Chapter 1

Introduction

This thesis is concerned with the soil physical effects (particularly soil temperature) that tillage and stubble have on early crop growth. Two contrasting crops were investigated: wheat (a winter growing monocotyledon) and soybean (a summer growing legume). Both were grown after a wheat crop, so that the influence of wheat stubble on each was investigated.

It has been widely observed that early growth in wheat is lower under no-tillage with stubble retention than under "conventional cultivation" systems in which stubble is removed by burning, and this may result in lower wheat yields at harvest. In contrast early growth and yields of summer crops are often higher under no-tillage. A number of factors could be responsible for the effect of no-tillage on early growth.

Conservation tillage systems that maintain crop residues will generally cause lower soil temperature because the mulch reduces energy transfer to the soil. A study by van Wijk *et al.* (1959) demonstrates that this will be beneficial to crop growth in some places and detrimental in others. Aston and Fischer (1986) observed a correlation between dry matter of young wheat plants and temperature differences induced by stubble management treatments and concluded that the differences could at least have partially been due to the soil temperature differences. Because they could not isolate the shading and insulating effects of stubble from other possible effects of stubble, they could not be certain that shading and insulating effects (as indicated by soil temperature) were the cause of the difference. In the experiments described in this thesis, the shading and insulating effects of stubble were separated from other effects by the use of artificial stubble constructed from shadecloth and plastic ribbon. Soil temperatures and crop growth were measured under this artificial stubble and relationships between soil temperature and above ground dry matter derived. These relationships were then tested to examine how well they predicted differences in dry matter production caused by the retention of real stubble.

The effect of stubble management on soil physical properties and the influence of soil physical properties on early crop growth will be reviewed in Chapter 2. Other soil physical properties such as penetration resistance and soil aeration are also discussed, while problems which are usually found in the conservation tillage systems such as soil nitrogen deficiency, plant diseases and phytotoxicity will be discussed briefly also in Chapter 2.

Two identical experiments on the influence of stubble management on soil physical properties and its effects on early crop growth were conducted in two different locations in northern New South Wales. The first experiment is described in Chapter 3 and was conducted in 1992 on wheat grown on a black cracking clay soil located at the Douglas McMaster Research Farm, Warialda. The second experiment is described in Chapter 4 and was conducted in 1993 on soybean grown on a chocolate soil located at the University of New England research station Laureldale, Armidale.

General conclusions from these experiments will be discussed in Chapter 5.

Chapter 2

Review of Literature

2.1 Introduction

Plant growth is influenced by many soil physical properties. However, as Letey (1985) pointed out, there are only four which affect plant growth directly. These are: water, aeration, temperature and mechanical resistance. Other soil physical properties, such as bulk density, texture, aggregation, aggregate stability and pore size distribution, affect plant growth only by their influence on water, aeration, etc. Letey (1985) cites experiments with tomato plants which illustrate this. Rickman *et al.* (1965) found that plant top and root growth of tomatoes grown in containers decreased with increasing bulk density. In a follow-up experiment, in which oxygen diffusion rate was varied independently of bulk density, Rickman *et al.* (1966) showed that bulk density had been affecting plant growth only through its effect on oxygen supply.

The present project is concerned with the soil physical effects of stubble management on early crop growth. Stubble management often involves tillage, so in reviewing the literature it is necessary to consider effects of tillage as well as stubble. Such effects can be divided into two stages. Firstly there is the effect of tillage and stubble on water, aeration, temperature and mechanical resistance, and secondly there is the effect of these on early growth. This approach is taken in the following review of literature, after an initial discussion of conservation tillage systems and early crop growth.

2.2 Conservation tillage systems and early crop growth

The ideal tillage strategy is one that controls weeds, maintains soil structure, will not cause erosion, controls root disease, allows early sowing, establishes good plant density with early vigorous growth, gives the greatest yield, and costs the least (Jarvis *et al.*,, 1991).

The adoption of conservation tillage systems, in which dead vegetative material is left on the soil as a surface mulch, has recently tended to play an increasingly important role in agricultural production (Bristow, 1988; Gupta *et al.,* 1983; Rothrock, 1992). It has a number of advantages when compared to the conventional system of a short cultivated fallow (Aston and Fischer, 1986). For example, conservation tillage systems have been found to have a major effect in preventing soil erosion from water and wind (Freebairn *et al.*, 1986; Holland *et al.,* 1987). Additionally, the systems conserve water by reducing evaporation (Gupta *et al.,* 1983) and in particular no-tillage with retention of stubble, has resulted in a greater store of water in the soil profile than conventional tillage (Freebairn *et al.*, 1986). Residue cover, if sufficiently high, was found by Adams *et al.* (1966) to improve infiltration and to decrease evaporation. Bond and Willis (1970) showed that wheat stubble levels above 4.0 t ha^{-1} were necessary to reduce evaporation. Adams *et al.* (1966) found that cracking soils needed even higher levels of surface residues to effectively reduce evaporation. Surface residues were found by Larson *et al.* (1970) to exert a significant influence on soil temperatures, reducing diurnal variation and decreasing summer temperatures, resulting in improved growing conditions for summer crops.

Conservation tillage systems have many effects on soil and plants which may be beneficial or harmful to plant growth. They influence, amongst other things, the heat and water balance of the soil, therefore directly affecting seed germination, plant emergence, root growth, nutrient uptake and plant development, and indirectly influencing soil water, aeration, soil structure, nutrient availability and decomposition of plant residues (Bristow, 1988; Hillel, 1980a; Wierenga *et al.,* 1982). Problems which are usually found in the conservation tillage systems are decreases in soil temperature and soil nitrogen, increases in plant diseases, phytotoxicity, and soil strength (Lovett *et al.,* unpublished report, no date). Soil physical effects are discussed in detail in sections 2.3 and 2.4. Other effects are briefly discussed here.

In a long term tillage trial in southern Queensland, it was found that, although organic C was maintained or even increased by zero-tillage and stubble retention when fertiliser N was applied, soil total N declined and, consequently, the C:N ratio increased over time (Dalal *et al.,* 1991). Standley *et al.* (1990) also observed the decline in soil N under zero-tillage and stubble retention in a Vertisol used for sorghum cropping in central Queensland. It is possible that these Vertisols have not yet reached the steady-state level for total N, and hence, soil total N levels are likely to decline further. Furthermore Perry *et al.* (1992) stated that incorporation of stubbles into the soil may tie up N, making it less available to plants. Cereal stubble has a low N content and as a result a high C:N ratio, for example as high as 100:1. The microorganisms that break down the stubble, on the other hand, have a low C:N ratio, about 20:1. When these microorganisms feed on the stubble residue, they take up N from the soil that would otherwise be available to the crop. Thus stubble retention may have adverse short-term effects on soil N availability and also may not prevent long-term soil N decline.

The production of toxic compounds from stubble of the preceding crop can cause crop damage. With no-tillage practices, phytotoxic products can be produced and leached from stubble before major residue breakdown takes place. However, with fallows of at least 6-7 months between crops, phytotoxin breakdown and leaching can remove phytotoxins before crop sowing. With opportunity cropping, in which a crop immediately follows the previous crop, the potential for residue phytotoxins inhibiting growth is increased. However, no significant effect of reduced seedling emergence was reported by White (1986) with opportunity cropping, suggesting no major effects of phytotoxins. Potential problems could occur with locally high concentrations of stubble due to poor straw spreading at harvest and wetter than normal sowing conditions.

Marley and Littler (1989) in their 11 year study of wheat grown by no-tillage found an increase in incidence of yellow spot (*Pyrenophora tritici-repentis*) and root lesion nematode (*Pratylenchus thornei*) in three out of 11 years. This possibility affected the use of the greater amount of available water stored in the no-tillage treatments. No-tillage and stubble retention has the potential to increase crop foliar diseases through pathogen survival on the crop residues remaining on the soil surface thus enabling contact with the following crops. Control of cereal diseases is possible by the use of suitable crop rotations to stop the build-up of diseases. Marley and Littler (1989) suggests that disease control through crop rotation could increase the yield advantage of no-tillage. Grain legume and oilseed crops would be suitable crops to be grown in rotation as either opportunity crops or following a set rotation.

2.3 Effects of tillage and stubble management on soil physical properties

2.3.1 Effects of tillage and stubble management on soil temperature

Soil temperature varies in response to changes in the radiant, thermal, and latent energy exchange processes which take place primarily through the soil surface. The effects of these phenomena are propagated into the soil profile primarily by thermal conduction. The radiant energy component of the energy balance is the net radiation which is the total of incoming radiation minus the reflected short-wave and the emitted long-wave radiation. It is expressed as

$$\mathbf{R_n = S_i - S_o + L_i - L_o} \qquad (1)$$

where **S** (Wm^{-2}) is short-wave radiation flux density (emitted from the sun) and **L** (Wm^{-2}) is long-wave radiation flux density (emitted from the earth and atmosphere). Subscripts **i** and **o** refer to incoming and outgoing radiation respectively (Bristow, 1988). Thus, the incoming radiation energy to the surface of the earth consists of solar radiation (short-wave) and sky radiation (long-wave and short-wave), while the outgoing radiation energy from the surface of the earth is the short-wave reflected radiation and the long-wave back radiation.

The partitioning of net radiation at the surface of a field is illustrated by the following energy balance equation:

$$\mathbf{R_n = LE + H + G} \qquad (2)$$

where **LE** is the outgoing latent heat flux density (Wm^{-2}) , i.e. the energy lost from the surface by evaporation of water. **H** is the outgoing sensible heat flux density (Wm^{-2}), i.e. the energy lost from the surface by warming the surrounding atmosphere. **G** is the soil heat flux density (Wm^{-2}), the energy which heats the soil below (Bristow, 1988; Hillel, 1980a; Hanks and Ashcroft, 1980; Campbell, 1977). Other energy terms are photosynthesis and respiration, which are negligible (Hillel, 1980a). From the energy balance equation we can calculate how much energy is used in processes such as heating and cooling the soil.

In the daytime Rn is positive and generally the soil temperature rises. In the nighttime, in the absence of direct solar radiation, the soil surface is warmer than the atmosphere, and the heat energy flows from the soil to the atmosphere. As a result, the nighttime net radiation flux is negative. The soil surface is cooled by outward radiation toward the atmosphere, and there is a flow of heat to the surface from the soil below.

In a freely transpiring well watered crop there is a close correspondence between net radiation and evaporation as evapotranspiration consumes most of the net radiation energy. As soil water becomes less available, more energy is then used for heating the soil or heating the atmosphere.

The main factors that affect soil temperature are classified into two categories: first, factors that influence the energy input to soil surface and second, those that influence the dissipation of heat from the soil surface.

One of the factors which affects energy input to the soil is albedo, that is, the reflection coefficient of the ground surface. Net radiation at the soil surface can be expressed as (Hanks and Ashcroft,1980; Buchan, 1991)

$$\mathbf{R_n = (1 - p)S_g + L} \qquad \mathbf{(3)}$$

where S_g is global short-wave radiation arriving at the surface of the earth, p is albedo, L is the net long-wave radiation. Albedo decreases with increasing darkness of soil, surface roughness, inclination of the sun, and soil moisture content. Low albedo increases Rn at the soil surface and so raises the soil temperature. Tillage increases surface roughness and so could be expected to increase Rn slightly at the soil surface.

The value for albedo for most soils varies from about 0.10 to 0.30 with an average value of about 0.20. Thus, changes in soil surface conditions do not cause very large changes in net radiation (Hanks and Ashcroft, 1980). Some values of albedo for soil and plants are shown in Table 1. Cereal straw has a relatively high albedo, and can be expected to reflect more radiation than a dark coloured soil. In addition, much of the radiant energy that is absorbed by surface mulches is either radiated back to the sky as long-wave radiation, or is transferred to the atmosphere as sensible heat or latent energy. Thus in the daytime, a mulch which is lying on the soil surface will insulate the soil against radiant energy inputs, resulting in lower daytime soil surface temperatures. In the case of a vertical mulch cover (Figure 1), analysis of the total energy balance becomes more complicated as the soil surface may be fully or partially shaded (Hares and Novak, 1992).

Table 1. Some representative values of albedo of soils and plants (Campbell, 1977; Marshall and Holmes, 1979).

Surface	Albedo (ρ)
Sand (dry)	0.30-0.40
Dark clay soil (dry)	0.14-0.20
Wet soil	0.18-0.25
Grass	0.24
Green cereal crop	0.20-0.26
Wheat	0.26
Maize	0.22

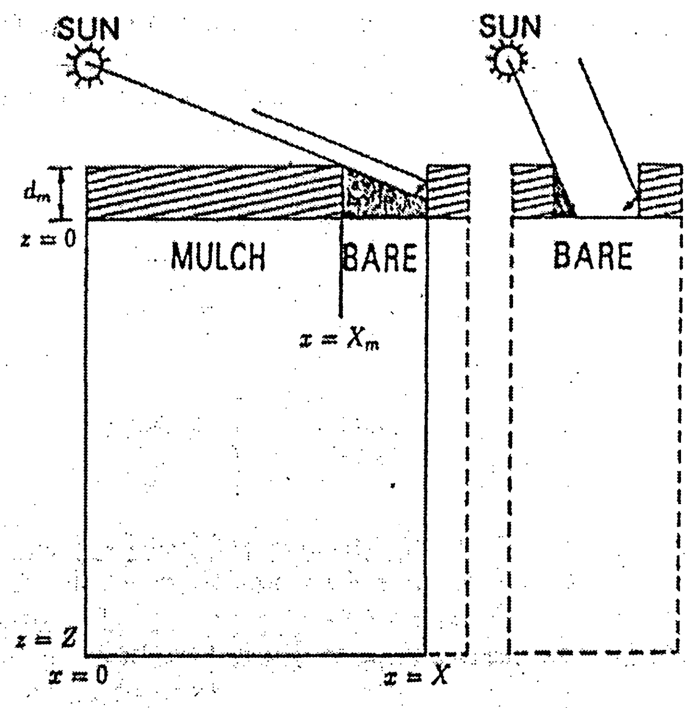


Figure 1. Soil surface shading by vertical stubble either (a) early in the morning or late in the afternoon or (b) near midday (After Hares and Novak, 1992)

At nighttime, where net radiation is negative, and energy is leaving the soil surface, the insulating effect of a mulch tends to keep the soil surface warmer than that of bare soil. In addition to its effects on net radiation, mulches slow convective transfer of energy (**H** and **LE**) by lowering the wind velocity at the soil surface.

An important factor in determining soil heat flux density is soil water content. In the daytime, if the soil surface is wet, most of the absorbed heat energy from the sun and sky radiation will be used to evaporate water and only small amounts of the heat energy will flow into the soil. In contrast, if the surface is dry, the absorbed energy raises the surface temperature and the resultant large temperature gradient causes considerable heat flow into the soil.

Bulk density influences heat movement into soil because as bulk density increases so do heat capacity and thermal conductivity. Tillage loosens soil aggregates, increases porosity, and hence decreases bulk density and thermal conductivity. This would tend to raise soil surface temperatures in the daytime, because less heat would be transferred into the soil. Daytime temperatures below the soil surface would tend to be lower.

The temperature regime of the soil surface responds to the periodic succession of days and nights, and summers and winters. Daytime heating and nighttime cooling are responsible for the diurnal period, and the annual period results from the variation of radiation throughout the year.

A temperature variation at the soil surface can be expressed as a function of time (Marshall and Holmes, 1979; Hillel,1980b)

$$\mathbf{T(0,t) = T_a + A_0 \sin wt} \tag{4}$$

where $\mathbf{T}$ is the soil temperature, $\mathbf{T_a}$ is the average soil temperature, $\mathbf{A_0}$ is the amplitude of the temperature wave, **w** is the radial frequency, and t is time.

At any depth **z** and time **t** (Campbell,1977)

$$\mathbf{T(z,t) = T_a + A_0\, e^{-z/D} \sin (wt - z/D)} \tag{5}$$

where **D** $[=(2k/w)^{1/2}]$ is called the damping depth, **k** is the thermal diffusivity of the soil. The equation also indicates that there is a phase shift in relation to depth. The decrease of amplitude and increase of phase lag with depth are typical phenomena in the propagation of a periodic temperature wave in the soil (Campbell, 1977; Hillel, 1980b; van Wijk *et al.*, 1959).

The zonal effects of a row crop (maize) on soil temperatures were studied by Lal (1978). The experiment was conducted from 1973 to 1975, for six consecutive growing seasons on an Alfisol soil in Ibadan, Nigeria. Treatments consisted of complete mulch, inter-row mulch, row mulch and without mulch (control). There were differences in soil temperature with respect to mulching, time of day and distance from the row. The differences in soil temperature due to mulching were slight or negligible for 08.00 h, and 3 to 4 ^oC for 15:00 h. Whereas there was slight or no difference in soil temperature in the row and inter-row zone at 08.00 h, differences were as high as 7 ^oC in the afternoon on a sunny day for unmulched plots, and 2 to 3 ^oC for the mulched treatments. The maximum temperature increased with distance from the row until the crop canopy was completed 40-45 days after seeding. Within the same mulch treatment, temperature differences of 3 to 5 ^oC between the row and inter-row zones were not uncommon. Differences of similar magnitude also existed for the same zone between mulched and unmulched strips. The differences in soil temperature between the row and inter-row zones, and among mulching treatments were small and not significant during the early hours of the day and, probably, during the night.

Field experiments which were used to study the effects of rice straw management practices such as straw incorporation, straw mulch, straw burning, farmyard manure incorporation, farmyard manure plus straw incorporation, and no straw as control on soil temperature, were reported by Bhagat and Verma (1991) who came to the conclusion that at 0.1m depth, soil temperature was not substantially affected by any of the treatments except the straw mulch. The minimum temperature for straw mulched soil was raised by about 2 ^oC over the unmulched soil. The straw mulch treatment maintained higher temperature in the nighttime and lower in the daytime. The increase in minimum and the decrease in the maximum soil temperature may be because of insulating and shading effects of the straw (Allmaras, *et al.,* 1964, Bhagat and Acharya, 1987). In a different experiment, Smika (1983) found that as the amount and height of straw increased, there was a decrease in wind velocity at the soil surface and a decrease in soil surface temperature.

The effectiveness of straw mulch in insulating the soil from freezing was studied by Hay (1977). A field experiment was conducted on the Macmerry soil series, a loam soil with a sandy clay loam subsoil, in the east of Scotland. Temperature was monitored in both cultivated and uncultivated (direct drilled) soil. The cultivated soil was ploughed conventionally (15cm depth) during the autumn preceding the measurements, while the soil surface in the uncultivated treatment was covered by a layer of stubble and dead vegetation to a depth of two or three straw thicknesses. He found that the uncultivated soil was protected from freezing and resulted in relatively high soil surface temperatures (>5 ^{o}C) over a period of several days in winter, which is beneficial for early plant growth.

In summary, tillage can affect several soil properties that affect soil temperature (such as albedo and thermal conductivity), but there is no evidence from the literature that there is a major effect on soil temperature. On the other hand, retained stubble tends to keep the soil cooler in the day and warmer in the night, and cooler in summer and warmer in winter.

2.3.2 Effects of tillage and stubble management on soil strength

The strength of a soil is a property of a body of soil which confers mechanical resistance to external disruptive forces such as compressing, crushing, shearing, penetrating or rupturing. Soil strength influences both tillage draft requirements as well as crop root elongation and penetration in exploitation of available soil water and nutrients. Soil strength may affect root development directly by influencing root growth, or indirectly by affecting the quality of tillage (Guerif, 1990).

A penetrometer is a device that can be forced into soil to determine the soil's penetration resistance (Campbell and O'Sullivan, 1991). Penetrometers are considered useful devices for evaluating the effects of contrasting tillage treatments on soil strength (O'Sullivan *et al.*, 1987). Figure 2 is an example which shows the results of penetration measurements made in a section across the direction of travel of a Paraplough, which is a slant-leg subsoiler. The variation in penetration resistance with depth of loosening and the unloosened soil can be seen clearly.

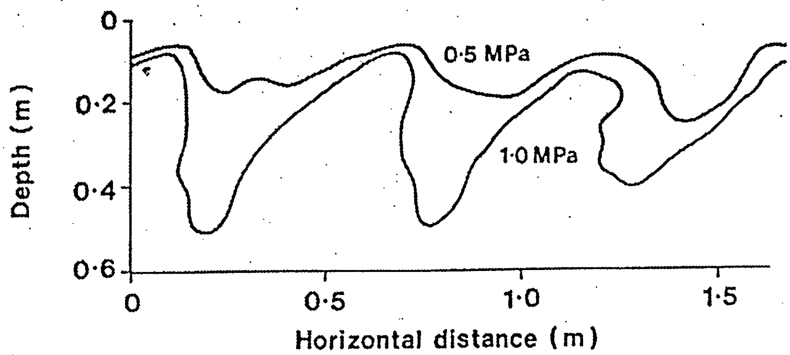


Figure 2. Variation of cone resistance with depth across the direction of travel of a slant-leg subsoiler, showing the 0.5 and 1.0 MPa contours (After Campbell and O'Sullivan, 1991).

Soil strength can be raised to high levels which will adversely affect plant growth by several means. Compaction lowers porosity and increases bulk density and this increases soil strength. Also as soil dries, soil strength increases. Soils which are well aggregated tend to have low soil strength, so if soils lose structure, their strength increases. Loss of soil structure can result from loss of organic matter and biological activity (Hamblin, 1985).

Tillage affects soil bulk density. The surface soil is loosened which lowers soil strength. However, trafficking associated with tillage can cause compaction and high soil strength below the plough layer. The compaction of soil loosened during the cultivation process was studied by Hodara and Slowinska-Jurkiewicz (1993). They found that significant change in soil penetration resistance was caused by changes in structure and physical properties. Observation of penetration resistance in tilled and untilled soil by Ehlers *et al.* (1983), shows that within the top 200 mm of the soil, penetration resistance was higher in untilled soil compared with tilled soil. However, in tilled soil at a depth of about 250-300 mm, penetration resistance was slightly higher in tilled soil compared with untilled soil (Figure 3).

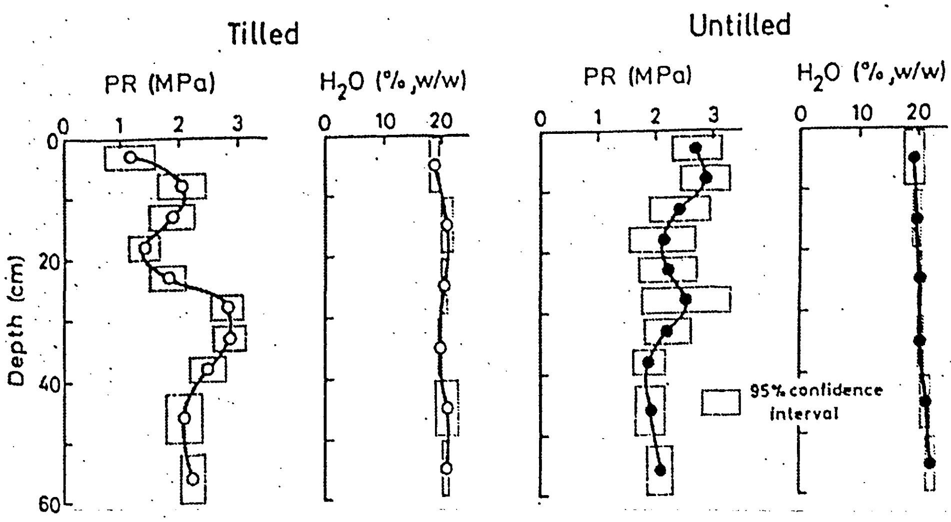


Figure 3. Penetration resistance and water content profiles of tilled and untilled soil (After Ehlers *et al.*, 1983).

Cropping has been linked to soil structure decline and increase in soil strength. Cropping with tillage rather than under a no-tillage system can speed up structural decline. Because of the strong dependence of soil strength on water content, comparison of soil strengths between tillage treatments may be complicated by water content differences. Campbell and O'Sullivan (1991) proposed the ideal way to determine the effect of tillage practices on penetration resistance. Measurements may be made at some standard water content or potential, such as field capacity, in order to ensure that any measured differences in penetration resistance are not due to differences in soil water status, which may be influenced independently by tillage.

Differences in structure associated with soil management may affect the relationship between penetration resistance and root growth. Ehlers *et al.* (1983) found that the limiting penetration resistance for root growth was greater in untilled soil (4.6-5.1MPa) than in tilled soil (3.6Mpa). This difference is explained by the build-up of a continuous pore system in untilled soil, created by earthworms and the roots from preceding crops. Root development follows biopores, cracks or planes of weakness (Wiersum, 1957; Russell, 1977; Whitely and Dexter, 1983, 1984), which are characteristic of well structured soils. In contrast, penetrometers follow a linear path which limits their usefulness in such soils. Ehlers *et al.* (1983) concluded that the untilled soil contained more cracks and biopores, which were available for root growth but were not detected by the field penetrometer.

tubble retention tends to maintain a moister surface than for a bare soil does (see ɜction 2.3.3). Consequently, soil strengths may be lowered.

ı conclusion, there are several factors related to tillage and stubble retention which ɜn affect soil strength, but the most important in practice appear to be the loosening f surface soil by tillage and the increase in soil strength below the plough layer by ɔmpaction.

2.3.3 Effects of tillage and stubble management on soil water

illage inverts soil, which can expose wet soil to the atmosphere and increase vaporation. It can also destroy transmission pores and cracks. This produces a ırottling effect on infiltration and may reduce accession of soil moisture and increase ınoff water loss, particularly in high intensity summer storms characteristic of ɔrthern NSW (Harte, 1990).

s discussed in section 2.3.1, stubble mulches lower net radiation at the soil surface ıd also impede latent energy transfer. As a consequence, first stage evaporation is owed and soil moisture close to the surface remains high for a longer period after infall (Adams, 1966; Army *et al.*, 1961). Surface stubble also increases infiltration 'riplett *et al.*, 1968) by protection of the soil surface from sealing, and by slowing the ɜlocity of runoff (Jones *et al.*, 1968).

levins *et al.* (1971) conducted studies to determine soil moisture under killed sod and ɔnventional tillage using corn as the growing crop. These studies which were ɔnducted from 1968 to 1970 on a silt loam soil in Kentucky, indicate higher moisture ɔntent under the no-tillage compared to conventional tillage. In 1968, soil moisture at e 23-cm depth was greater under no-tillage compared with conventional tillage. In)69, soil moisture at 0-8cm depth was 10-15% by volume higher under killed sod an under conventional tillage. The soil moisture seasonal distribution in 1970 llowed the 1969 pattern in that the upper 30cm had a higher average soil moisture ɔntent under no-tillage management. An overall calculation indicated that soil oisture content in the 0-15cm depth during the course of the experiment was 19% by ɔlume higher in no-tillage plots than conventional tillage plots. This extra amount of ant-available water was sufficient to carry the growing crop for short drought periods ' two or three weeks.

In their studies on the response of soybean to no-tillage, Holland and Felton (1983) observed significantly greater levels of profile moisture accumulation in no-tilled Vertisols in northern NSW compared to those conventionally tilled. Figures 4 and 5 show soil moisture at 150cm depth at sowing and harvest for Warialda and Croppa Creek.

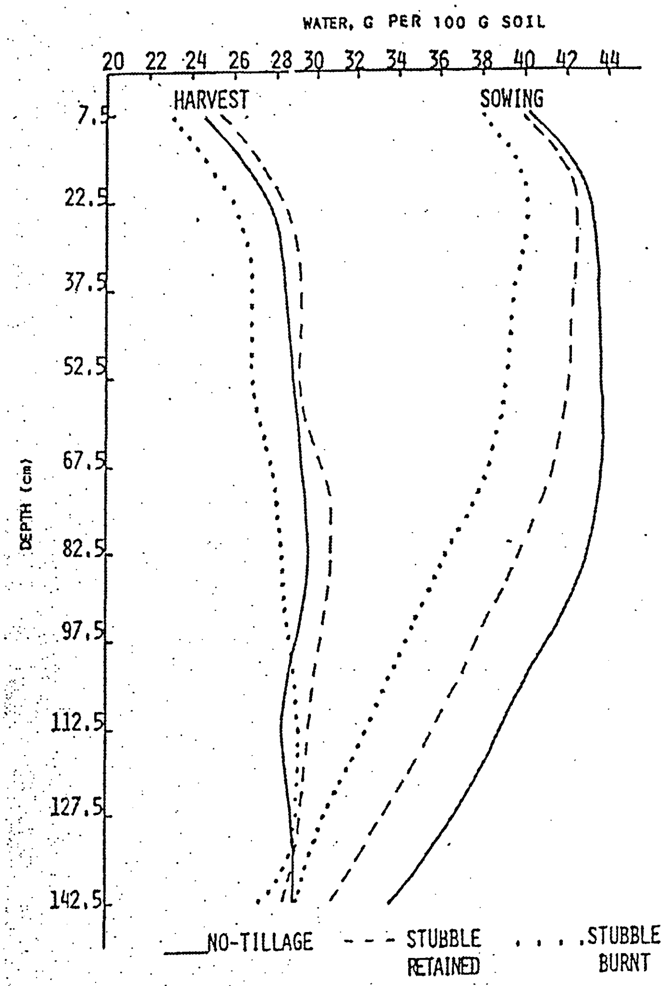


Figure 4. Soil moisture content distribution with depth and different tillage systems at sowing and harvest of sorghum in Warialda (After Holland and Felton, 1985).

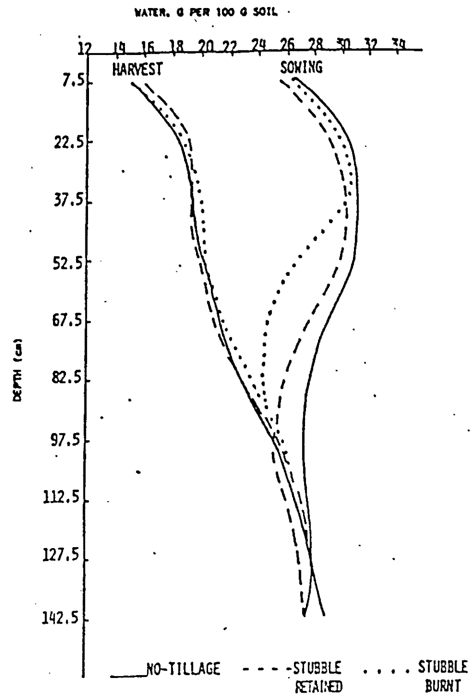


Figure 5. Soil moisture content distribution with depth and different tillage systems at sowing and harvest of sorghum in Croppa Creek (After Holland and Felton, 1985).

There was an extra 27mm of water present in the no-tillage fallow compared with the stubble retained treatment at Warialda, and an extra 26mm of water in the no-tillage fallow at Croppa Creek. Although soybeans produced more dry matter in the no-tillage system, they failed to convert this to a higher grain yield at both sites. However, in a similar experiment conducted by Herridge and Holland (1983), an extra 36mm of rainfall was received at a Tamworth site compared with the Warialda site which led to better early growth and resulted in a higher grain yield (Herridge and Holland, 1983).

Duley and Russel (1939) compared the effects of straw management and type of tillage on soil water storage. Water storage with the surface straw treatment was much greater than with any other treatment. Stubble-mulch tillage was developed primarily for controlling wind erosion in the U.S., and also contributed to the increases in water storage compared with clean tillage. For example, in Kansas, available water contents were 135, 152 and 180 mm to 1.8m depth with one-way disk, plough, and stubble-mulch tillage treatments, respectively. This was believed to have been respponsible for the differences in wheat grain yields which averaged 0.61, 0.45, and 0.93 Mg/ha with the respective treatments (McCalla and Army, 1961).

Fawcett (1978), from a study of a range of sites in the northern NSW wheatbelt over three years, concluded that: (i) soil moisture levels could be increased by stubble retention and/or reduced tillage systems; (ii) increased moisture was attributed to a reduction in the disintegrative swelling and sealing of surface soil during heavy rain and a resulting increase in water entry compared to treatments without stubble; and (iii) only where evaporation was high (30-40mm per week) did the advantage of stubble reduction clearly reduce evaporation of water and add to accumulated fallow moisture.

2.3.4 Effects of tillage and stubble management on soil aeration

Aeration measurements can be classified by the kind of parameter measured: capacity, intensity, and rate. The capacity factor is expressed as air filled porosity which is the volume fraction of soil that is occupied by gas. Intensity is the oxygen concentration in the gas-filled pores or dissolved in the soil solution. The rate factor is the diffusion rate either in the gas-filled pores or through the liquid films. Air filled porosity is the parameter that has been most used to describe aeration. Often it is measured at a standard matric potential such as -10 kPa, which is often equated with field capacity. One reason for the popularity of air filled porosity is that it can be calculated from the soil moisture characteristic. After discussing the available data, several reviewers (cited by Erickson, 1982) suggested that the minimum limit of air filled porosity in soils for the growth of common crops is about 0.1 m^3 m^{-3} or 10%. Using this approach the effect of tillage on aeration could be evaluated by following air filled porosity changes with time by making bulk density and soil moisture measurements and calculating air field porosity. However, such studies would have dubious results because the soil matrix is subject to change after tillage and the 0.1 m^3 m^{-3} limit of air filled porosity for normal plant growth is questionable (Erickson, 1982).

Currie (1962) concluded that soil cultivation can help aeration. Increasing the air filled porosity improves air movement into the soil profile. Breaking up soil aggregates into smaller units can influence the air composition within these units and promote more active root growth. Ehlers (1983) determined complete pore size distributions on tilled and untilled field plots. The greatest changes due to tillage were in the large pores (>30 μm) which are related to air filled porosity because of their large size (i.e. drained at -10kPa).

Dowdell *et al.* (1983) compared ploughing and direct drilling and followed the soil oxygen concentrations at three depths for three growing seasons. The mean oxygen concentrations varied with the seasonal rainfall. Direct drilling resulted in higher oxygen concentrations than did ploughing during the wetter winters, averaging 10.2 and 7.2%, respectively. The higher oxygen concentrations found in direct drilling were possibly due to a system of continuous large pores and channels which developed in the direct drilled plots but which were destroyed by annual ploughing.

Tillage can also create aeration problems by compacting the soil below the plough layer. Large pores are those which are most easily destroyed by compaction, and these are also the pores which are responsible for oxygen transport in moist soil.

2.3.5 Conclusion

Tillage can affect several soil properties including soil albedo and thermal conductivity that affect soil temperature , but has only a minor effect on soil temperature. On the other hand, the effect of mulch, insulating, shading, lowering soil surface wind velocity, and hence latent and sensible heat fluxes, was believed to play an important role in keeping the soil warm. Stubble mulches tend to keep the soil cooler in the day and warmer in the night, and cooler in summer and warmer in winter.

2.4 Effects of soil physical properties on early crop growth

2.4.1 Soil temperature and early crop growth

Plants are unable to maintain their cells and tissues at a constant optimum temperature and therefore their leaves, stems and roots are profoundly affected by changes in their surrounding air or soil temperature. The temperature of a leaf depends upon: (i) time of day (regular diurnal variation), (ii) month of the year (regular seasonal variation), (iii) cloudiness and wind speed (irregular, short-term variation), (iv) position in the canopy, (v) height above the soil surface, (vi) leaf dimensions; whereas root temperature depends mainly upon (i) and (ii) but also upon (vii) depth below the soil surface; (viii) soil properties (Fitter and Hay, 1981).

However, improvement of our understanding of how growing plants respond to surrounding temperature as experienced in the field is limited by variability of soil and air temperature. The influence of temperature on plant growth is further complicated by uncertainty over the response of growing plants to the diurnal and seasonal variation in field temperature (Fitter and Hay, 1981). In addition to these problems of variability, it has been found that different stages of plant development, and different physiological processes, may have different temperature optima (Hay and Walker, 1989; Milthorpe and Moorby, 1979).

Soil temperature is an important factor in crop production because it affects metabolic processes (Letey, 1985). Soil temperature seems to be implicated in all the main elements of plant growth: the development of root systems and the rates at which they absorb water and nutrients; the expansion of leaves and the extension of stems; transpiration and photosynthesis; dry matter production and shoot/root ratios; flowering and fruiting (Monteith, 1979).

The rate of germination and pre-emergence growth of crop plants is strongly dependent on soil temperature. For a range of crop species the rate of unfolding of leaves from the terminal bud is controlled by air temperature rather than soil temperature (Hay and Walker, 1989; Fitter and Hay, 1981). For monocotyledons such as wheat leaf expansion occurs at the apical meristem which is just below the soil surface in the young plant, and so leaf expansion is affected more by soil temperature than air temperature. Since air and soil temperatures tend to be closely linked, good linear relationships have been established for cereals between crop growth stage and accumulated air temperature above a base temperature (Hay and Walker, 1989).

2.4.2 Soil strength and early crop growth

Much of the literature on soil strength and plant growth has looked at the relationship between soil strength and emergence (Sedgley and Barley, 1963). In contrast, less is known about the response of the pre-emergent shoot to mechanical impedance. Most of what is known about the response of subterannean plants organs to soil strength has been derived from root growth studies (Barley and Greacen, 1967). Whilst both the shoot and root rely upon shear, tensile and compressive elastic and plastic failure to grow, there are significant differences between roots and shoots in terms of the strength environment they experience and their response to strength.

Soil strength limitations to root growth are often associated with massive soil structure or compaction. For example, pre-emergent shoot growth problems in hardsetting soils are linked to the collapse of the seedbed after rainfall and rapid drying, which leads to high soil strength. Under such a dynamic strength environment, the shoot is engaged in a race with time to reach the surface before soil strength prevents further shoot growth. In summer cropping systems, poor aeration is unlikely to be a limitation at the same time as high soil strength, whereas the simultaneous occurrence of high soil temperatures and high soil strength is likely (Abrecht and Bristow, 1990). Because of the bias in research towards roots, little work has been done to examine the influence of temperature on the relationship between shoot growth and soil strength. Greacen (1986) did however note that there was evidence of temperature affecting the relationship between root growth and soil strength.

Roots also differ from shoots in that they are able to exert greater axial pressure and hence are able to grow through higher strength soils (Taylor and Ratliff, 1969; Collis-George and Yoganathan, 1985ab). In addition, whereas the axial pressure in roots is greater than radial pressure, in shoots the axial and radial pressures are the same (Pffeffer, 1893 cited in Gill and Bolt, 1955; Barley and Greacen, 1967). Due to the relatively static nature of the root strength environment, many studies of root response to strength have focused on the maximum soil strength at which roots can grow. Less attention has been paid to characterising root growth rates as a function of soil strength for the full range of soil strengths found in the field.

Finally, as Sedgley and Barley (1963) noted, seedling emergence is generally linked to some empirical measure of soil strength such as bulk density, rather than to the actual force required by the shoot to expand as given by the cavity expansion pressure (Farrel and Greacen, 1966). The only experiments linking cavity expansion pressure to shoot growth which this writer is aware of were carried out by Collis-George and Yoganathan (1985b) for wheat seedlings. Even then, their emphasis was on the maximum cavity expansion pressure at which the seedling could grow and not the seedling response to a range of cavity expansion pressure, although these could be calculated from their papers (Collis-George and Yoganathan, 1985a and b).

As with other soil properties, changes in bulk density that accompany stubble retention are determined to some extent by environmental conditions and tillage practices. In humid temperate regions, a combination of high clay content and high soil moisture at the time of sowing predisposes increases in bulk density where direct drilling is practised, compared to conventional tillage (Cannell *et al.*, 1980). These authors considered such increases would restrict root growth which, in turn, might restrict nitrogen uptake. Working with sandy loam and clay loam soils in temperate zones, Pidgeon and Soane (1977) found that under no-tillage conditions the bulk density increased for the first three years due to natural compaction and vehicular traffic, with little change thereafter.

Soil bulk density affects plant growth (seedling emergence and root penetration) through its effect on the pore size distribution. Like the pore volume, its effect is influenced by the the soil moisture content. Masujima (1963) found that for a ρ_b of 1.25 Mg/m^3 at 200 kPa soil moisture tension, roots of red clover would not penetrate soil, but these roots would penetrate the same soil if the soil moisture tension is decreased to 100 kPa. For the cereal crops, beans and vetch, and for a wide range of soils on which the soil moisture is optimum, bulk densities of 1.0-1.5 Mg/m3 are the most desirable with the lower densities being preferable on the heavy soils (Hanks and Thorpe, 1956, Gardner, 1962).

It is evident from the foregoing that the influences of porosity, pore size and pore rigidity, aeration, moisture content and moisture movement, and bulk density are very much inter-related and complicated. A dense soil, for example, is usually poorly aerated (even though it may have a large micro-porosity). Also, if the average root diameter that grows into subsoil is assumed to be nearly 200 µm (Wiersum, 1957), then when soil particles are less than 800 µm, pore size will be less than the root diameter, and roots will therefore not be expected to penetrate the soil. Yet, this is not the case in clay soils, even though most of the pores may be destroyed by compaction; because, provided it has not dried out, the clay soil is usually plastic enough for plant roots to penetrate readily if aeration is adequate.

A plant root growing into a rigid system is only able to penetrate a pore that has a diameter exceeding that of the root tip (Wiersum, 1957). For a Black Earth, cracks, may exceed 1.5 cm and extend to a depth of 80 cm or more Buringh (1968). The influence of ped surface incident angle and critical ped strength on the rate of root elongation in several crop species growing in cracking clays has been studied by Whitely and Dexter (1983). They found that where roots were forced to grow in cracks at very different angles to the preferred geotropic direction, extension rates were reduced to a half or a third of the unrestricted rate, even when cracks were wide, water potentials high and soil strength less than 2 MPa. However when cracks were oriented at 45° to 90° from the horizontal, elongation rates were consistently higher, irrespective of crack width, than for roots growing through soil peds. Even at the high soil water potentials used, strength was a significant barrier to penetration.

The strength of the soil is influenced by the moisture content. Hanks and Thorpe (1956) point out that it appears that an inter-relationship between seedling emergence and limiting crust strength exists for some soils and that the lower the moisture content, the lower the limiting crust strength. Taylor and Gardner (1963), after a study of some hard pan soils, reported that high strength may be caused either by an increase in bulk density or by a decrease in soil moisture content; and that the soil strength concept may be valid only when voids provide few or no avenues for roots to penetrate a high strength soil mass. Ehlers *et al.* (1983) found that the limiting penetration resistance for root growth was greater in untilled soil (4.6-5.1 MPa) than in tilled soil (3.6 MPa). This difference is explained by the build-up of a continuous pore system in untilled soil, created by earthworms and the roots from preceding crops.

2.4.3 Soil aeration and early crop growth

Plant growth is adversely affected if there is an insufficient supply of oxygen to the roots (Glinski and Stepniewski, 1985). Plants experience lack of aeration when the rate of oxygen diffusion into the soil is slower than the rate of consumption of oxygen, by roots and soil microorganisms. Cannell and Jackson (1981) stated that because of slow diffusion of oxygen in water, the main restriction to soil aeration is the presence of water filled macro and/or micropores. An excess of water could impede the movement of CO_2 out of the soil, which would also restrict soil aeration.

Morphological and physiological effects of anaerobic soil conditions on plant growth have been summarised by Russell (1977) and Cannell and Jackson (1981). Russell (1977) concluded that in poorly aerated media, especially with a high accumulation of CO_2 in the root zone, plant roots become less permeable to water and this could result in reduced water and nutrient uptake. Russel (1957) and Taylor and Ashcroft (1972) found that plant roots were thicker, shorter and darker in a soil with inadequate oxygen content than in a normal condition. These authors also indicated that root hairs were less developed in that poorly aerated soil.

Even if the whole of the air space is occupied by O_2 at any one time, it is obvious that as plant roots utilise the O_2 in their metabolic processes and give out CO_2 as a by-product, the concentration of O_2 within the root zone decreases, and more O_2 has to diffuse to the root zone to replace the amount used by the roots. The rate at which this diffusion takes place (as well as the rate at which the by-product of metabolism, CO_2, diffuses out the root zone) will determine whether the optimum O_2 concentration can be maintained or not. Lemon (1962) stated in his theory on soil aeration and plant root relations that: root respiration is limited by internal O_2 diffusion, which in turn is influenced by oxygen diffusion rate (ODR) within the soil in the immediate environment of the root. Stolzy *et al.* (1961) observed that an ODR within the soil of less than 18-23 x 10^{-8} g/cm^2/min reduced or stopped root initiation. For soybeans, cannage, grain sorghum, sweet corn and dwarf field corn grown in lysimeters, Williamson (1964) obtained the highest yields at an ODR of 15 x 10^{-8} g/cm^2/min, whereas an ODR of less than 5 x 10^{-8} g/cm^2/min resulted in decreases in yields of from 25-75%, depending upon the crop. Soil aeration and its effect on plant growth are closely related to the soil moisture content, because the amount of air present within the soil pores is determined by the amount of water present within the pores. Since plant roots depend upon soil air (i.e. the oxygen within the soil air) for their metabolic processes, this relationship between soil moisture and soil air is rather important. Boekel (1963) observed that on heavy clay soils, the air content had to be greater than 15% by volume before high crop yields could be obtained, whilst Miller and Mazurak (1957) showed that aeration appeared to limit the rate of stem elongation in sunflowers when air occupied less than 4% of the pore space. Trouse and Humbert (1961) obtained 10% as the critical level for sugar cane growth - a value which is close to the 9-12.2% (average 11%) obtained by Robinson (1964) for sugar cane on a low humic latosol. With small grains, however, Czeratzki (1966) observed that an air capacity of 1% by volume was optimal. Gill and Miller (1956) in studying the influence of aeration on growth of seedling roots demonstrated that the ability to overcome mechanical resistance is related to the amount of O_2 in the growth medium; and that the rate of growth of unimpeded roots declines when the O_2 content falls below 10%. Gingrich and Russel (1957) also observed, whilst studying effects of soil moisture tension and osmotic stress on root growth, that growth as a function of moisture tension departed from linearity when O_2 was above 5.25% and therefore non-limiting. Also, the effect of moisture tension on radicle growth characteristics was insignificant until O_2 concentration of the root atmosphere needed for maximum growth was above 10.5%. The foregoing seems to confirm Vomocil and Flocker's (1960) view that the growth limiting level of soil air space is in the vicinity of 10-15% for most crops.

2.4.4 Soil water and early crop growth

The soil matrix holds water in two ways. Water is adsorbed onto the surface of soil particles, and also held as capillary water in the micro and macropores. The capillary and adsorptive forces arise from water's properties of hydrogen bonding and dipolarity (Singer and Munns, 1992). These two properties cause water molecules to cohere to one another and to adhere to compatible surfaces such as humus or soil minerals that are charged and have oxygen atoms to share hydrogen atoms with water (Singer and Munns, 1992).

Colloidal particles such as clay and humus have a net negative charge so that water is adsorbed onto their surface forming a film of around the particle. Clay soils have a large surface area, hence water adsorption is the predominant force. As a soil dries, the film decreases in size and water is held more tightly by the clay particle and is harder for plants to obtain. The soil therefore contains a quantity of water that is unavailable to plants. Capillarity tends to become more significant at higher water contents. Water is held within soil pores. Macropores have a diameter greater than 60um and are involved with aeration and infiltration, being responsible for rapid drainage of water. Micropores are less than 60um in diameter. Those in the 30-60um diameter range have much slower internal drainage than macropores. Macropores with diameter 0.2-30um are responsible for the storage of water that is available to plants. Soil pores that are less than 0.2um hold unavailable water. When a soil is saturated, all the pores are full of water. As the soil dries, water is initially lost from the macropores as the capillary forces are relatively weak. The smaller the diameter of the soil pore the stronger the capillary force. Capillarity is most important in those soils with fine continuous pores. Sandy soils have a large proportion of macropores, therefore drain more easily and retain less water than a clay soil.

Plants cannot grow without water. The important parameter which links soil water to plant growth, however, is not soil water content but soil water potential. Water potential refers to the energy with which water is retained by the soil and consequently to the energy necessary for water to be removed from the soil by plant roots. Different types of soil contain different water amounts at a given potential. There is a relationship between soil water content and potential for a given soil, and thus it is possible to measure soil water content and infer the water potential value if the appropriate relationship between the two is known.

Responses of crops to moisture stress differ, depending on the purpose for which the crop is grown. Where the total fresh weight and quality of harvested plant parts are the important criteria, high moisture stress often decreases the yield of such crops. Where yields of protein, rubber, wax, seed and total solids in plants are of primary importance, yields are often increased by high moisture stress during the latter stages of plant growth (Rhamadar *et al.,* 1966). For bean and forsythia plants, grain sorghum and orchard grass, moisture stress greater than 5 atm causes significant reduction in germination and growth (Evans and Stickler, 1961; Perrier *et al.,* 1961; Wilkie *et al.,* 1961). Hagan *et al.* (1957) found that the rate of transpiration, the dry weight, green weight, flower and bud production in Ladino clover showed the most rapid decrease when soil moisture tension reached 4 atm. Gardner (1962) stated that soil moisture stress of about 0.5 atm decreases soil penetration by cotton roots. Zero matric potential is not necessary good (and in some cases, even detrimental) for seed germination (Ghildyal and Janal, 1966) and the soil moisture stress range 0.1-5 atm appears optimal for most agronomic crops.

Total water content of a soil does not indicate the amount of water available to the plant. The available water content of a field soil is defined by Russell (1973) as the amount of water a crop can remove from the soil before its yield is seriously affected by drought. It is the amount of water a soil holds between its condition at field capacity and at its permanent wilting point. The field capacity of a soil is the maximum amount of water that a soil can store against gravity (MacLeod *et al.*, 1988). At this point, water has moved out of the macropores and has been replaced by air. The micropores are filled with water and it is from there that plants will adsorb water. The permanent wilting point is defined as the water content of a soil at which plants will not regain turgor, even if the soil water content is raised (Singer and Munns, 1992). At permanent wilting point, the soil still contains water, but the water molecules are bound tightly to the soil particles and cannot be taken up by plant roots.

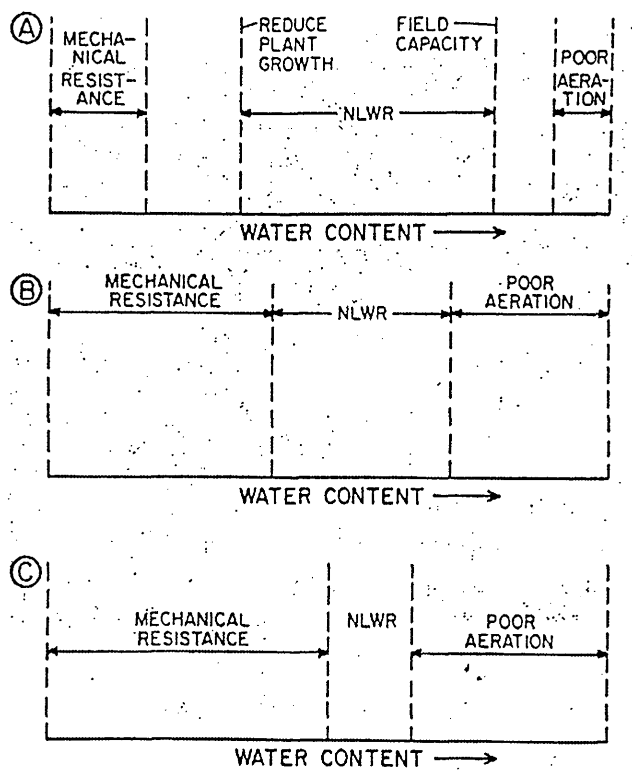


Figure 5a. Generalised comparative value of NLWR as affected by soil water content, mechanical resistance and aeration for soils with increasing bulk density and decreasing structure in going from case A to C (After Letey, 1985)

In practice, water availability may be affected by soil aeration and soil strength. The optimum range of water content is therefore assessed on the non-limiting water range (NLWR). That is, the range of water content in which plant growth is not seriously reduced by water availability, aeration or strength as illustrated in Figure 5a. The NLWR is determined by factors such as soil structure and texture. Bulk density and pore size distribution affect the relationship between water and both aeration and soil strength (Letey, 1985). Soils with a large NLWR that is usually limited by permanent wilting point and field capacity, are relatively easy to manage physically. Excess water drains away and there is reasonable water storage. Soils with narrow NLWR (e.g. hardsetting soil) are more difficult to manage.

2.5 General Conclusion

Maintaining crop residues on the soil surface through use of conservation tillage systems, initially with stubble mulch tillage practices and more recently by reduced or no-tillage methods, has contributed greatly to the conservation of soil and water resources. While the extra water storage may be beneficial to crop growth in dry years and especially for summer crops there are also some adverse soil physical effects. Lower soil temperatures under stubble and higher soil strengths when soil is not loosened by tillage may impede the growth of winter crops. For summer crops lowered soil tempertures may be advantageous. Also the increased surface soil moisture under stubble may assist emergence in hardsetting soils. No evidence of aeration differences between tillage and stubble management treatments affecting early crop growth were found in the literature.

Chapter 3

Influence of Stubble Management on Early Growth of Wheat

(Warialda Experiment)

3.1 Introduction

Retention of standing stubble in wheat has often been associated with poorer early growth. For example, Reeves and Ellington (1974) reported that in 1968 and 1969 wheat growth from emergence to heading was superior on conventionally cultivated plots compared with direct drilled plots. Several reasons have been proposed for this early growth lag. Incorporation of stubble close to the seed may limit growth through phytotoxic effects (Lovett and Jessop, 1982) or soil nitrate depression (White, 1984). The absence of tillage and soil loosening may limit plant growth through high soil strength (Chan *et al.*, 1987, Cornish and Lymbery, 1987). Pathogenic microorganisms associated with stubble may also be involved in some cases (Chan *et al.*, 1987 and 1989).

In winter, a major effect of surface mulch of plant residues is depression of average soil temperature, but daily minimum soil temperature is generally increased. Soil temperatures in the seed zone and the deeper depth are usually decreased and this can lead to a delay in seed germination, slow seedling growth, and reduced yields in temperate areas with cool, wet springs (Bristow, 1988; Gupta *et al.,* 1983).

Aston and Fischer (1986) observed lower dry matter production for young wheat plants grown with stubble retained and also lower average soil temperatures. They concluded that the difference in growth could be caused at least partially by the difference in temperature.

The objective of this experiment was to determine if soil temperature differences could account for the depressed early wheat growth associated with no-tillage stubble retention on a black earth at Warialda. The experimental approach was to grow wheat under simulated stubble made of shadecloth and plastic ribbon. This simulated the shading and insulating effects of stubble without the other effects of phytotoxicity, soil nitrate depression or microbial pathogens. The relationship between soil temperature and dry matter production was tested to see if it could predict the growth lag under real stubble.

3.2 Materials and Methods

This experiment was conducted in 1992 on black cracking clay soil located at the Douglas McMaster Research Farm, Warialda. The soil at the experimental site is a black earth, which is representative of the near-flat Quarternary alluvial floodplains and terraces bordering many watercourses in the northern NSW wheatbelt (Harte,1984). High fertility and good soil physical attributes mean that this soil is most suited to the production of cereals and summer crops (Harte, 1990). Table 2 provides a summary of the description and physical properties of the soil profile.

The experimental work was carried out on a long-term tillage trial site run by New South Wales Agriculture. The plots used for the artificial stubble experiment had been sown continuously to wheat from 1981 to 1990. No crops were sown in 1991, so that when the 1992 crop was sown the site had been fallowed for approximately 18 months. Two adjacent plots of the tillage trial were used for the artificial stubble experiment, namely no-tillage stubble retained and stubble burned. The no-tillage stubble retained plots had weeds controlled during the fallow with herbicide, and wheat was sown directly into standing stubble from the previous crop. For crops sown from 1981 to 1988 the no-tillage stubble burned plots had stubble burned after harvest and were cultivated during the fallow. After the 1989 crop the no-tillage stubble burned plots were cultivated but not burned, and after the 1990 crop stubble was retained without cultivation. Stubble was burned shortly before sowing. Wheat was sown on 26 May 1992, with 10 kg P /ha as Triphos.

Table 2. Soil physical properties and morphological description of black earth (After Harte, 1990)

	Depth (mm)	Soil morphological description	Particle size distribution (%)			
			Clay	Silt	Fine Sand	Coarse Sand
	0 - 150		46.3	13.6	36.7	3.4
	150 - 300		51.3	11.7	33.6	3.3
	300 - 500		54.2	11.7	30.3	4.2
	500 - 850		54.8	11.5	29.9	3.8
Horizon 1	0 - 100	Black medium clay. Blocky peds, earthy fabric. pH 8.5				
Horizon 2	100 - 400	Black heavy clay. Strong blocky peds, to massive. Cracks 5-10mm. pH 8.5				
Horizon 3	400 - 1000	Black heavy clay. Strong blocky peds with lenticular patterns. Cracks 5-10mm. pH 8.5				

In this experiment wheat was grown in 1.5x2.0m plots. Four treatments were applied to the plots and were replicated 3 times in blocks:

1. No-tillage fallow with no soil disturbance except at sowing and complete chemical fallow for weed control (NT)

2. No-tillage fallow with no soil disturbance except at sowing, complete chemical fallow, and with stubble burned (NB)

3. Same as NB, but with artificicial stubble at a low intensity (S1)

4. Same as NB, but with artificial stubble at a high intensity (S2)

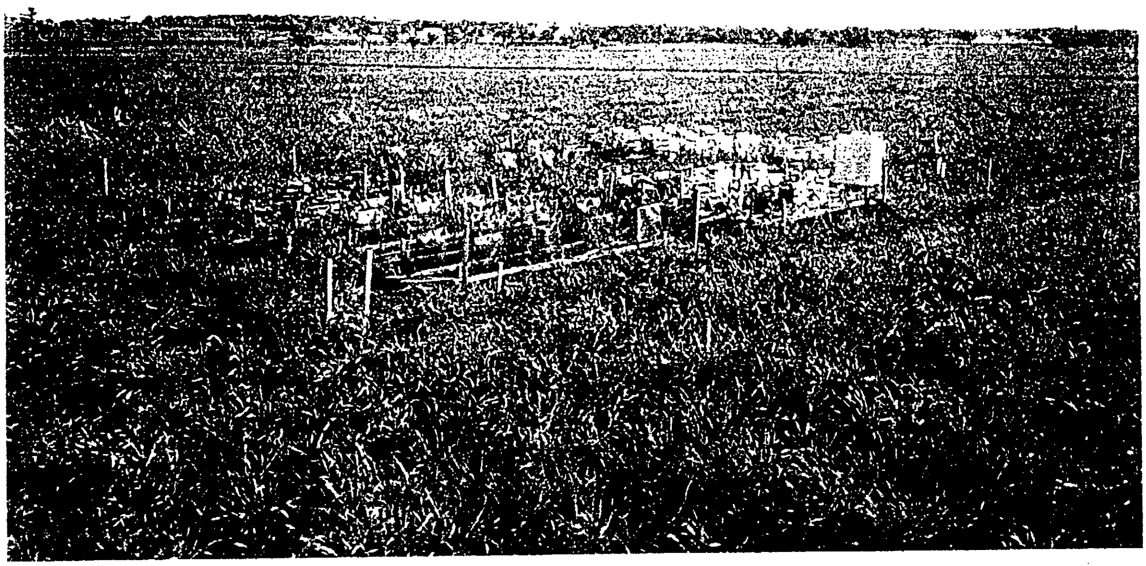


Plate 1. The lay-out of Warialda experiment.

The experiment was set up at the boundary of the larger no-tillage stubble retained and no-tillage stubble burned plots of the NSW Agriculture trial, with the NT plots of the present experiment on the stubble retained side and all other plots on the stubble burned side. The artificial stubble was made of 25x25cm pieces of shade cloth, low density shade cloth for S1 and high for S2, and combined with yellow plastic ribbons (200x1.5cm), 6 strips for S1 and 10 strips for S2, which were loosely arranged over the soil surface. The shade cloth simulated the standing mulch (30cm row spacing) and the plastic ribbon simulated the incorporated mulch on the soil surface. Thus each 1.5 x 2.0 m plot consisted of six rows of artificial stubble, with a new wheat crop growing down the centre of the 30 cm space between each row. This technique was designed to mimic the effect of real wheat stubble in the field, but have no deleterious effects of stubble such as phytotoxicity, nitrate depression or microbial effects.

Plate 1 shows the lay-out of the experiment in Warialda, and the detail of the treatments is described in Appendix A1. Table 3. shows the main events during the field experiment.

Table 3. The main events during the field experiment

Date	DAS *)	Event
26 May 1992	0	sowing
6 June 1992	11	setting up the experiment
24 June 1992	28	addition of 20kg N/ha (Nitram)
		measurement of: - soil temperature - Σ plant/m - no. of leaves
30 July 1992	65	soil sampling for nitrate/ammonium
		plant sampling for dry weight
		plant sampling for plant development stages
		measurement of: - soil temperature - penetration resistance - moisture content
		photography
10 September 1992	107	soil sampling for nitrate/ammonium
		plant sampling for dry weight
		plant sampling for plant development stages
		measurement of: - soil temperature - penetration resistance - moisture content
		photography
24 November 1992	151	final harvest
		plant sampling
		soil sampling

Note:

*): DAS = days after sowing

During the course of the experiment, the following parameters were measured:

3.2.1 Penetration resistance and soil moisture content

A Rimik Cone Penetrometer (Rimik Pty Ltd) was used to measure soil penetration resistance at the trial site. This equipment was a combination of a recording cone penetrometer model CP02 -64K memory and model CP12 interface unit.

Sites were sampled at different times during the experimental period to obtain an adequate spread of data needed to obtain the relationship between soil penetration resistance and moisture content. There were three replications for each treatment.

Sampling times and corresponding plant growth stages were: (i) 24 June 1992 (Emergence), (ii) 30 July 1992 (Tillering), and 10 September 1992 (Before flowering).

Soil moisture samples were obtained whenever penetrometer measurements were made. Soil moisture content was observed twice, 65 DAS (12 to 65 days after sowing) and 107 DAS (12 to 107 days after sowing), for all treatments in block II to obtain gravimetric soil moisture contents at 100 mm intervals from 0 to 300 mm depth and for all treatments in the two other blocks (blocks I and III) from 0 to 100 mm depth. The sampling strategy for soil penetration resistance and gravimetric moisture is shown in Figure 6 (Harte, 1990).

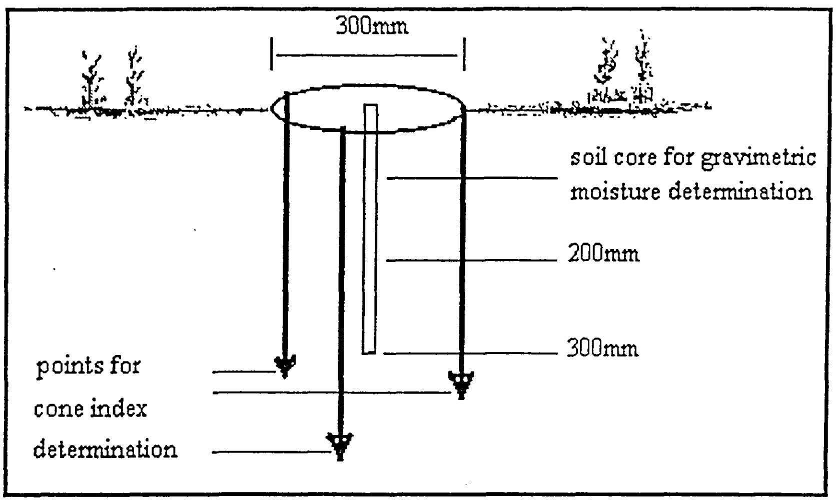


Figure 6. Sampling strategy for soil penetration resistance and moisture determination (After Harte,1990)

3.2.2 Soil Temperature

Soil temperatures were monitored hourly during the course of the experiment by using Copper-constantan thermocouples which were buried 1 cm deep in all plots and recorded on a Campbell Scientific 21x Micrologger . The maximum, average and minimum temperatures were also measured. The daily meteorological data during the experiment, including total rain and windspeed, were gathered at a weather station near the plots.

3.2.3 Plant and other soil measurements

Leaf emergence, number of tillers, plant development stages, length from root to top node, number of heads, 1000 grain weight, grain %N, grain yield, and above-ground plant dry weight were used as indicators of plant development and plant growth.

In this experiment, observations of leaf emergence were taken 28 DAS; the number of tillers, length from root to top node, and plant development stages were taken 65 DAS; the plant sampling for dry weight were taken 65 and 107 DAS; and the density of plants were taken 151 DAS.

Leaf emergence was averaged from 2 observations of 1m length row from the inner row of each plot. Plant samples for the number of tillers, length from root to top node and plant development stages were taken 0.5m from two the inner rows of each plot.

Observations of phasic development of the shoot growing point, on a scale from 0 to 12 as described by Andrews *et al.* (1991), were obtained by viewing their apical meristems under the microscope.

Soil was extracted in the field with 2M KCl, and then filtered and analysed for nitrate and ammonium by autoanalyser on returning to the laboratory. Total N on plant samples was determined by dry combustion using a Carlo Erba CNS analyser.

3.2.4 Relationship between soil temperature and early growth of wheat

To obtain the relationship between soil temperature and growth of wheat, mean average, maximum and minimum soil temperature and above-plant dry weight from each chosen wheat growth stages i.e. 65 DAS (12 to 65 days after sowing) and 107 DAS (12 to 107 days after sowing) were compared.

To compare the effect of treatment, the statistical procedure adopted involved fitting linear regression relationships to the soil temperature - plant components data.

All data were analysed by the statistical package NEVA except for regression analysis which was analysed using SYSTAT. Only results which are statistically significant at a probability of at least 5% (P < 5%) will be discussed in the text of all chapters unless otherwise stated.

3.3 Results

3.3.1 Soil water

During the experimental period, total rainfall for the experiment was 116 mm, which occurred some time between week 0 and week 15. There was no rain from week 15 till week 20 of the observations during the course of the experiment. Weekly rainfall for the period of crop growth in the experiment is shown in Figure 7.

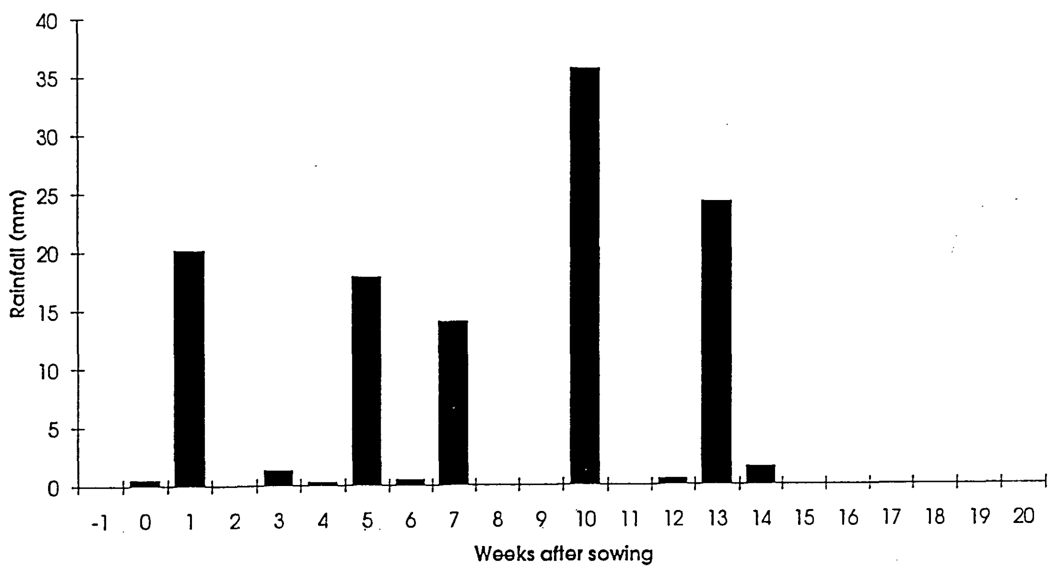


Figure 7. Weekly rainfall between 20 May - 21 November 1992 (20 weeks, week 0 is the sowing time) on the experiment sites in Warialda

Figures 8 and 9 show the effect of stubble treatments on soil moisture, at soil depth zones 0 - 100, 100 - 200, and 200 - 300 mm. Analysis of variance showed no significant differences between treatments.

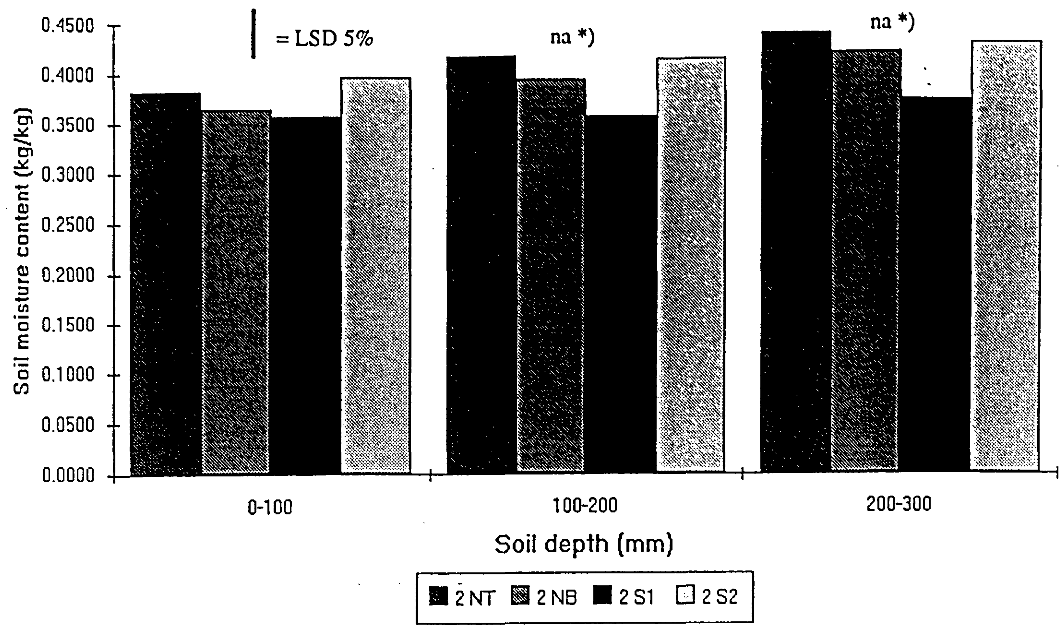


Figure 8. The effect of stubble treatments on soil moisture, at soil depth zones 0 - 100, 100 - 200 and 200 - 300 mm, 65 DAS. na shows that LSD 5% is not available (single measurement)

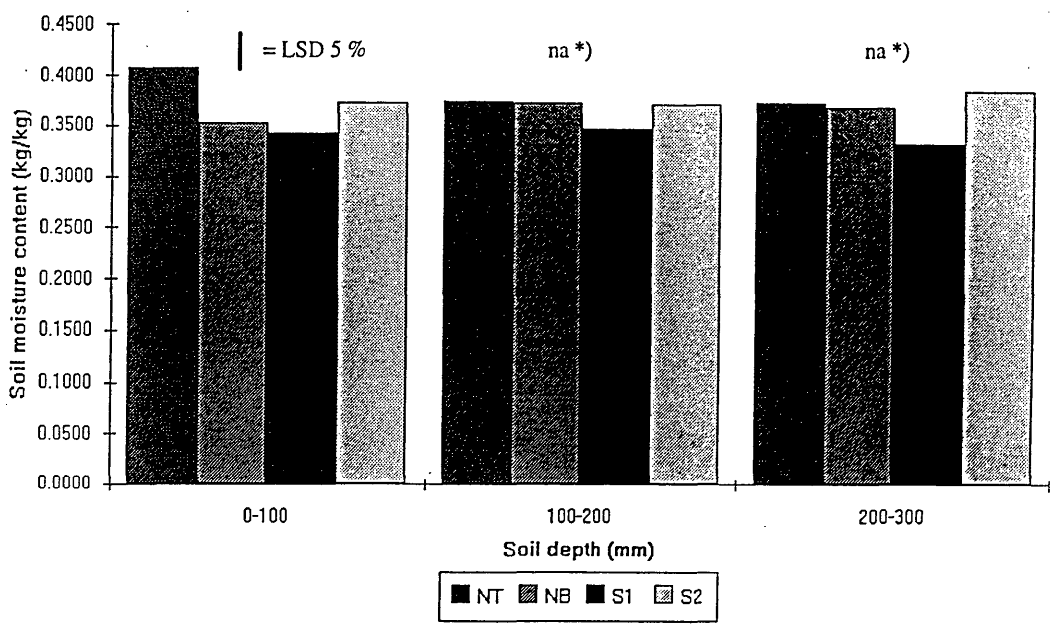


Figure 9. The effect of tillage treatments on soil moisture, at soil depth zones 0 - 100, 100 - 200 and 200 - 300mm, 107 DAS. na shows that LSD 5% is not available (single measurement)

3.3.2 Penetration resistance

Figures 10. and 11. show the relationships between soil penetration resistance and soil depth and between soil moisture content and soil depth at various sampling times for each of the stubble treatments. Analysis of variance showed no significant differences between treatments.

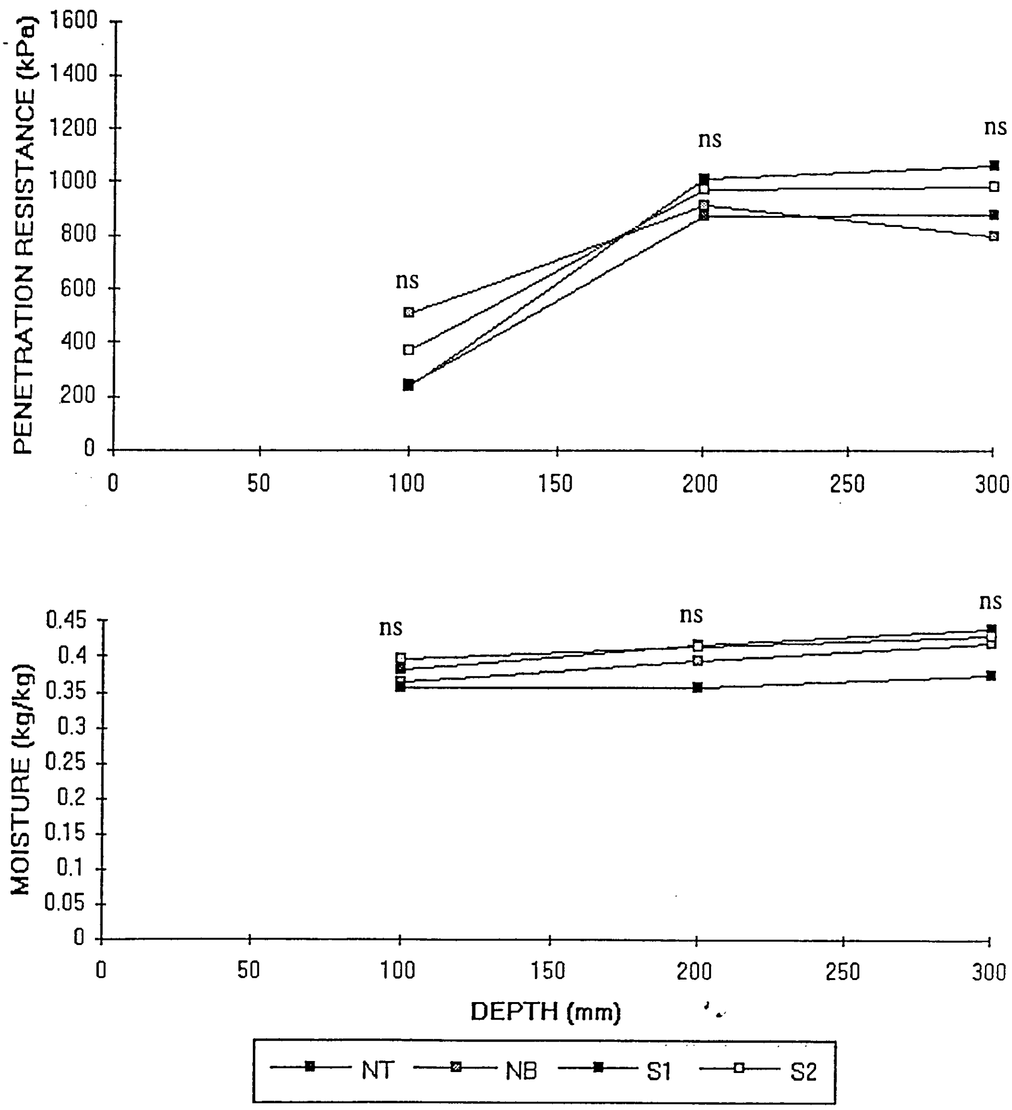


Figure 10. Penetration resistance and moisture content profiles of stubble treatments 65 DAS. ns (not significant)

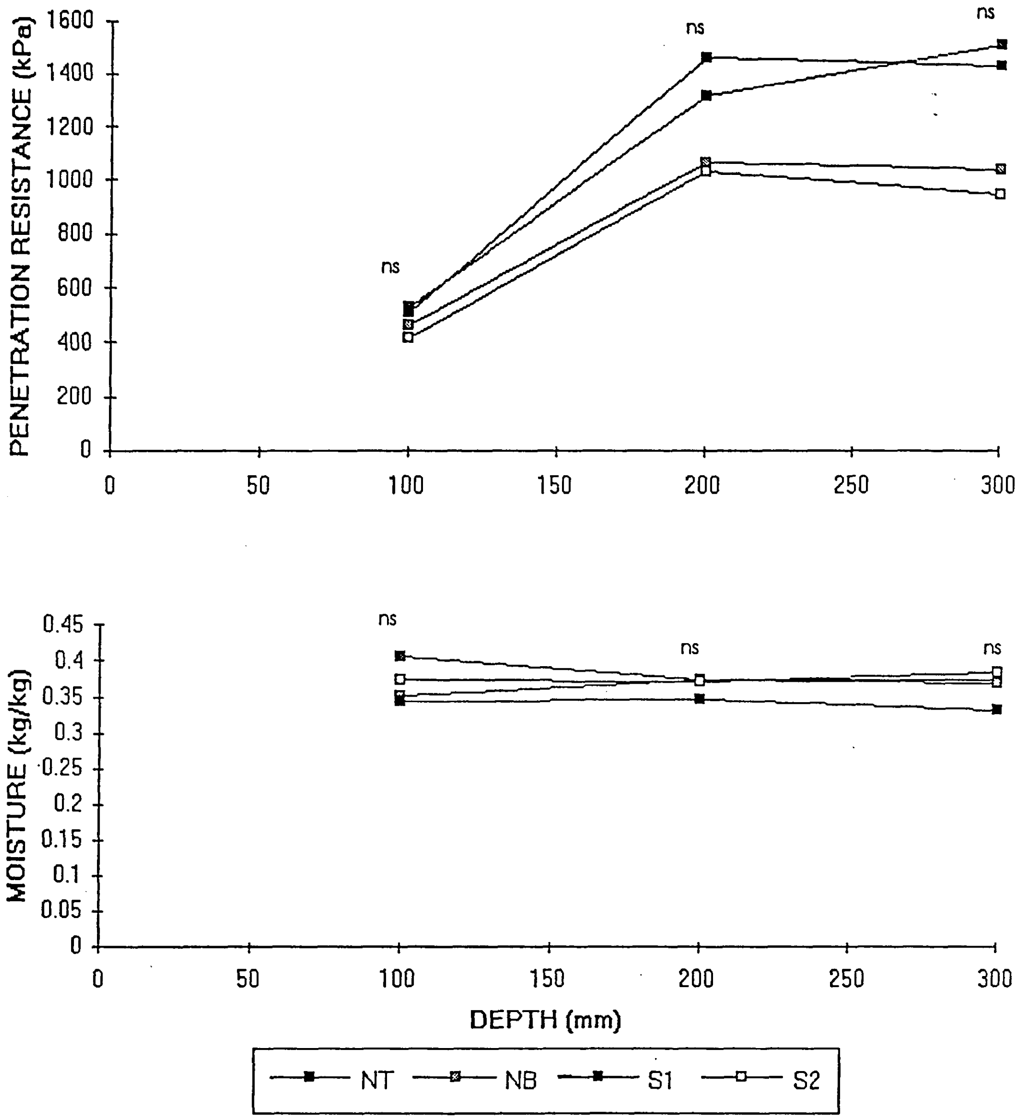


Figure 11. Penetration resistance and moisture content profiles of stubble treatments 107 DAS. ns (not significant)

3.3.3 Plant growth and development

Table 3a. shows the mean values of several components of early plant growth and development in this experiment. The plant establishment was within the desired plant density for the region of between 88 and 99 plants m^{-2}. The leaf emergence up to 28 days after sowing was between 2 and 3 leaves. The observation on tillers up to 65 days shows that the average number of primary tillers was between 2 and 4. Plant development stage up to 65 DAS was between stage 2 and stage 4. The length from root to top node up to 107 DAS was between 13cm and 15cm.

Table 3a. Plant growth and development

	Treatment					
	NT	NB	S1	S2	LSD 5%	P
Plant/m2 151 DAS	93	98	90	99	20	0.72
Leaves emerged 28 DAS	2.83	2.92	2.67	2.67	0.68	0.78
Number of tillers 65 DAS	3.83	3.42	3.75	2.92	0.94	0.18
Plant development stage 65 DAS	3.25	3.08	3.33	2.83	0.88	0.60
Length from root to top node 65 DAS (cm)	14.3	13.6	14	14	2.0	0.77
Above-ground plant dry matter 65 DAS (kg/ha)	539	592	430	258	249	0.06
Above-ground plant dry matter 107 DAS (kg/ha)	5542	3996	3782	2676	2057	0.07

The mean grain yield for the NB treatment was the lowest of the treatments. There were no significant differences between tillage treatments (P<0.05).

The low grain yield of the NB treatment was derived from low level of any observation of the plant components: heads/m2, 1000 grain weight and above-ground dry matter (Table 4).

Table 4. Yield data for final harvest

	Treatment					
	NT	NB	S1	S2	LSD 5%	P
Heads/m2	469	448	536	465	50	0.02
1000 grain weight (g)	32.1	32.1	33.2	33.2	3.6	0.86
Above-ground plant dry matter (t/ha)	12.7	12.7	14.4	13.0	1.9	0.16
Grain %N	1.97	1.97	2.07	2.27	0.32	0.22
Grain yield (t/ha)	4.8	4.8	5.7	5.4	0.81	0.10

The mean percentages of plant-N and soil organic-N are detailed in Table 5.

Table 5. The effect of stubble treatments on plant N and soil inorganic-N concentration at 65 DAS

	Treatment					
	NT	NB	S1	S2	LSD 5%	P
Plant %N	4.43	4.40	4.64	4.64	0.17	0.02
Soil inorganic-N ($\mu g\ g^{-1}$)	17	32	30	13	36	0.55

There was no significant differences between tillage treatments for soil inorganic-N at 65 DAS. However there were differences in plant N, with the artificial stubble treatments having significantly higher N concentrations than NT and NB treatments (P<0.05).

3.3.4 Soil temperature

Table 6. Effect of stubble treatments on mean average, maximum and minimum soil temperature 65 DAS (12 to 65 days after sowing)

Soil temperature	DAS	NT	NB	S1	S2	LSD 1%	LSD 5%
Average	12 to 65	9.97	10.32	9.62	8.94	0.68	0.46
Maximum	12 to 65	17.09	17.58	17.57	14.09	4.17	2.87
Minimum	12 to 65	5.29	5.72	4.76	5.42	1.56	1.08

Table 7. Effect of stubble treatments on mean average, maximum and minimum soil temperature 107 DAS (12 to 107 days after sowing)

Soil temperature	DAS	NT	NB	S1	S2	LSD 1%	LSD 5%
Average	12 to 107	10.69	10.78	10.07	9.65	0.57	0.20
Maximum	12 to 107	16.85	16.56	16.33	14.06	2.95	2.03
Minimum	12 to 107	6.36	6.74	5.74	6.28	1.26	0.87

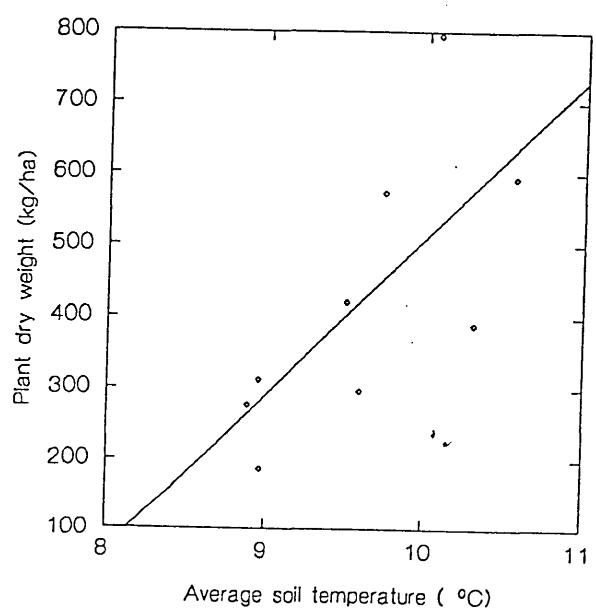
Analysis of variance showed that average soil temperatures at both times were significantly different (P<0.05). All soil temperature determinations were separately bulked and averaged for each treatment. Soil temperature values were collated against corresponding unit plant components and plotted accordingly. These relationships are shown in Figures 12. and 13. and Table 8 which are compiled from all data collected across various sampling times. Where they could be determined, regression equations and significant levels of regression are also shown.

Table 8. Equations and significant levels of regression between above-ground plant dry weight and days after sowing (65 and 107 DAS)

	Soil temperature	DAS	a	b	y	P
Above-ground	Average	12 to 65	220.14	-1691.865	y = 220.14x - 1691.865	0.036
plant dry weight	Maximum	12 to 65	36.224	-168.097	y = 36.224x - 168.097	0.247
	Minimum	12 to 65	69.958	55.898	y = 69.958x + 55.898	0.587
	Average	12 to 107	872.015	-5378.792	y = 872.015x - 5378.792	0.332
	Maximum	12 to 107	215.592	111.101	y = 215.592x - 111.101	0.457
	Minimum	12 to 107	322.212	1469.867	y = 322.212x - 1469.867	0.717

Table 8 shows that the only significant difference ($P<0.05$) of the relationship between above ground dry matter and soil temperature is for the average soil temperature. No relationships were found between average daily maximum or minimum temperature and above ground dry matter.

A



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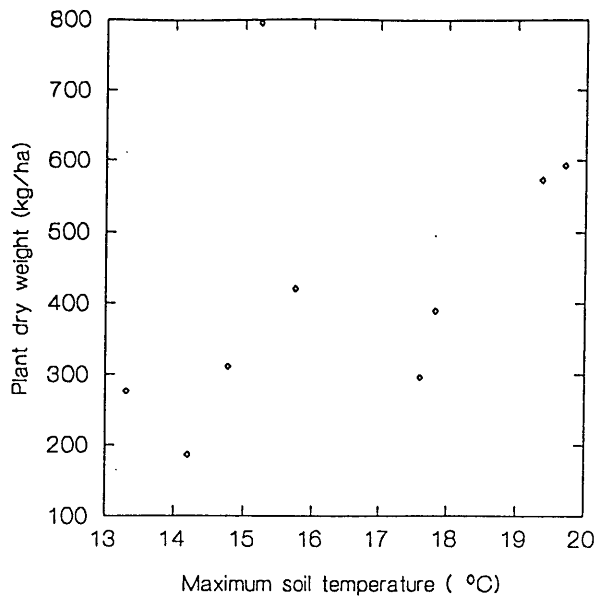

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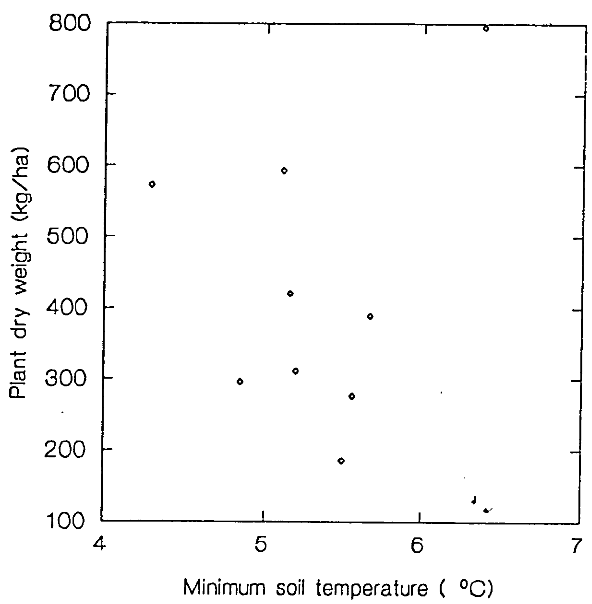
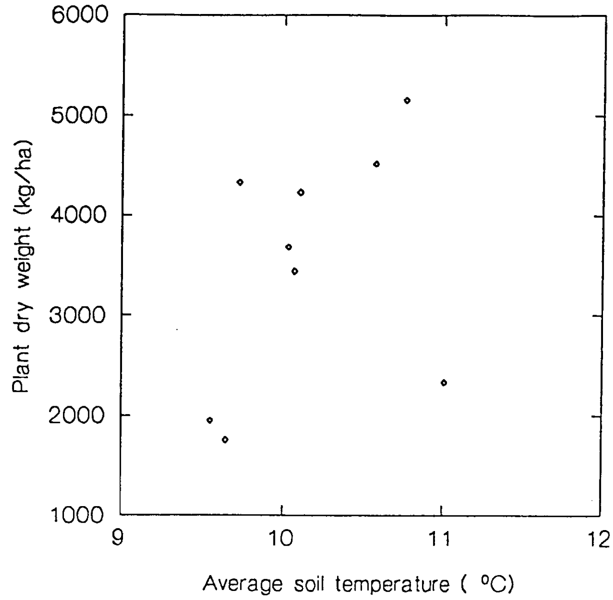
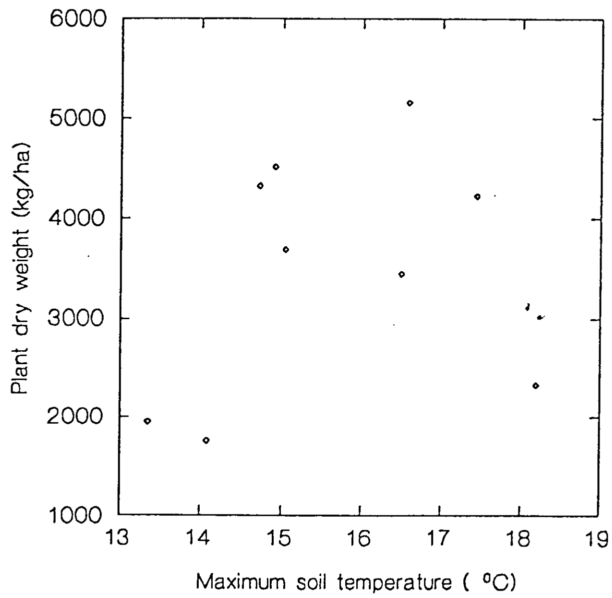


Figure 12. Effect of stubble managements on the relationship between soil temperature and dry matter 65 DAS

A


6000
5000
4000
3000
2000
1000
Plant dry weight (kg/ha)
9
10
11
12
Average soil temperature (°C)

B


6000
5000
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Plant dry weight (kg/ha)
13
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17
18
19
Maximum soil temperature (°C)

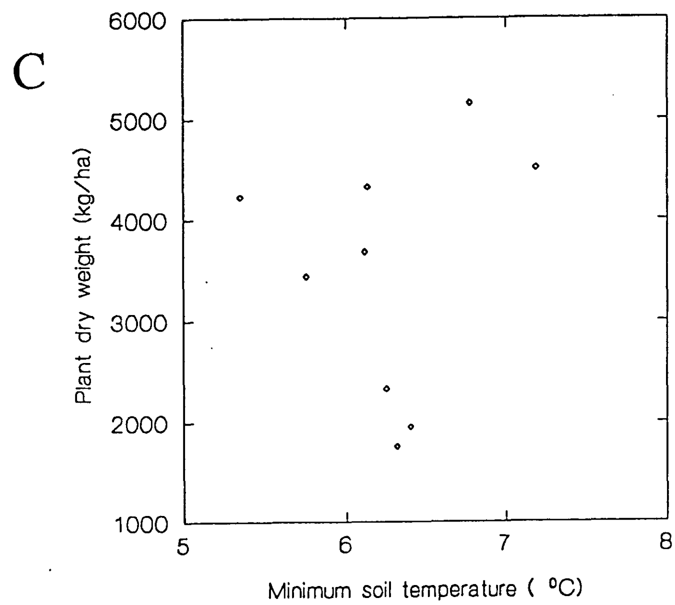


Figure 13. Effect of stubble managements on the relationship between soil temperature and dry matter 107 DAS

3.4 Discussion

3.4.1 Soil water

Gravimetric soil moisture contents at 65 and 107 DAS varied little between treatments or depths and ranged from about 0.33 to 0.43 kg/kg (Figures 8 and 9). Where replicate samples were taken (i.e. 0 to 100 mm depth), AOV showed no significant differences between treatments. The soil moisture contents for the Warialda black earth at -10 kPa matric potential are 0.48 kg/kg (100 mm depth) and 0.45 kg/kg (200 mm depth). At -

1500 kPa matric potential the soil moisture content is 0.28 kg/kg (100 and 200 mm depth) (Lockwood, unpublished data). The soil moisture contents at 65 and 107 DAS were all within the available water range. This and the observation of frequent rainfall for the first 14 weeks after sowing (Figure 7) suggests that soil moisture was not limiting plant growth during this period.

3.4.2 Penetration resistance

Penetration resistances at 65 and 107 DAS increased with depth from 100 to 200 mm although soil moisture contents did not (Figures 10 and 11). This was probably caused by the soil 200 and 300 mm depth being more compact than at 100 mm. Bulk density measurements were not made. Penetration resistances did not exceed 1.5 MPa, so that root growth would not be expected to be limited by soil strength. In addition the black earths are well structured, so that roots can follow the lines of weakness between the aggregates; on the other hand the penetrometer cannot, as it moves through the soil in a straight line. Penetrometer readings in this soil will tend to over-estimate the resistance to root growth.

3.4.3 Plant growth and development

There was no effect of treatment on the various plant development and growth parameters listed in Table 4. There were, however, hints of effects ($P<0.10$) of experimental treatment on above-ground dry matter. Similarly AOV for 107 DAS showed no effect of treatment on daily average, maximum or minimum soil temperature (12 to 107 DAS) (Table 7). However when above-ground dry matter for the NB, S1 and S2 plots was plotted against soil temperature, linear regression showed one significant relationship (Table 8 and Figures 12 and 13). This was a relationship between average soil temperature (12 to 65 DAS) and above-ground dry matter, which showed that the trend of decreasing average soil temperature with increasing shading was correlated with decreasing dry matter yields.

3.4.4 Relationship between soil temperature and dry matter

The literature shows that many growth processes in cereals are dependent on temperature, and can be linearly related to the product of time and temperature above a minimum known as the base temperature (which is known as accumulated temperature or thermal time and is measured in degree days). For a given time period this implies that the rate of such a process is linearly related to temperature. Also it means that daily average temperatures are likely to be good predictors, so long as the minimum temperature remains above the base temperature. For example, Baker *et al.* (1980) found that when leaf appearance stage was plotted against temperature, the relationship was linear.

During the early stages of growth of an emerged monocotyledon such as wheat, before stem elongation takes place, leaf expansion occurs at the stem apex located just below the soil surface, and it has been shown that leaf growth is dependent on the temperature at this site (Boatwright *et al.*, 1976). At 65 DAS the plants had not yet developed to the stage of ear initiation (ear initiation would be scored as 4), and thus stem elongation and the movement of the shoot apex above the soil surface also had not occurred. This means that leaf expansion rates would be dependent on soil temperature just below the surface. At 107 DAS however stem elongation had taken place and so leaf expansion was controlled by air temperature rather than soil temperature. The lack of a relationship between DW at 107 DAS and average soil temperature is consistent with this and also suggests that a process of catching up has taken place.

3.4.5 Other factors that could affect dry matter

It is necessary to consider if the observed relationship between soil temperature and dry matter could be influenced or caused by other confounding factors. Some of these are discussed below.

Soil water: AOV detected no significant differences in soil water contents between treatments and there was no suggestion of a trend of increasing or decreasing water content from NB through S1 to S2. The shading and insulating properties of surface mulches tend to lower evaporation rates from soil, so if any effect was to occur due to the artifical stubble it would be expected that soil water would tend to increase with intensity of stubble which could increase growth if soil water was limiting. This would give the opposite effect on plant DW to that which was observed.

Soil strength: Care was taken when the artificial stubble treatments were established to avoid doing anything which could affect soil strength, such as loosening or compacting the soil. For example the plots were not walked on, but rather the shade cloth, etc. were installed from planks above the soil surface (see materials and methods section for details). The lack of difference in penetrometer resistances between treatments suggests that differences in DM were not due to differences in soil strength.

Nitrogen nutrition: N fertiliser was spread over all treatments (see materials and methods). There was no significant difference between treatments in soil inorganic N at 65 DAS. The artificial stubble treatments had significantly higher plant N concentrations than NB or NT. This may be associated with the lower dry matter under the artificial stubble treatments. As wheat plants grow and develop their tissue concentrations fall (Reuter and Robinson, 1986). In any case there is no evidence from this of N nutrition being a causative factor in the the differences in dry matter at 65 DAS.

Other shading effects of the artificial stubble: As explained in the literature review, stubble and mulches can lower average soil temperatures by preventing some solar radiation reaching the soil surface. The same shading process will correspondingly affect the amount of photosynthetic radiation reaching the leaves of young plants that have not yet grown sufficiently high. The effects of shading on both average soil temperature and on photosynthesis cannot be separated in this experiment. However it is assumed that the extent to which photosynthetic radiation is prevented from reaching the soil surface (and leaves close to the soil surface) by shading is directly related to the depression of average soil temperature, so that soil temperature is an indicator of both processes.

3.4.6 Use of relationship between soil temperature depression and dry matter to predict difference between NT and NB

The relationship between dry matter at 65 DAS and average soil temperature implies that dry matter increased by 220 kg ha^{-1} $^{o}C^{-1}$. The difference between soil temperatures in the NT and NB treatments was 0.36 ^{o}C, which would give a predicted dry matter difference of 75 kg ha^{-1}, which is close to the measured difference of 53 kg ha^{-1}.

This relationship can also be used to examine differences between NT and NB treatments measured at the Warialda trial prior to the present project (Table 9)

(Lockwood, unpublished data). In 1990 there was an estimated difference in temperature of 0.1 ^{o}C and in DM at 65 DAS of 160 kg ha^{-1}. The temperature DM relationship would predict a difference of only 22 kg ha^{-1} in 1990, but in that year there was evidence of poorer N nutrition in the stubble retained plots which could have accounted for the difference. In 1991 there was an estimated temperature difference of 1.1 ^{o}C, which would predict a DM difference of $1.1 \times 220 = 240$ kg ha^{-1}, which is of the same order as the measured difference of 167 kg ha^{-1}. In that year plant and soil analyses detected no differences in N nutrition between NT and NB. Thus, in the absence of N nutrition problems, the effect of temperature on DM at 65 DAS is sufficient to explain the lower early growth resulting from retention of standing stubble.

Table 9. Estimated differences in average soil temperature 65 DAS (12 to 65 days after sowing) at 10 mm depth and estimated above-ground dry matter at 65 DAS in 1990 and 1991

	1990		1991		1992	
	Estimated dry matter (kg ha^{-1})	Measured average soil temperatu re (^{o}C)	Estimated dry matter (kg ha^{-1})	Estimated average soil temperatu re (^{o}C)	Measured dry matter (kg ha^{-1})	Measured average soil temperatu re (^{o}C)
No-tillage, stubble burned	444	9.62	488	10.55	592	10.31
No-tillage, stubble retained	284	9.50	321	9.42	539	9.97
Difference	160	0.12	167	1.13	53	0.34

In a study at Murrumbateman, NSW Australia, soil temperatures were measured at different depths under a wheat crop sown by three different methods in a dry (1982) and a wet (1983) season (Aston and Fischer, 1986). Generally soil temperatures at any particular depth under conventional tillage (CT) were warmer during the day and cooler during the night than under no-tillage (NT). These differences persisted throughout both growing seasons but were least during the wet year. Wheat plants showed early vigor with CT and had a larger shoot dry weight per plant at the 4½-leaf stage. Furthermore, they found that there is a correlation between dry matter difference and soil temperature difference between CT and NT treatments.

The relationship derived in this experiment is compared to one derived from their data on three stubble management treatments. Their 1982 data cannot be used for comparison as they do not give the sowing date. However it is possible to use their 1983 data for plant dry weights at 71 DAS. They measured top dry weights for individual plants rather than on an area basis. They also report that wheat was sown at 100 kg ha^{-1}. Assuming a normal establishment rate this could be expected to yield about 230 plants m^{-2} (Verrell and Komoll, 1991). This figure has been used to calculate above-ground dry matter on an area basis in Table 10. A regression of dry matter against average soil temperature at10 mm below the surface yielded a slope of 192 kg ha^{-1} $^oC^{-1}$, which is similar to the 220 kg ha^{-1} $^oC^{-1}$ obtained at Warialda for 65 DAS. This adds some further weight to the conclusion of Aston and Fischer (1986) that their observed differences in early wheat growth "could at least have partially been due to the patterns of soil temperature".

Table 10. Relationship between above-ground dry matter at 71 DAS for wheat at Murrumbateman in 1983 (Aston and Fischer, 1986)

Treatment	Plant top dry weight at 71 DAS (mg $plant^{-1}$)	Above ground dry matter at 71 DAS (kg ha^{-1})	Average soil temperature (1 cm depth) (^oC)
Conventional cultivation	175	212	7.6
No-tillage, stubble burn, high soil disturbance when sown	120	276	7.7
No-tillage, stubble retained, minimum disturbance	92	403	8.5
Slope of regression line for dry weight on temperature: 192 kg ha^{-1} $^oC^{-1}$			

In conclusion, the data in this chapter show negative effects of residues on the early growth of wheat. Under the experimental conditions, it seems unlikely that water storage or nitrogen immobilisation or phytotoxicity or soil strength caused these effects since the soil was close to field capacity, showed no indications of N or other nutrient limitations, produced no phytotoxin agent, and had a soil strength less than 1.5 MPa (Figures 10 and 11). The results suggest that the effects were due to the average soil temperature near the growing point during the early plant growth and development process.

Chapter 4

Influence of Stubble Management on Early Growth of Soybean

(Laureldale Experiment)

4.1 Introduction

With summer crops stubble retention may have some advantages for early growth if temperatures near the surface of bare soil exceed the optimum for early growth. Un-tilled soils are generally wetter and cooler and have less plant-available mineral N than soils which have been cultivated (Thomas *et al.*, 1973; Doran, 1980; Dowdell *et al.*, 1983; Marley and Littler, 1989). The degree to which these factors lead to increases or decreases in yield depends upon the root and aerial environments of the growing crop, and to the effects of tillage and stubble practice on crop diseases and pests (Marley and Littler, 1989). Lindemann *et al.* (1982) reported a 22% reduction in the seed yield of no-tillage soybean, relative to cultivated plots, in trials in the cool, northern part of the USA. By contrast, yield increases of 0.9 to 1.5 t ha^{-1} were recorded for no-tilled sorghum, compared to cultivated plots, in the semi-arid region of Texas, USA (Baumhardt *et al.*, 1985). Similar results to those in southern USA were found for two different crops. No-tilled soybean outyielded cultivated soybean by 66% (Holland *et al.*, 1984) and no-tilled sorghum outyielded cultivated sorghum by an average of 0.5 t ha^{-1} (Holland and Felton, 1989).

The objective of this experiment was to determine if the differences in growth and development of soybeans that are observed under stubble were caused by differences in soil temperature. The objective was to be achieved by conducting a field experiment in which soybeans were grown in bare soil, under no-tilled wheat stubble, and under two intensities of artificial stubble (i.e. under similar experimental conditions as the Warialda experiment).

4.2 Materials and Methods

The experiment was conducted at the University of New England research station "Laureldale", Armidale, New South Wales from January to April 1993 (latitude 30^{o}

32' and longitude 151° 38'). The soil is a chocolate soil (Uf 6.32, Northcote, 1979) with a cropping history for the last 20 years. The land was previously grown with wheat, the straw of which, in some parts, was left as one of the treatments. Soybean [*Glycine max* (L.) Merr.], i.e. the indeterminate variety Valder, was planted. The experimental plots were each 2.0x1.5m. Treatments and experimental design were similar to those described in Chapter 3, materials and methods section, except for the plot randomisation in each block.

The previous wheat crop was harvested from the experiment plots by cutting the straw 0.5 to 1cm height, except for NT which was left standing in the plots to a height of 25cm. To obtain the rate of residue of 1 to 1.5 t ha^{-1}, 20 to 25 cm chopped straw was left on the surface of the plots.

Soybean was sown by hand at a rate of 600,000 seeds ha^{-1} for all treatments in each plot, which had 5 rows, 2-3cm deep and 30cm row spacing, or 60 seeds per row. Seeds rate were then adjusted so that plant establishments were 400,000 plants ha^{-1}, or 24 plants per row. All treatments were inoculated twice (19 January and 8 February 1993) with a commercial legume innoculant Group H, 1.5kg and 2kg respectively. Soil temperatures were continuously monitored using two Copper-constantan thermocouples wired in parallel which were inserted 1 cm deep in the soil in each plot for all treatments. Weed control during crop growth consisted of two sprays 100 l ha^{-1} each of Verdict 104 to control grass seed crops, grass pastures and wheat on all plots. All plots were fertilised with 30 kg P and 60 kg K per ha. and when necessary, irrigation was applied so that soil moisture did not limit growth.

Table 11. shows the main events during the field experiment.

Table 11. The main events during the field experiment.

Date	DAS	Event
15 January 1993	-3	harvested previous crop (wheat)
17 January 1993	-1	row spacing
18 January 1993	0	sowing
19 January 1993	1	1st innoculant spray
20-24 January 1993	2-6	artificial stubble installed
24-25 January 1993	6-7	thermocouples installed
30 January 1993	12	1st weed control
5 February 1993	18	soil sampling for moisture content
8 February 1993	21	2nd innoculant spray fertilisers applied
9 February 1993	22	plant thinning
10 February 1993	23	plant sampling for dry weight
12 February 1993	25	measurement of: - plant leaves - plant height
19 February 1993	32	irrigation
21 February 1993	34	irrigation
24 February 1993	37	irrigation
26 February 1993	39	measurement of: - plant leaves - plant height
1 March 1993	42	2nd weed control
3 March 1993	44	soil sampling for moisture content
10 March 1993	51	irrigation
17 March 1993	58	measurement of: - plant leaves - plant height
22 March	63	irrigation
8 April 1993	80	measurement of: - plant leaves - plant height
8 April 1993	80	plant sampling for dry weight
8 April 1993	80	soil sampling for moisture content
13 April 1993	85	irrigation
20 April 1993	92	irrigation
26 April 1993	98	irrigation
2 May 1993	102	plant sampling for dry weight

Plate 2 shows the lay-out of the experiment at Laureldale, and the detail of the treatments is described in Appendix A2.

Plate 2. The lay-out of Laureldale experiment.

During the course of the experiment, the following parameters were measured.

4.2.1 Soil Temperature

Soil temperatures were monitored hourly during the course of the experiment by using two Copper-constantan thermocouples wired in parallel and buried 1 cm deep in all plots. The average readings for each pair were recorded automatically on a Campbell Scientific 21x Micrologger. The daily maximum, average and minimum temperatures were also measured.

4.2.2 Plant Development and Plant Growth

In this experiment, seed emergence, number of plant leaves, plant height, developing pods dry matter and above-ground plant dry weight were used as indicators of plant development and plant growth.

In this experiment, observations of seed emergence were measured 6, 11, 16, and 22 DAS; the leaves emerged and plant height were measured 25, 39, 58, and 80 DAS, and the plant samplings for dry weight were taken 22, 80, and 102 DAS; and the developing pods dry matter samples were taken 102 DAS. Counts of seedling emergence began when a seedling had penetrated the surface of the upper layer of the seedbed. Two plant samples, for observations of leaf emergence and plant height, were taken from each row of the plots. Difference between treatments was obtained by comparing the mean average of these measurements.

Plant growth was measured by destructively harvesting 0.5m per row from two adjacent rows (i.e. second row and fourth row) in each plot. At 102 DAS the soybeans had been killed by frost so that only the weight of the developing soybeans and pods was recorded. Dry matter samples were dried for 48 hours in a force-draft oven at 80 ^{o}C before weighing.

4.2.3 Soil Moisture Content

During the experiment, irrigation to all plots was necessary whenever it was found that there was one or more plants showing signs of water stress. The time interval between successive irrigations was always at least one week.

Soil moisture content was observed three times (5 February, 3 March, and 8 April 1993) in all plots during the course of the experiment. All measurements were taken at depths 0 to 50 mm, 50 to 100 mm, 100 to 200 mm, and 200 to 300 mm, except on 5 February. On 5 February, soil measurements were taken only to a depth of 100mm. When the soil was irrigated, soil moisture samples were taken before irrigation. Samples were transported to the laboratory in plastic bags for oven-drying to obtain gravimetric soil moisture content.

4.2.4 Relationship between soil temperature and early growth of soybean

To obtain the relationship between soil temperature and growth of soybean, mean average, maximum and minimum soil temperature and above-plant dry weight from each chosen soybean growth stage i.e. 22 DAS (7 to 22 days after sowing), 80 DAS (7 to 80 days after sowing), 102 DAS (7 to 102 days after sowing), and between mean average, maximum and minimum soil temperature and developing pods dry weight 102 DAS (7 to 102 days after sowing) were compared.

To compare the effect of treatment, the statistical procedure adopted involved fitting linear regression relationships to the soil temperature - plant components data.

4.3 Results

Analysis of variance showed no significant differences between stubble treatments for any soil or plant properties measured during this experiment. Treatment means are tabulated with LSDs so that any trends between treatments can be observed.

4.3.1 Soil water.

During the experiment period, total rainfall and irrigation were 338 mm and 81 mm, respectively.

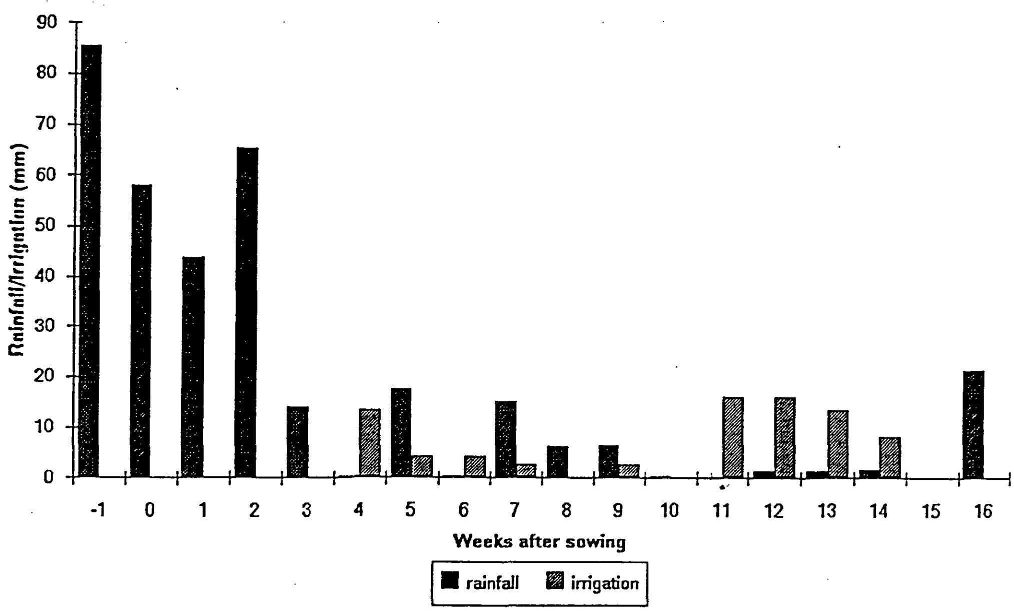


Figure 14. Weekly rainfall and irrigation between 11 January - 16 May 1993 (16 weeks, week 0 is the sowing time) on the experiment sites in Laureldale.

Table 12 shows the effect of stubble treatments on soil moisture, at soil depth zones 0 - 50, 50 - 100, 100 - 200, and 200 - 300 mm.

Table 12. The effect of stubble treatments on soil moisture content at soil depth 0 - 50, 50 - 100, 100 - 200, and 200 - 300 mm.

Date	Soil Depth (mm)	Soil Moisture Content (kg/kg)				LSD 5%
		NT	NB	S1	S2	
5/2/93	0-50	0.159	0.146	0.146	0.150	0.014
(18 DAS)	50-100	0.252	0.251	0.237	0.234	0.026
	100-200	na	na	na	na	na
	200-300	na	na	na	na	na
3/3/93	0-50	0.182	0.192	0.193	0.189	0.043
(45 DAS)	50-100	0.243	0.255	0.267	0.236	0.033
	100-200	0.269	0.310	0.300	0.283	0.115
	200-300	0.271	0.343	0.341	0.379	0.154
8/4/93	0-50	0.134	0.135	0.143	0.129	0.025
(80 DAS)	50-100	0.198	0.192	0.207	0.179	0.043
	100-200	0.292	0.200	0.257	0.248	0.194
	200-300	0.234	0.249	0.301	0.301	0.079

4.3.2 Plant growth and development

Table 13 shows the mean values of several components of early plant growth and development in this experiment.

Table 13. Plant components during the course of experiment.

	Treatment				
	NT	NB	S1	S2	LSD 5%
Emergence 6 DAS(%)	39	32	31	36	26
Emergence 11 DAS(%)	55	53	54	53	29
Emergence 16 DAS(%)	70	78	70	68	19
Emergence 22 DAS(%)	74	80	73	73	20
Leaves emerged 25 DAS	1.54	1.67	1.47	1.51	0.35
Leaves emerged 39 DAS	4.89	5.02	4.49	4.76	0.97
Leaves emerged 58 DAS	5.91	6.18	5.86	6.20	1.48
Leaves emerged 80 DAS	8.91	8.67	9.34	9.22	2.94
Plant height 25 DAS (cm)	7.8	6.4	6.4	7.1	1.9
Plant height 39 DAS (cm)	17.1	14.3	14.9	16.4	3.9
Plant height 58 DAS (cm)	27.9	24.2	23.3	25.6	7.7
Plant height 80 DAS (cm)	39.8	32.6	33.6	37.0	11.3

Above-ground plant dry matter increased up to the last sampling taken at anthesis.

Table 14. Above-ground plant dry matter during the course of experiment

	Treatment				
Plant components	NT	NB	S1	S2	LSD 5%
Above-ground plant dry matter 22 DAS	0.065	0.062	0.043	0.046	0.050
Above-ground plant dry matter 80 DAS	3.78	3.28	3.32	2.78	1.16
Above-ground plant dry matter 102 DAS	4.80	4.48	4.65	4.49	1.59
Developing pods dry matter 102 DAS	0.83	0.93	0.92	0.63	0.60

4.3.3 Soil temperature

Table 15. Effect of stubble treatments on mean average, maximum and minimum soil temperature 24 DAS

Soil temperature	DAS	NT	NB	S1	S2	LSD 5%
Average	7 to 24	17.63	17.46	17.86	17.40	1.13
Maximum	7 to 24	30.39	30.24	31.32	30.06	2.90
Minimum	7 to 24	7.57	7.56	7.71	7.41	0.75

Table 16. Effect of stubble treatments on mean average, maximum and minimum soil temperature 80 DAS

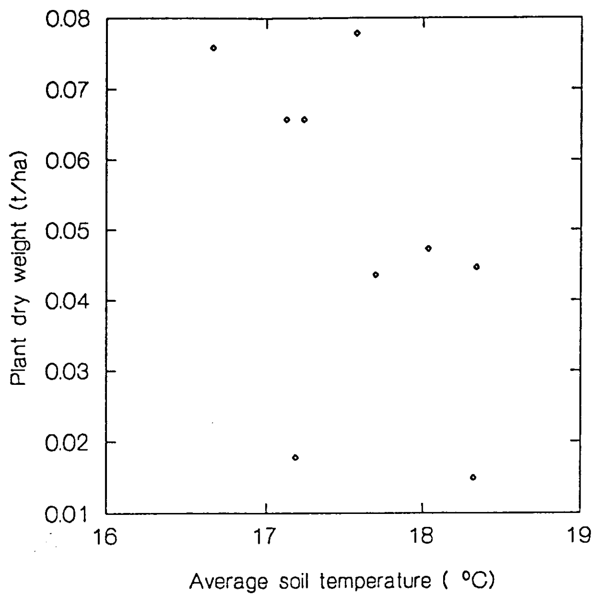
Soil temperature	DAS	NT	NB	S1	S2	LSD 5%
Average	7 to 80	14.75	14.69	15.07	14.63	1.21
Maximum	7 to 80	29.49	29.65	30.78	29.58	3.10
Minimum	7 to 80	2.93	2.61	2.57	2.57	0.82

Table 17. Effect of stubble treatments on mean average, maximum and minimum soil temperature 102 DAS

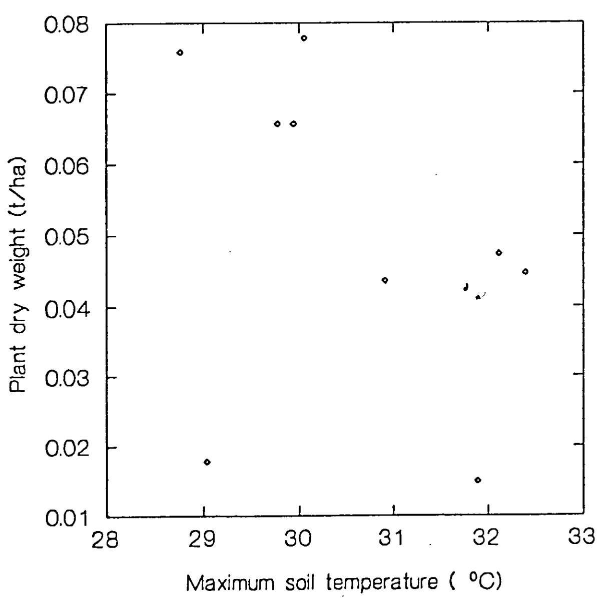
Soil temperature	DAS	NT	NB	S1	S2	LSD 5%
Average	7 to 102	14.70	14.64	15.00	14.59	1.19
Maximum	7 to 102	28.88	29.52	29.89	31.18	2.69
Minimum	7 to 102	2.83	2.52	2.47	2.48	0.80

These data were derived by the same procedures as the corresponding data in Chapter 3 section 4. These relationships are shown in Figures 15,16, 17 and 18 and Table 18 which are compiled from all data collected across various sampling times. Where they could be determined, regression equations and significant levels of regression are also shown.

A


0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Plant dry weight (t/ha)
16
17
18
19
Average soil temperature (°C)

B


0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
Plant dry weight (t/ha)
28
29
30
31
32
33
Maximum soil temperature (°C)

C

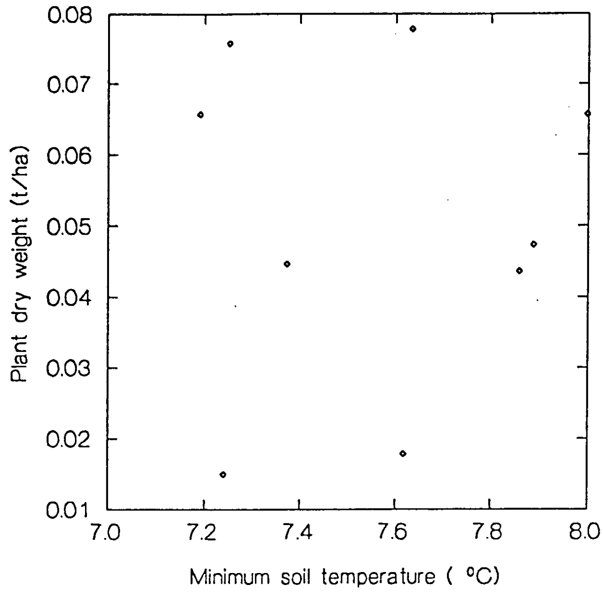
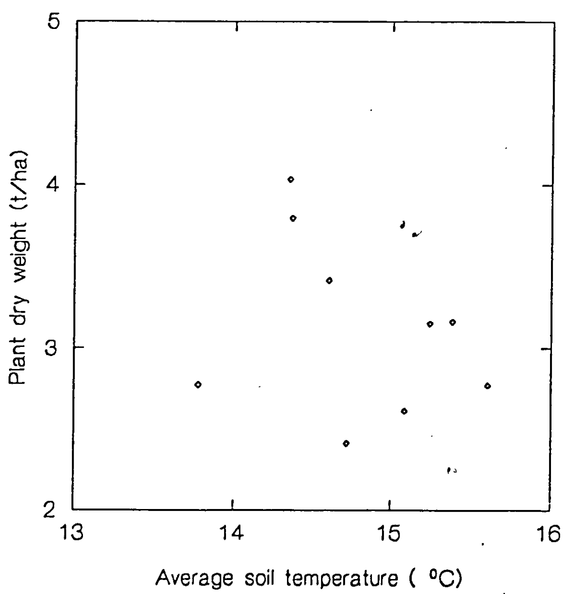
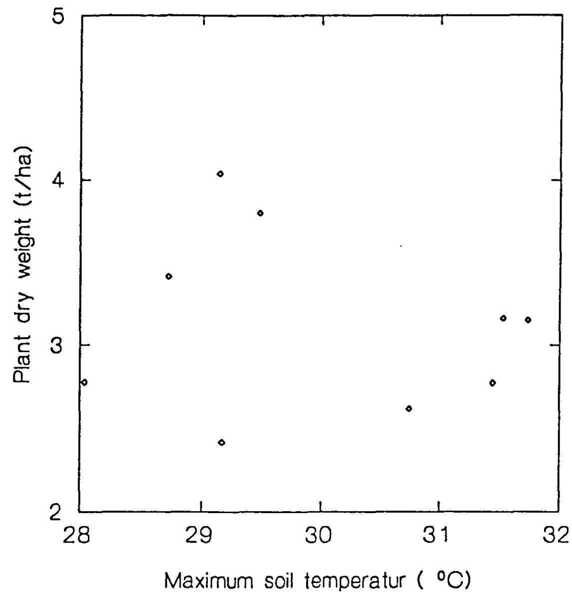


Figure 15. Effect of stubble management on the relationship between soil temperature, (A) average, (B) maximum and (C) minimum, and plant dry matter 22 DAS.

A



B



C

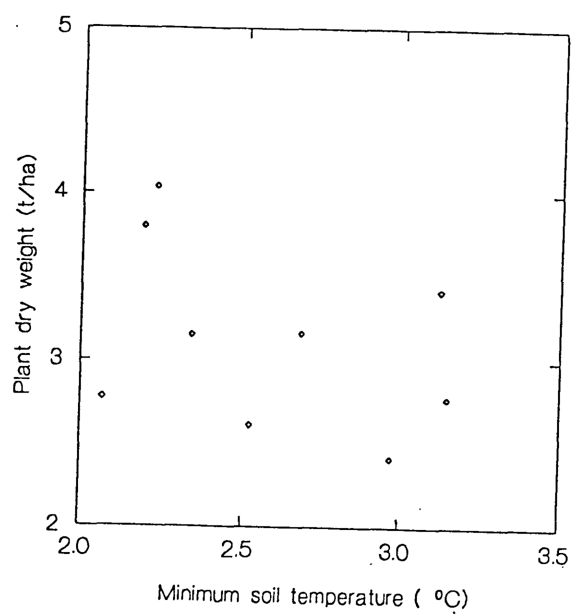
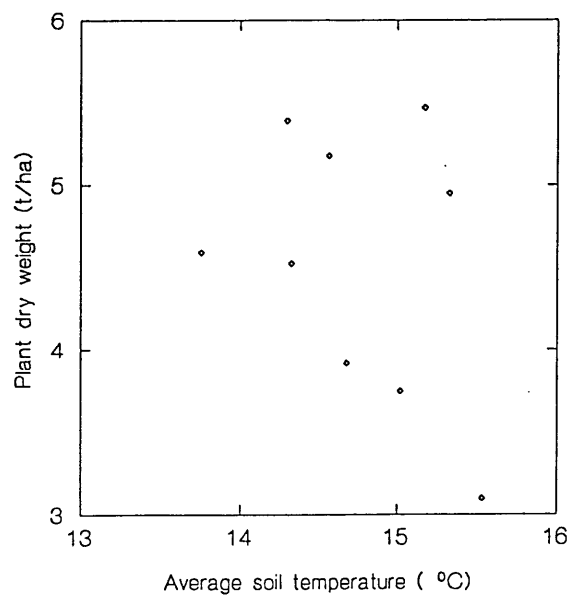
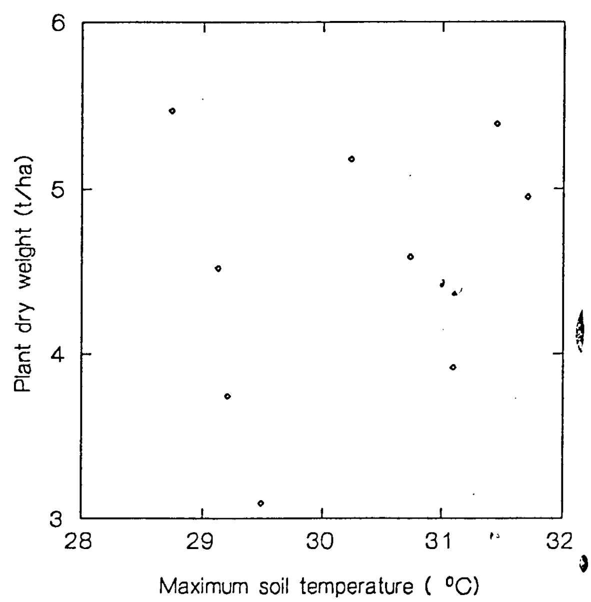


Figure 16. Effect of stubble management on the relationship between soil temperature, (A) average, (B) maximum and (C) minimum, and plant dry matter 80 DAS.

A


Plant dry weight (t/ha)
6
5
4
3
13
14
15
16
Average soil temperature (°C)

B


Plant dry weight (t/ha)
6
5
4
3
28
29
30
31
32
Maximum soil temperature (°C)

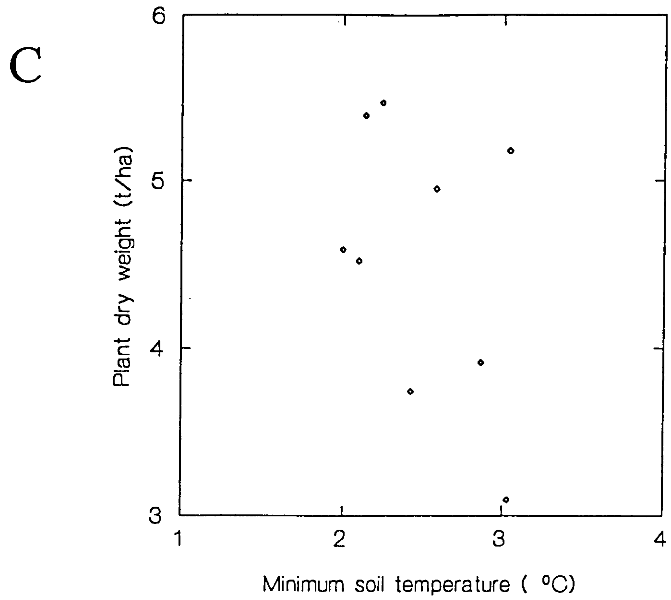
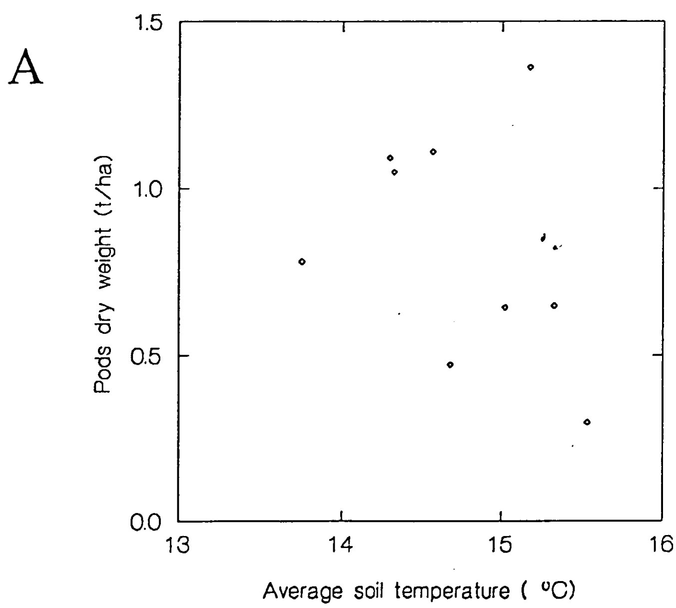


Figure 17. Effect of stubble management on the relationship between soil temperature, (A) average, (B) maximum and (C) minimum, and plant dry matter 102 DAS.



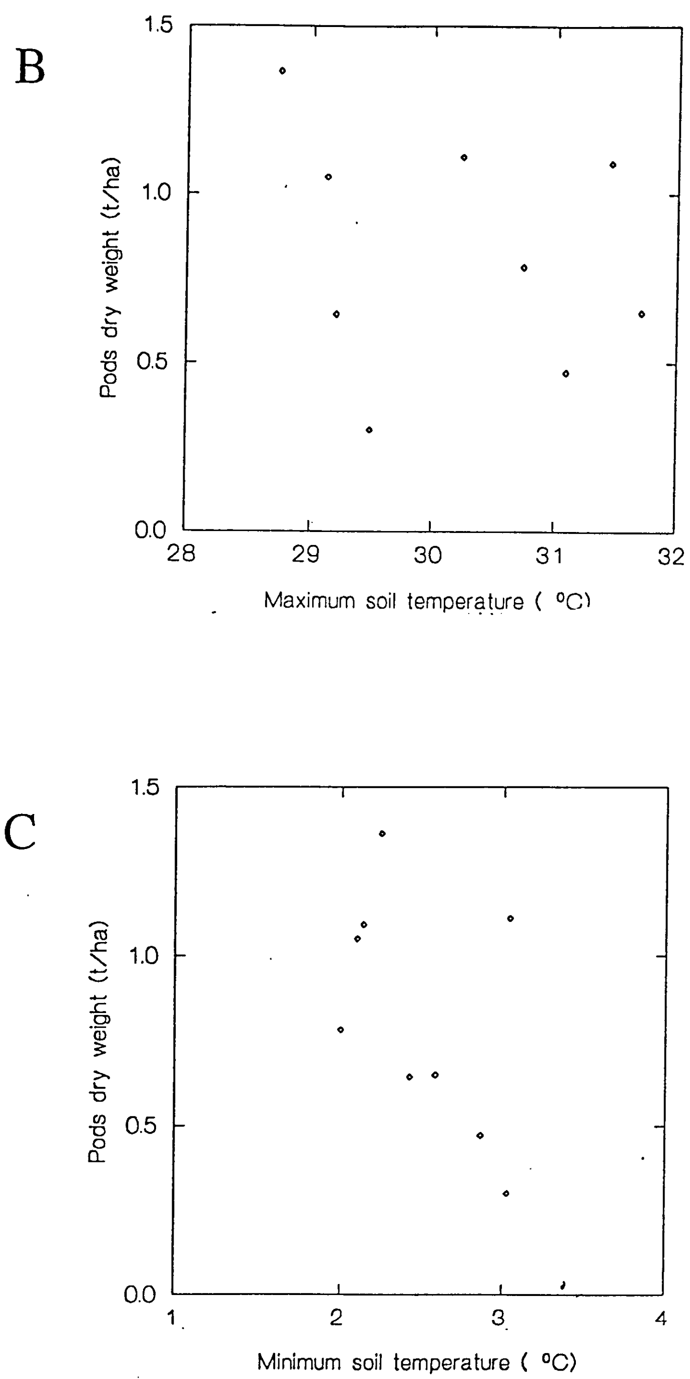


Figure 18. Effect of stubble management on the relationship between soil temperature, (A) average, (B) maximum and (C) minimum, and pods dry matter 102 DAS.

Table 18. Effect of stubble treatments on mean average, maximum and minimum soil temperature 7 to 102 days after sowing.

	Soil temperature	DAS	a	b	y	P
Above ground plant dry weight	Average	7 to 24	-0.021	0.417	y = -0.021x - 0.417	0.149
	Maximum	7 to 24	-0.007	0.253	y = -0.007x - 0.253	0.305
	Minimum	7 to 24	0.003	0.024	y = 0.003x + 0.024	0.905
	Average	7 to 80	-0.269	7.104	y = -0.269x + 7.104	0.45
	Maximum	7 to 80	-0.067	5.136	y = -0.067x + 5.136	0.664
	Minimum	7 to 80	-0.507	4.437	y = -0.507x + 4.437	0.305
	Average	7 to 102	-0.467	11.421	y = -0.467x + 11.421	0.387
	Maximum	7 to 102	0.17	-0.594	y = 0.17x - 0.594	0.55
	Minimum	7 to 102	-0.845	6.644	y = -0.845x + 6.644	0.255
Developing pods dry weight	Average	7 to 102	-0.205	3.852	y = -0.205x + 3.852	0.373
	Maximum	7 to 102	-0.076	3.112	y = -0.076x + 3.112	0.533
	Minimum	7 to 102	-0.421	1.876	y = -0.421x + 1.876	0.175

Table 18 shows that no relationships were found between average daily maximum, average or minimum temperature and above ground dry matter.

4.4 Discussion

Field experiments in northern New South Wales have shown that no-tillage with stubble retention can increase the yields of summer crops including soybean. The effects of tillage practices, which included no-tillage, fallow and double crops practices, on six summer crops were examined in northern New South Wales by Herridge and Holland (1992). Dry matter yields, when averaged over all crops, were increased by 34 and 14% under no-tillage at sites A and B, but at sites C, tillage practice did not affect yields. From this experiment, they also found that soybean was the most responsive crop to no-tillage with the increase in grain yield being 46, 15 and 18% at sites A, B and C, respectively. This increasing yields was attributable to the 192 mm (site B) and 230 mm (site C) rainfalls during November and December that replenished the soil profile with water down to > 750mm.

Further observation on the response of legume double crops to stubble retention and stubble incorporation tillage practices was conducted by Wheatley (1993) in his experiments in Willow Tree and Armidale, New South Wales. He found that no-tillage increased the yield of double-cropped soybean by 33-60% compared to the conventional tillage practice of stubble incorporation in two experiments (experiments 1 and 3), but because of poor establishment of no-tillage and mulch soybean sown after a fallow in experiment 2, there was no significant effect observed from this experiment. The increase in yield for double-cropped soybean was due to the facts that (1) any practice which maintains surface stubble (such as no-tillage) has the potential to increase soybean grain production provided that satisfactory crop establishment is achieved, (2) narrow row spacing of 0.5m has the potential to increase the yield of double-cropped soybeans compared with wide row spacings (0.65 and 1m), when sowing is delayed past the optimum time, and (3) there is increased infiltration of rainfall for double-cropped soybean compared with other tillage treatments.

4.4.1 Soil water

Stubble, real or artificial, had little or no effect on soil water contents (Table 12). At 18 DAS there was a hint of an effect in the 0 - 50 mm zone. Soil water contents were in the order NT > S2 > S1 = NB. In the literature review it was noted that stubble retention is associated with increased soil water. This is due, amongst other things, to lower evaporation, and could explain the trend in 0 - 50 mm soil water contents at 18 DAS. No other similar trends are found in Table 12.

4.4.2 Plant growth and development

Stubble management treatments did not influence soybean seedling emergence, leaf emergence and plant height at any date.

4.4.3 Soil temperature

In contrast to the Warialda experiment, there were no trends in soil temperatures between treatments. It was found that the 5% LSDs for the effects of stubble treatments on average soil temperature in this experiment were 1.13, 1.21 and 1.19 ^{O}C (at 24, 80 and 102 DAS respectively) which was much higher than those observed in the Warialda experiment (0.46 and 0.20 ^{O}C at 65 and 106 DAS, respectively). The lower sensitivity of this experiment as indicated by the higher LSDs may explain why no effect of artificial or real stubble on soil temperature was found. The reason for the high experimental error is not clear. Thermocouples were installed in the same way as at Warialda. The variability at 24 DAS (before canopy closure) might be related to variability in the pattern of shading within the plot, resulting from the shadecloth. Lal (1978) found considerable spatial variation in soil temperature in a summer row crop (see Chapter 2 section 2.3.1). However this would be expected to disappear as the growing soybean crop closed the canopy and became more of an influence on the shading than the rows of artificial stubble, and yet no decrease in LSD was observed.

4.4.4 Relationship between soil temperature and dry matter

In contrast to the Warialda experiment, no relationship was found between above ground dry matter and soil temperature. This is consistent with the observations of no effect of artificial stubble on either plant dry weights or on soil temperature. It may be that the experimental error was simply too large for a relationship to be detected. Another possibility is that soybean growth is relatively independent of small changes in soil temperature. Unlike cereals, leaf expansion in soybean occurs above the ground and is therefore determined by air temperature rather than soil temperature.

Chapter 5

General Discussion

The influence of fallow methods and crop residue management on soil physical properties has been widely studied (Black, 1970). Jessop and Stewart (1983) stated that there were beneficial effects following stubble retention including increased water infiltration, improved soil structure and the control of soil erosion, and minimisation of both absolute levels of soil temperature and fluctuation of soil temperature. Important negative effects of stubble retention include immobilisation of mineral nitrogen, reduced winter/spring soil temperatures and possible phytotoxic effects.

Experiments reported in this thesis were conducted to gain a better understanding of the effects of stubble management on the early growth of a winter and summer crop. In particular the role of soil temperature was investigated. Other factors including soil water, soil strength and soil nitrogen were also examined.

For wheat grown at Warialda it was shown that the difference in dry matter production at 65 DAS between no-tillage plots with stubble retained or burned could be explained by differences in average soil temperature at 10 mm depth. Examination of data collected in 1990 and 1991 (before this project) showed that soil temperture could explain differences in 1991, but not in 1990 when soil nitrogen was limiting in no-till with stubble retained. The relationship between soil temperature and dry matter derived from the artificial stubble at Warialda was also similar to the relationship between dry matter at 71 DAS and soil temperature found by Aston and Fischer (1986) at Murrumbateman in 1983.

In contrast no relationship was found between soil temperature and dry matter production in summer growing soybeans. It is possible that the absence of a relationship was due to the relatively high variability in soil temperatures that was observed within treatments. Indeed no effect of artificial stubble treatments on soil temperature was detected.

The different behaviour of the cereal and legume in regard to soil temperature is consistent with the different sites at which cell division for leaf expansion occurs in the two plants. In young cereal plants leaf expansion occurs at the shoot apex, just below the soil surface and it has been shown that growth is responsive to soil temperature at this site rather than to air temperature (Boatwright *et al.*, 1976). On the other hand, for dicotyledons like soybean the sites of leaf expansion and hence temperature control of leaf growth are above the ground (Hay and Walker, 1989) and hence influenced more by air temperature than by soil temperature.

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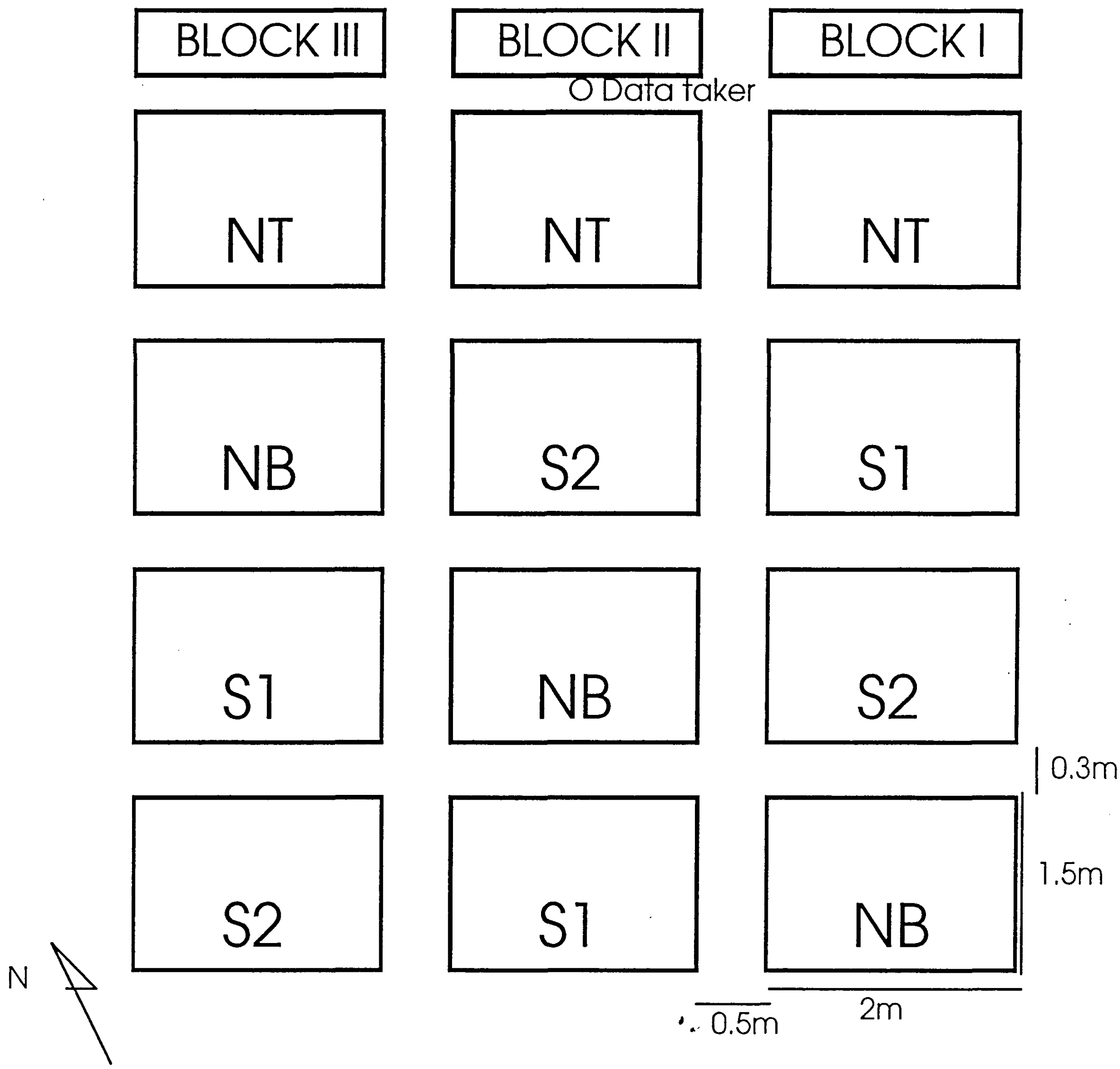
Appendices

Appendix 1. Experimental design and plot lay-out of Warialda Experiment



Appendix 2. Experimental design and plot lay-out of Laureldale Experiment