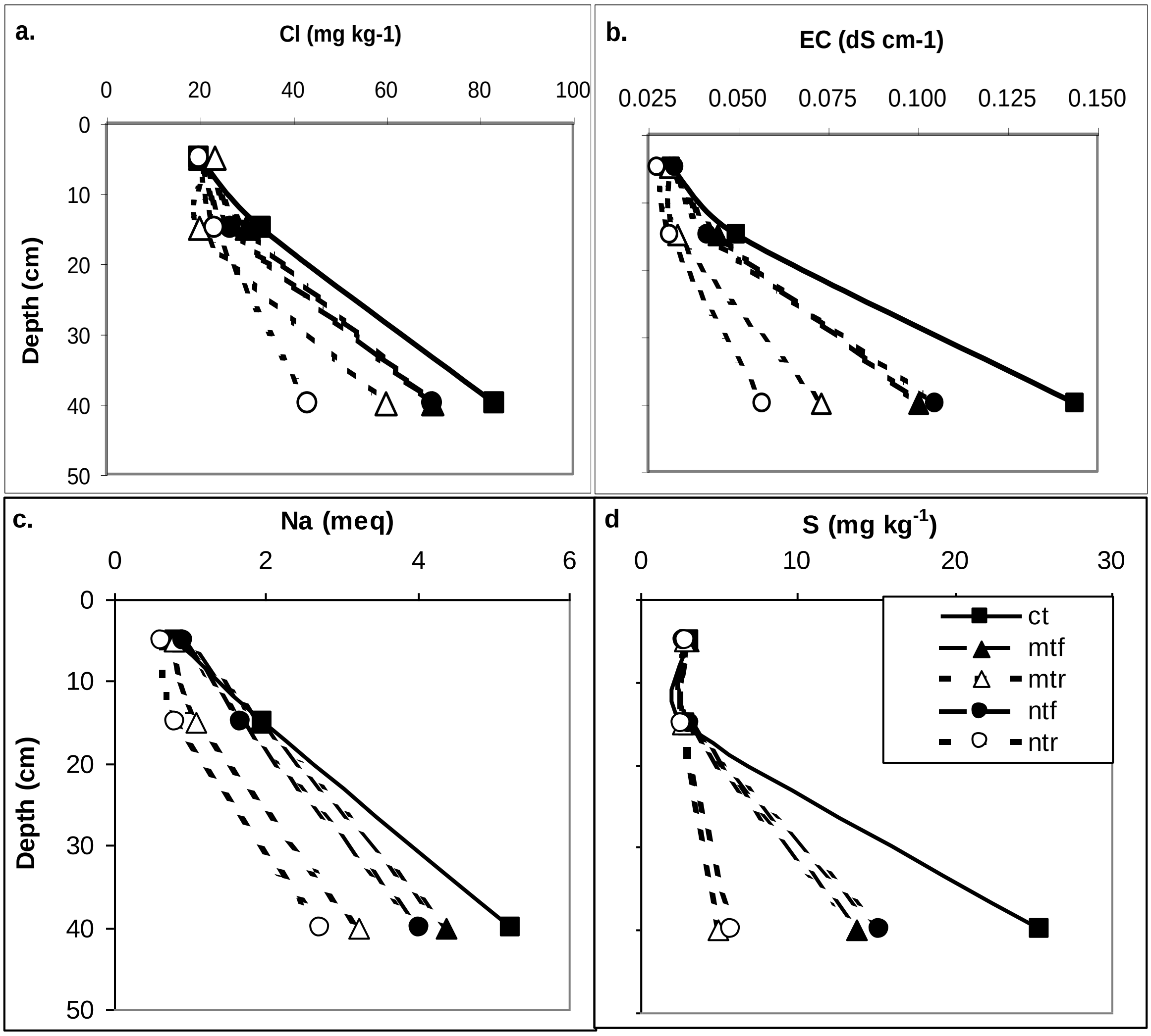


Figure 41. Effect of tillage treatments on soil concentration of a. Cl, b. EC, c. Na and d. S at three depths in July 1996.

3.11 Harvesting effects on row profiles.

Profile shape pre the final harvest was significantly ($P<0.001$) different for each of the three treatments measured (Table 23). The depressions in the inter-row in CT flat and NT flat were due to prior cultural activities (e.g. fertiliser application, weed control, harvesting of plant crop). Mean profile height post the final harvest was similar for CT flat and NT ridge but less for NT ridge. The extent of change during the harvest operation was significant and similar for CT flat and NT flat but not significant for NT ridge (Figures 42 and 43).

Table 23. Mean profile height before and after the final harvest plus the extent of change in profile height.

		Mean profile height (cm)	
TREATMENT	**Before harvest**	**After harvest**	**Change due to harvest**
CT flat	5.33	8.94	-3.61
NT flat	3.35	6.32	-2.97
NT ridge	9.26	8.95	0.30
l.s.d. (P=0.05)	*0.89*	*0.92*	*1.32*

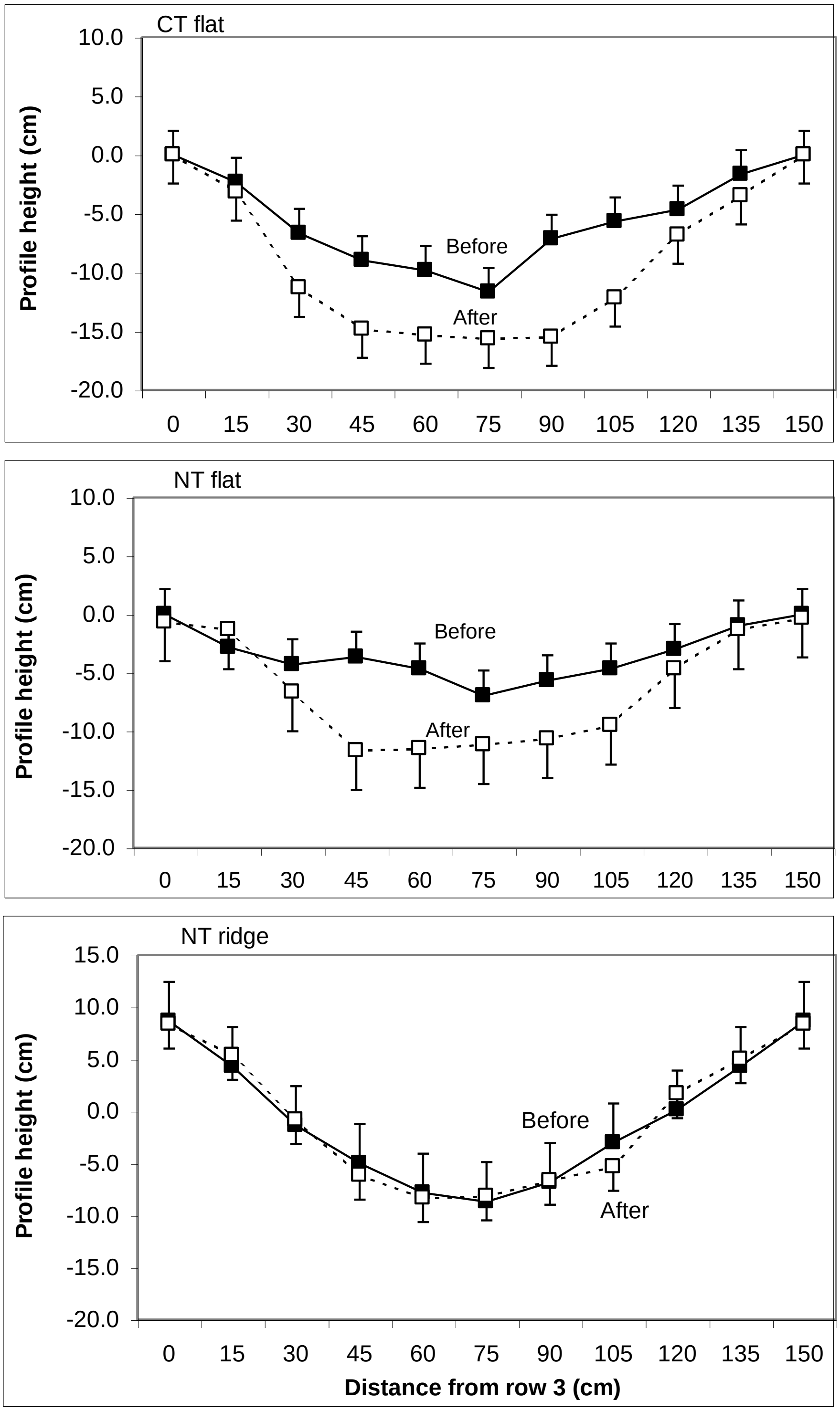


Figure 42. Profile shapes before and after the final harvest for CT flat, NT flat and NT ridge. *(Vertical bars are l.s.d.(P=0.05) values for that data set).*

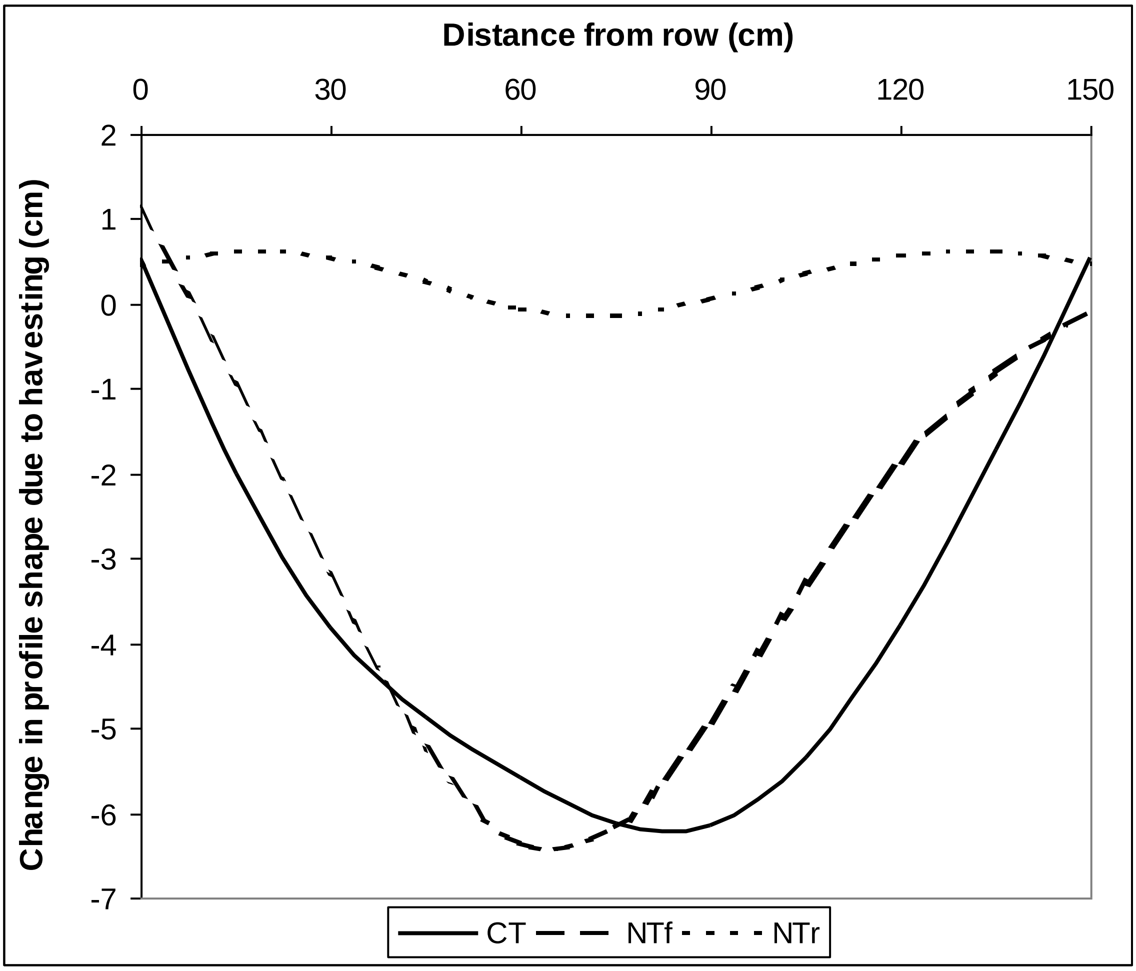


Figure 43. Changes in profile shapes due to harvesting for CT flat, NT flat and NT ridge.

4. Discussion and conclusion.

The data indicates that ridging had the largest and most consistent effect on cane and sugar yield even though this was not statistically significant for the ratoon crop. The lack of significance in the ratoon crop was probably due to the low rainfall in1994/95 (53% of long-term average) and in the first half of 1995/96. Soybean rotations during the fallow period significantly improved cane (but not sugar) yields in the plant crop but had no effect in the ratoon crop. Increased sugar yields were most frequently associated with increases in stalk yield rather that increased CCS, as CCS was typically unaffected by any of the experimental treatments.

Ridging effects were also measured in a number of soil parameters. The top 30cm of the ridges had lower bulk density and were drier than the flats. This soil was high in Cl, EC, Na and S and there was some leaching of these elements in the ridges. Also row profile of the ridged plots was not affected by a wet harvesting but that of flat plots was. Soybean rotations during the fallow period resulted in higher cane leaf N, a greater root mass, lower bulk density and higher organic carbon levels than did a bare fallow.

In Australia, yield increases following the implementation of ridge tillage on poorly drained alfisols and vertisols is typically associated with improved soil aeration and drainage (Tisdall and Hodgson). Although ridge tillage is commonly used in a number of conventional farming systems (eg cotton) there has been limited research into its application within conventional sugarcane farming systems. Van Antwerpen et al (1991) assessed the viability of using ridge tillage on poorly drained duplex soils in South Africa. In 13 separate crops, grown on 5 individual field trials, they observed stalk yield increases ranging from 5 to 20 t/ha due to the use of ridge tillage. Van Antwerpen et al reported that ridges had consistently lower bulk density and were consistently drier than flat soil indicating that they were better drained. They also found that roots concentrated in the surface 20cm of the profile under flat cultivation, whereas they tended to be well distributed to a depth of 600mm within a ridge. Crop water use was therefore greater under ridging as water was extracted to a greater depth within the profile. Van Antwerpen et al also noted that ridge tillage reduced the incidence of compaction within the planting furrow as traffic was better controlled. In Australia, McMahon and Ham (1994) reported that ridge planting increased cane stalk yields on the heavy clay soils of the Burdekin irrigation area by upto 20 t/ha and attributed this to improved soil drainage based on qualitative observation.

As with ridge tillage there is very little published information available concerning the influence of legume rotations on sugar cane yields. Leguminous rotations might be expected to improve the yields of the subsequent cane crop through several mechanisms, the most obvious being the fixation of atmospheric nitrogen by symbiotic bacteria. However, rotations may also improve productivity by a range of other mechanisms including the reduction of pathogen populations, the stabilisation of soil structure through the addition of organic matter, and development of soil porosity through drilling by crop roots.

From the results of this investigation it can be concluded that moling and deep ripping provided no clear advantage over laser levelling alone. Although moling and ripping may have had some small impact upon soil bulk density and water content, this impact was not associated with increased crop performance.

Similarly, the data from the Broadwater trial also tends to indicate that, in the short term, varying the intensity of tillage operations has no clear impact on either soil properties or crop performance. However, data collected from adjacent fields tends to indicate that long term CT is associated with a relative decline in the structural quality of the soil. The degradation of soil structure under long term CT techniques is consistent with yield reductions throughout the Broadwater district.

The above conclusions are supported by the results of research conducted upon a long-term tillage trial in Grafton at the same time as the Broadwater. The results of the Grafton work clearly associate the degradation of soil physical and chemical properties under long-term CT with declining crop yields. The Grafton work also demonstrated that the stabilisation of soil structure under long term NT was associated with sustained higher yields. The structural condition of the CT and NT soils collected from fields adjacent to the Broadwater trial tends to indicate that the Broadwater soil will respond to long term CT and NT in a similar manner to that observed in the Grafton trial. These comparisons have obvious significance to the sugarcane farming industry in the Broadwater district. The adoption of NT will not only reduce the immediate capital costs, it is likely to avoid the degradation of soil structure typically associated with long-term CT, and thereby produce a sustainably higher yielding crop in the long term.

The inclusion of soybean during the fallow period improved the yield of the subsequent sugarcane crop. Soybeans significantly reduced soil water content early in the fallow. The drying of the profile during part of the fallow could have reduced compaction during the ploughing of the CT and MT treatments following the destruction of the legume. However, there were no trends within the data to support this conclusion. The influence of the soybean on soil structure and consequently crop yield, is expected to be minimal relative to that of increases in soil nitrogen through nitrogen fixation by the soybean.

The most significant treatment effect was that of ridging. As with the flat treatments, varying tillage intensity appeared to have a limited impact on the yield or soil properties of the ridged treatments. The crop response to ridging was clearly associated with the modification of the soil structural condition by ridging. The data indicates that ridging increased soil porosity and improved the drainage of soil water within the profile. Relative to flat profiles, ridged profiles had a greater depth of topsoil in the root zone and tended to store significantly greater soil water at depth. Aside from the response of the soil to ridging, there was also an indication that roots were more prolific within the surface of ridges, and that ridged cane was drawing water from a greater depth within the profile.

The findings of this project need to be tested on other soils and over an extended period of time. The sorts of questions that need to be asked are:

1. Do ‘self-mulching’ soils respond differently to reduced tillage and to ridging when compared with other soils in both the short and the long term?
2. One practical aspect of ridging is that it forces a ‘controlled traffic’ management system on the producers and harvesting contractors. On what soils do the benefits of ‘controlled traffic’ (eg. reduced compaction, better roots growth and distribution) accrue and how long do these take to develop?
3. This project was conducted during a dry period. If what way would the results differ in a wet period?