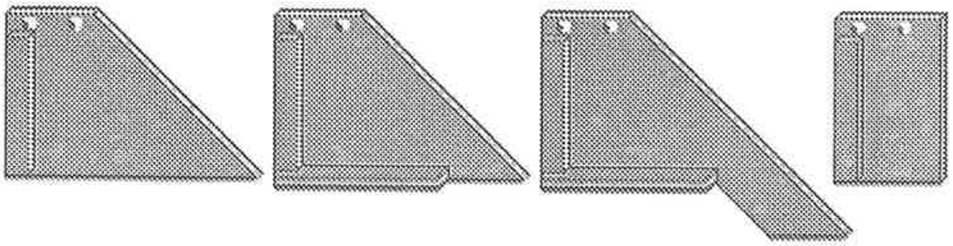
THE EFFECTS OF NARROW SEEDING POINTS ON SOIL STRUCTURE, SEED PLACEMENT AND CROP GROWTH IN DIRECT DRILLING SYSTEMS



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LIST OF ABBREVIATIONS AND SYMBOLS

α	rake angle (degree).
θ_a	water content at air filled porosity (m^3 m^{-3})
θ_{afp}	water content at air filled porosity (m^3 m^{-3})
θ_{fc}	field capacity water content (m^3 m^{-3})
θ_{fc}/θ_s	upper limit of available water content (m^3 m^{-3})
θ_m	mass water content (kg kg^{-1})
θ_{nlaw}	non-limiting available water (m^3 m^{-3})
θ_{paw}	plant available water (m^3 m^{-3})
θ_S	saturated water content or total porosity (m^3 m^{-3})
θ_v	volumetric water content (m m^{-1})
θ_v/θ_s	degree of saturation
θ_{wp}	wilting point water content (m^3 m^{-3})
θ_{wp}/θ_s	lower limit of available water content (m^3 m^{-3})
ρ_b	bulk density (Mg m^{-3})
ρ_d	particle density (2.65 Mg m^{-3}).
ρ_w	water density (0.998 Mg m^{-3}).
45-0-0	narrow seeding point with 45° rake angle
45-W-0	narrow seeding point with 45° rake angle and wings
45-W-S	narrow seeding point with 45° rake angle, wings and blade
90-0-0	narrow seeding point with 90° rake angle
ANOVA	analysis of variance
C. Sand	coarse sand
CL	clay loam
CL94	clay loam site in 1994
CL95	clay loam site in 1995
CRC	Cooperative Research Centre (Soil and Land Management)
CT	conventional tillage
d	sowing depth (mm)

D M	dry matter
d_c	critical depth (mm)
E	emergence as a proportion of total seed sown (%)
F. Sand	fine sand
f	forward distance of soil failure (mm)
fc	field capacity (m^3 m^{-3})
K	uniformity of emergence
LSD	least significant difference
m	emergence delay
M	total emergence
m'_w	mass of water retained in the soil after 48 hours of drainage (kg)
m_s	oven dry mass of soil in the core (kg)
m_w	mass soil water content
NS	not significant
P_E	penetration energy (kJ m^{-2})
P_r	penetration resistance (MPa)
$P_{r\ critical}$	critical penetration resistance (MPa)
$P_{r\ i}$	i th penetration resistance (MPa)
r	forward distance of soil failure (mm)
RCBD	randomised complete block design
s	side crescent (mm)
SE_p	pooled standard error
SL	sandy loam
SL93	sandy loam site in 1993
SL94	sandy loam site in 1994
SL95	sandy loam site in 1995
TDR	time domain reflectometer
TTT	tillage test track
w	tool width (mm)
wp	wilting point
z_i	i th depth interval (mm)

ABSTRACT

Extensive studies in tillage research have revealed that conventional cultivation practice in Australia has caused damage to soil structure producing water logging, erosion, hardsetting and crusting, especially in those soils with weak structure. Following adoption of conservation tillage practices there has been development of appropriate equipment that allows a marked reduction in tillage requirements while still obtaining profitable and sustained crop production.

The interest in narrow points by farmers is driven by their interests to provide a suitable environment for seed placement and establishment, but with minimal disturbance and damage to soil. This has resulted in many manufacturers of tillage tools now supplying a range of narrow points in addition to the many variations in shape developed and used by farmers. However, it is still unclear how the shape of narrow sowing points affects seedling emergence and the early growth of crops and particularly under a range of soil conditions. The effect of sowing implements on soil physical properties is not well known. In particular, little information is available on the effects of narrow point shapes on soil structural quality.

Four narrow sowing points which embodied fundamental design principles (45 and 90° rake angles, with and without wings, and one with extended blade below sowing depth plus wings.) but which also represent some of the features in commercial use by farmers were constructed. The efficiency and effectiveness of the sowing points is evaluated by extent of draft force vertical force, soil failure, critical depth and wear rate. A special Tillage Test Track facility were used for this purpose.

The selected points with respect to seed placement and emergence rate were compared in the laboratory (soil bins) and in the field. In the field experiments a conventional cultivated treatment was included by using a control point following with two passes of a standard sweep cultivator. Crop establishment, crop growth and yield were compared in 1993 in the field on a sandy loam soil and in 1994 at two soil types (sandy loam and clay loam) by using the selected sowing points and conventional treatment. The 1994 experiments were repeated in 1995 to obtain the yield and its components.

The effects of these points on general soil physical properties including bulk density, pore structure, penetration resistance, soil temperature and water content were examined and compared. Pore structural attributes (porosity, pore surface area per unit volume of soil and mean pore size) were obtained for the sowing points and conventional treatment by using the resin impregnation, photography and image analysis methods and compared. A motorised cone penetrometer with cone of 6.25 mm diameter and 30° internal angle was used to measure soil strength in the field. To measure the soil temperature, a set of thermocouples with a data logger was installed in the field experiments and used to read the output voltages from the thermocouples at frequent intervals. The soil volumetric water content was monitored to a depth of 300 mm during the period between sowing to anthesis using a time domain reflectometer (TDR).

The effects of the points on soil structural quality of a seedbed after sowing wheat with one of the five different sowing points were measured on both soils in the field. Soil structural quality was assessed in terms of plant available water and air-filled porosity at field capacity. The

effect of soil strength development on drying was assessed in terms of the limitations imposed on total plant available water and the consequent moderation to assessed structural quality.

The sowing point with wings and extended blade caused slower speed of wheat emergence which was the result of greater sowing depth variation compered to the other sowing points. Despite this better early plant growth and higher grain yields were obtained from this point in most of the cases. This sowing point operated deeply to decompact soil up to 120 mm and ameliorate tillage pans or hard layers to this depth. Lower soil bulk density and penetration energy values indicating more soil disturbance were found with this point than other points. A warmer seedbed was created by using this point and the conventional cultivated treatment from germination to the end of emergence compared to other treatments. Generally the point with an extended blade produced a seedbed with more favourable soil physical properties (greater porosity and pore surface area) and improved pore attributes (total porosity and surface area of pore space) to a greater depth than other treatments.

Using the sowing point with wings and extended blade which loosened the soil below the seedbed produced good structure quality at all soil depths to 150 mm on the sandy loam soil and in 50 mm soil depth on the clay loam soil. However, if soil strength limitations to water availability were considered, soil structural quality in soil below the sowing points was poor to very poor for all treatments except for the point with the extended blade, which remained good to moderate. The point with wings but without an extended blade produced the next best physical quality in the seedbed particularly at a soil depth of 50-100 mm. This point also gave better early plant growth and grain yield compared to other points except the point with wings and extended blade.

STATEMENT OF ORIGINALITY

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

To the best of author's knowledge this thesis contains no material previously published or written by another person except where acknowledgment is made in the text. I certify that any help received in preparing this thesis, and all sources used, have been acknowledged in this thesis.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Seyed-kazem Shahidi

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CHAPTER 1

INTRODUCTION

Extensive studies in tillage research have revealed that conventional cultivation practices in Australia have caused damage to soil structure producing water logging, erosion, hardsetting and crusting, especially in those soils with weak structure (eg. Gradwell and Arlidge, 1971; Hughes and Baker, 1977; Francis et al., 1988; Haynes and Knight, 1989). As far back as 1945, Russell (1945) was saying that intensive tillage was not essential for seedbed preparation and crop establishment. During the 1980's researchers and leading farmers began to respond to Russell's philosophy because of the obvious soil degradation that was occurring. As a consequence a conservation tillage ethic has evolved in Australia.

Following adoption of conservation tillage practices there has been development of appropriate equipment that allows a marked reduction in tillage requirements while still obtaining profitable and sustained crop production. Over the years in Australia, for example, the number of tillage operations used by farmers for seedbed preparation has declined greatly. Now direct drilling, is used in which soil disturbance is limited to that necessary to place seed in the soil (Jones et al., 1977). The decline in importance of the plough in tillage systems could have as great an impact on agriculture in the future as intensive cultivation has had in the past. However, continued research and application of new technology in direct-drilling will be required for this to happen.

In the past 30 or 40 years many new systems have been discussed or publicised but have not been widely adopted, often for technical reasons (eg. difficulty in handling crop residues).

Direct drilling is continuously evolving as a result of research and development and there is an urgent need for this trend to continue.

One of the conservation tillage (direct-drilling) components is the use of narrow sowing points. The interest in narrow points by farmers is driven by their interests to provide a suitable environment for seed placement and establishment, but with minimal disturbance and damage to soil. This has resulted in many manufacturers of tillage tools now supplying a range of narrow points in addition to the many variations in shape developed and used by farmers. There have been some attempts to compare narrow sowing points which showed that winged points were superior to others by increasing soil disturbance, creating fracture planes below the seed groove, and reducing soil strength (Godwin and Spoor, 1978 ; Chan and Mead, 1990). Rainbow et al. (1992) tested the effects of seeder point type in different machine configurations and soil types. They concluded that spear points significantly increased plant emergence and early growth compared with all other narrow point types on all soils. However, it is still unclear how the shape of narrow sowing points affects soil physical properties, seedling emergence, the early growth and crop yield, particularly under a range of soil conditions.

Aims and outline of this study

The hypothesis of the work reported here is that narrow seeding points of appropriate shape can be used to improve soil physical properties, seed placement, establishment, early vigour, better plant growth and increased crop yield.

The aim of this study was to investigate to what extent different shapes of narrow sowing points affect seed placement and physical properties of soils. The effect of the soil on the sowing points is also of concern and is addressed by measuring draft force requirements and wear rates of selected points.

In order to achieve these aims the study had these specific objectives:

1. Selection and construction of four narrow sowing points which embody fundamental design principles but which also represent some of the features in commercial use by farmers.
2. Evaluation of these points in terms of draught requirements and wear rates.
3. Comparison of the points in direct drilling systems, with respect to seed placement, emergence, crop establishment, crop growth, yield, and their effects on soil physical properties including bulk density, pore structure, penetration resistance, soil temperature and water content.

Structure of the Thesis

This thesis is structured as follows:

Chapter 2 is a literature review which compares conventional cultivation with conservation tillage and their effects on soil physical structure, chemical properties and soil biology. The review then focuses on the development of seeders for direct drilling and narrow seeding points.

Chapter 3 covers the design of selected sowing points and reports on an evaluation of their force requirements (draft and vertical forces), wear rate, soil failure and critical depth.

Chapter 4 reports on the effect of sowing points on seed placement (laterally and vertically), depth of soil cover over the seed and seedling emergence in a laboratory environment.

Chapter 5 examines the effects of these points on general soil physical properties.

Chapter 6 evaluates the effects of the points on soil physical quality defined in terms of non limiting available water.

Chapter 7 reports the effects of the sowing points on seedling emergence, crop growth and crop yield.

Chapter 8 integrates the results and summarises the conclusions from all the experimental work and addresses the hypothesis that the shape of seeding points affect seed placement, soil physical properties, crop establishment, crop growth and crop yield.

CHAPTER 2

REVIEW OF LITERATURE

2.1 The effects of direct drilling and use of narrow seeding points on soil conditions and crop growth.

2.1.1 Introduction

The continuing growth of world population has placed growing demands on food production systems. Hand tools and later power implements have been a key part of the struggle for more efficient food production for a long time.

Early humans learned that food supplies were more accessible when they brought production nearer to their domain rather than going in search of it. They also identified the need to place seeds under the soil surface using a stalk to dig holes in the soil. Therefore the first agricultural tools came into existence. Little by little, they started to combat pests and to irrigate their crops when needed. Domesticating animals and using their power, also increased man's capability to cultivate land and produce more food. The introduction of steam to power tractors in 1868, followed by internal combustion engines for tractors in the early 1900s heralded the horsepower era that allowed the development of huge tractors with the capability of pulling the large tillage implements, which are in use today.

In recent decades the need for new land, crops, machinery and greater power requirements, has become even more demanding as the world population grows. Together with better cultivation, fertilisers, enhanced pest control and expanded irrigation, agriculture has increased total food production dramatically in the past century.

In the past 30 or 40 years many new systems have been discussed or publicised but have not been widely adopted, often for technical reasons. Direct drilling is continuously evolving as a result of research and development and there is an urgent need for this trend to continue.

2.1.1.1 Aims of the review

The purpose of this literature review is to determine the effects of tillage with tines on:

1. Soil biological, chemical and physical properties.
2. Establishment, early growth and final yield of dryland crops, particularly wheat.
3. Development of narrow seeding point design in relation to minimising tillage of structurally weak soils.

2.1.2 Conventional cultivation

2.1.2.1 Introduction

Tillage modifies aggregate and pore size distribution and rearranges the soil surface. Houghton and Charman (1986) defined "cultivation" as mechanical preparation of the soil for the growing of crops. Conventional tillage systems vary greatly but generally consist of autumn or spring ploughing with two to four discings before planting. Post emergence cultivation was also routinely used until the late 1940s to control weeds. Until the mid 1950 s, intensive tillage produced the best yields for most farmers. In the northern hemisphere soil was tilled in autumn to absorb moisture over winter, and the bare dark surface facilitated warming in spring. During the same period, secondary tillage and cultivating operations increased to as many as five discings before planting and few machinery passes during crop growth.

In Australia, where soil is inherently of low fertility, and farming systems are mostly rain-fed, tillage comprises cultivations, including the soil disturbance associated with the sowing operation, and treatment of crop residues to allow the machinery to operate (Cornish and Pratley, 1991). Dryland farming systems comprise crops, pastures and fallow periods with the fundamental aim of making efficient use of limited water. Cultivation and the burning of crop residues have been an integral part of these systems in the past.

2.1.2.2 General effects of cultivation on soils

Tillage inverts, pulverises, and mixes the surface soil profile to include plant residues and animal materials that have accumulated on the soil surface since it was last disturbed. This has the effect of loosening compacted layers caused by field operations during the growing season, as well as crusts, hardsetting or consolidation caused by rain or irrigation. Properly used, tillage can be an important restorative tool that can alleviate soil related constraints in achieving potential productivity or utility. However the benefits may only be short lived, because inappropriate tillage causes soil structural degradation.

Under wheat cropping in Australia, cultivation has been regarded as the major cause of soil structural degradation (Greacen, 1983). Soil degradation, the decrease in soil's actual and potential productivity owing to land misuse, is a major threat to agricultural sustainability and environmental quality. The degree of soil degradation depends on the soil's susceptibility to degradative processes, land use and land management. Tillage can play an important role in

the dynamic processes governing soil degradation. A number of researchers (Gradwell and Arlidge, 1971; Hughes and Baker, 1977; Francis et al., 1988; Haynes and Knight, 1989) have confirmed the deterioration of soil physical properties with cultivation. Cotching et al. (1979) reported serious concern that intensive cultivation in some agricultural soils may lead to a deterioration in soil structure and other physical properties of soil and decrease crop yields as a result.

Tillage is implicated in the progressive decline of soil structure over a long period of time (Dalal and Mayer, 1986). Harte (1984, 1988) observed higher bulk density and decreased aggregate stability after extended periods of cultivation for a range of red-brown earths, calcareous red earths, grey and brown clays and sandy loams in northern New South Wales.

Repeated cultivation at a fixed depth can cause hardpans to develop (Ellington, 1986). These compacted layers constrain root growth and reduce the ability of plants to take up nutrients. They also impede drainage of water down the profile, which may cause water-logging, and therefore decrease the yield of crops or pastures. Tillage has been shown to reduce rainfall infiltration into loamy soils, and increase suspended sediment mobilisation (Bligh, 1984). Severe restriction of microbial activity in soil increases the effect of physical disruption of aggregates associated with cultivation (Tisdall et al., 1978).

Research shows that when virgin soils are brought into cultivation and cropped, organic matter contents generally decrease rapidly. In long term studies, covering 60- 80 years, carbon (C) and nitrogen (N) losses due to cultivation from a Canadian Prairie soil ranged between 20-60 % and 40-60 %, respectively (Voroney, et al., 1981). Russell and Williams (1982) also observed up to 60 % loss of organic matter from Australian surface soils as a result of cultivation. In the semi-arid tropical regions of Australia, C losses averaged 36 % and N losses averaged 36 % in 20-70 years of cultivation (Dalal and Mayer, 1986). Recent studies have also shown reductions in soil physical, chemical and biological fertility with continuous cultivation of red-brown earths in South Australia (Fawcett et al., 1992).

2.1.3 Features of direct drilling

2.1.3.1 Introduction

The decline in soil physical quality arising from conventional cultivation prompted agricultural scientists to consider methods of crop production that involved less soil cultivation. The development of herbicides in 1955 allowed chemical spraying to replace tillage as a means of controlling weeds.

Intensive tillage to prepare a seedbed was shown to be unnecessary for crop establishment by Russell (1945). He showed that early weed control was important in achieving satisfactory crop yields. Ross and Cox (1981), and Ross and Hughes (1985) suggested the need to use alternative cultivation practices, including direct drilling, in order to limit mechanical disturbance of the soil. The least tillage is that required for seed placement. Reduced tillage has the potential to maintain better soil structure for intensive and sustainable agricultural cropping. To enhance soil quality and therefore increase the potential yield of the product, continued effort is needed to identify tillage methods and appropriate equipment that will augment productivity and soil resilience and stability.

2.1.3.2 Aims of direct drilling

Most commonly, farmers reduce the number of cultivations before sowing the crop and use herbicides to control weeds. The adoption of direct drilling has been shown to control soil erosion, enhance crop performance, and use energy more efficiently. Direct drilling is considered to be an integral component of sustainable cropping systems that maintain resources, such as soil and water, while providing an adequate and economical level of production, both now and for generations to come (Hoare, 1992).

2.1.3.3 Types of direct drilling

Direct drilling was defined by Phillips (1973) as the introduction of seed into untilled soil in narrow slots with trenches of adequate depth and width for seed placement. Many terms are used to describe direct drilling such as conservation tillage, no-tillage, zero tillage, mulch tillage and others. All refer to practices where a crop is sown into untilled soil with reliance on herbicides to control weeds. However, in this review the term of direct drilling is used for all related terms.

2.1.3.4 Weed control

Reduction in tillage frequency and soil disturbance by tillage has been achieved through the introduction of modified tillage implements and greater use of herbicides to replace tillage. Replacing tillage for weed control with herbicides became possible following the discovery of the herbicidal properties of the bipyridyls in 1955 (Jeater, 1963). Tillage was therefore optional for crop establishment in some soils where weed control was the main purpose of those tillage operations (Halpin and Bligh, 1974).

Early success with minimum tillage techniques prompted the question of whether cultivation was needed at all. In the late 1950s, two multinational chemical companies, ICI (initially) and Monsanto (later) in England developed knock-down herbicides (Bipyridyls and Glyphosate respectively) which could be used to control weeds before sowing. These companies worked with many research organisations worldwide to develop the direct drill system, which required no presowing cultivation (Steed et al., 1994).

The increased use of pesticides in the direct drilling system has raised questions relative to its environmental impact. However in countries where pesticides are normally used in conventional systems, only contact herbicides are added to the system. Technology of application, selection of herbicides, crop rotations and other information must be adapted by the grower using the direct drilling concept.

2.1.3.5 Fuel savings

Direct drilling results in fuel savings obtained from reduced land preparation operations, compared to conventional cultivation. Peak demands for fuel on the farm occur during land preparation and planting.

2.1.4 Soil physical properties

Direct drilling will likely continue to be one of the most important practices to protect the soil, preserve soil water and reduce energy consumption in cropping systems. The major advantages of the direct drilling system have been reported widely. Ellington and Reeves

(1978) gave a summary of the direct benefits that they had observed from direct drilling in north-east Victoria in Australia. These included reduced land preparation time, improved timeliness of sowing and greater area of crop sown within a given time, better soil trafficability in wet conditions, more land available for grazing prior to sowing, reduced requirements for machinery, capital, labour and energy, improved soil structure due to less compaction from less traffic and from increased organic matter close to the surface, and reduced erosion hazard.

However, these benefits of direct drilling are not necessarilyy always realised. For example, as discussed later in this review, direct drilling may result in poorer soil physical properties compared to that observed immediately after tillage.

One of the reasons for the adoption of direct drilling is the expectation that soil physical properties will improve in the long term. However, in the short term direct drilling is often associated with increased bulk density, reduced air-filled porosity and increased soil strength when compared with conventional tillage (Gantzer and Blake, 1978; Hill and Cruse, 1985; Kay et al., 1985; Heard et al., 1988; Hammel, 1989; Larney and Kladivko, 1989 and Hill, 1990).

2.1.4.1 Bulk density and porosity

In numerous experiments bulk density was shown to be greater in the topsoil with direct drilling than with cultivation (for example Ellis et al., 1977; Pidgeon and Soane, 1977; Ehlers et al., 1983; Mielke et al., 1986; Culley et al., 1987; Carter et al., 1990; Chang and Lindwall, 1992; Edwards et al., 1992; Pierce et al., 1992; Mahboubi et al., 1993). Francis and Knight (1993) stated that bulk density was greater under no-tillage at 0-150 mm soil depth on the Wakanui silt loam soil. In some instances there have been no differences in bulk density in the topsoil between tillage treatments (Blevins et al., 1983; Campbell et al., 1989; Chang and Lindwall, 1989; Francis and Knight, 1993). By contrast, in Australia on a duplex soil prone to consolidation under cultivation, Carter and Steed (1992) found a lower bulk density with direct drilling than with conventional cultivation.

Differences in cultivation systems affect total soil porosity. Depending on soil type, direct drilling, can increase or decrease macropore volume relative to conventional tillage practices (Carter, 1988; Chan and Mead, 1989; Logsdon et al., 1990). Gregorich et al. (1993) showed that soil porosity was consistently lower under direct drilling treatments in the 0-250 mm soil depth. There were also significant differences in porosity between conventional cultivation and direct drilling at the 100-150 mm soil depth. The decrease in porosity over the 200-300 mm depth may reflect the compaction resulting from a combination of traffic and overburden pressure. Herman and Cameron (1993) found that minimum tillage resulted in a greater volume of 0.2-60 μm diameter pores. The volume of pores in this size range is important as it represents the available water storage capacity of the soil. Francis and Knight (1993) indicated that the macropore volume was significantly less in direct drilled soil than in conventionally tilled soil, but only at 0-20 mm depth, with no difference between treatments at greater depth.

Conservation tillage practices, such as direct drilling, can indirectly influence infiltration capacity through changes in pore space geometry (Klute, 1982). Macropore continuity is enhanced or is more efficient, under direct drilling compared with tilled soils, regardless of differences in macroporosity (Ball et al., 1988; Carter, 1988). Surface porosity is commonly lower with no tillage although the amount and connectivity of macropores may be greater than in cultivated soils, with resultant improved drainage characteristics (Ehlers, 1975).

2.1.4.2 Soil strength

Soil strength is a critical physical factor controlling shoot and root penetration. Critical values of penetration resistance at which root growth is inhibited vary, depending on the crop species. Ball and O'Sullivan (1982) reported that emergence of spring barley was reduced in soils with cone penetrometer resistances greater than 2.5 MPa. Weaich, et al. (1992) reported that penetrometer resistance values in excess of 1.1 MPa were inhibitory to maize shoot growth and by 2 MPa, all shoot growth had ceased. Taylor and Gardner (1963) found that the percentage of cotton taproots penetrating through cores decreased progressively as penetrometer soil strength increased until, at about 3 MPa strength, root penetration ceased. In general, root elongation in most species is reduced by 50 % when penetration resistance is 0.7 to 1.5 MPa and is restricted completely at penetration resistances greater than 3 (Taylor and Gardner, 1963) to 4 MPa (Kirkegaard, 1990).

Many plant experiments inadvertently alter soil strength along with manipulation of the desired variable. Taylor et al. (1966) indicated that experiments imposing tillage, salinity or compaction are especially vulnerable to incidental changes in soil strength. These changes, if they are of sufficient magnitude, affect plant growth.

There is increasing concern that long-term continuous conservation tillage may cause increased compaction and soil strength and be detrimental to shoot and root growth and crop yield. Conventional tillage over time leads to an increase of soil strength of both topsoil and subsoil layers as well as to further deterioration of other structural and physical properties (Domzal et al. 1993). After conventional cultivation, structurally weak soils tend to lose structural porosity during wetting and to harden during drying with resulting high strength which can impede root development since alternative growth pathways available in structured soil have been lost (Ley et al., 1995).

Increased surface soil strength under direct-drilled regimes has been reported. Francis et al. (1987) showed significantly greater soil strength in direct drilling than conventional cultivation at all soil depths in silty loam soil. These conclusions confirm the finding of others (Soane and Pidgeon, 1975; Ellis et al., 1977; Ball and O'Sullivan, 1982). However, the effect of the higher soil strength on root density is variable, depending on soil structural conditions. Well structured soils tended to show less root restrictions due to high strength compared to poorly structural soils (Finney and Knight 1973; Ellis et al. 1977; Hamblin and Tennant 1979; Ehlers et al. 1980).

Godwin and Spoor (1978) showed that there is a critical working depth for all narrow tines below which soil strengthening occurs rather than soil loosening. They showed that the attachment of wings to the tine foot increased soil disturbance particularly at depth, and reduced soil strength allowing more effective soil rearrangement. Chan and Mead (1990) compared several points and showed that winged points were superior to standard combine points for creating fracture planes below the seed groove and loosening the soil. However, there is a lack of knowledge in the literature on effect of direct drilling systems with narrow seeding point on soil physical properties particularly on soil strength.

2.1.4.3 Erosion

The most important advantage in adopting direct drilling is reduced soil erosion. Direct drilling practices favour the retention of crop residues on the soil surface which often results in a decrease of soil erosion. The least risk of erosion is obtained by direct drilling as soil structure is dependent on organic binding agents produced by soil micro-organisms (Tisdall and Oades, 1982). Bligh (1991) found that direct drilling crops using narrow points reduced rill erosion.

Studies have been conducted worldwide comparing the magnitude of soil losses from direct drilling and conventional tillage systems. McGregor et al. (1975) found that on a highly erodible soil in Mississippi, soil erosion was reduced from 17.5 ton ha^{-1} to about 1.8 ton ha^{-1} when a zero-tillage system was used. Also Triplett and VanDoren (1977) reported that direct drilling reduced soil erosion by as much as 50 fold in their studies in the USA.

In Australia, Freebairn (1986) showed that soil erosion from direct drilling areas averaged 2 ton ha^{-1} $year^{-1}$ compared to 30-60 ton ha^{-1} $year^{-1}$ from bare fallow. Bligh (1994) reported that soil loss averaged 3.6 ton ha^{-1} under traditional tillage from approximately two-hectare contour bays at Chapman in West Australia. Whereas an average of only 50 kg ha^{-1} of soil was eroded after direct drilling on intervening contour bays using 50 mm-wide, 'inverted T'-shaped points. Edwards (1980) observed spectacularly reduced runoff under minimal soil disturbance cropping whilst Freebairn and Wockner (1986) also measured lower water erosion with direct drilling, compared to conventional tillage. Sowing crops with minimal soil disturbance reduced surface runoff and suspended sediment loss after three seasons (Bligh, 1991).

In experiments in Mississippi under direct drilling, where crop residues remained on the soil surface, compared to tilling, soil losses from water erosion were reduced by 85 % (McGregor et al. 1975), but on gently sloping sites, where erosion was not a severe problem, erosion rates after direct drilling treatments were little different from those after ploughing (Lal et al. 1989). Soil cover can reduce soil erosion by reducing runoff volume through stubble protecting the soil surface, thus reducing aggregate breakdown, compaction of the surface by raindrops and loss of transmission pores (Loch, 1989). Reduced soil disturbance and increased organic matter from remaining crop residues on the soil surface under direct drilling is likely to lead to an improvement in soil structure over time (Hamblin, 1980).

2.1.4.4 Plant water availability, water uptake and storage

Blevins et al. (1971) conducted studies to determine soil moisture under direct drilling and conventional tillage using corn as the growing crop. These studies indicated that under direct drilling conditions, decreased evaporation and greater moisture storage resulted in a water reserve which could carry the crop through periods of short-term drought without detrimental moisture stress developing in the plants. Hamblin and Tennant (1979) and Hamblin et al. (1982) reported that direct drilled wheat in loamy sand in Western Australia had lower water use (1.78 mm water day $^{-1}$) compared with wheat under cultivation (2.30 mm water day $^{-1}$). They concluded that the higher value under cultivation in the subsoil indicate more water was used by roots in this treatment.

Wiese and Unger (1974 reported increased efficiency of irrigation using a direct drilling system for wheat and grain sorghum production) in Texas: between 65 and 130 mm of irrigation water per hectare was conserved in comparison to cultivated tillage. Such an increase in efficiency could become more important as energy costs for irrigation increase and available irrigation water supplies are diminished a major issue emerging in many parts of world.

2.1.4.5 Soil temperature

Soil temperature affects on crop emergence are very predictable, and were often found to override any other factors in emergence studies (De Jong and Best, 1979). Hay (1977) suggested that soil temperature was a major factor determining the temperature of the wheat seedling apex and hence leaf extension rate. Similar results have been found with maize (Watts, 1971). Lindstrom et al. (1976) stated that temperatures of approximately 4, 33 and 23 °C are typical minimum, maximum and optimum soil temperatures for wheat germination, respectively.

Tillage effects on soil thermal properties have been considered in only a few field studies. Aston and Fischer (1986) showed that the soil temperatures in a conventionally cultivated treatment were warmer during the day and cooler during the night than in direct drilled treatments. Fortin (1993) recorded differences in seed zone temperature between tillage treatments. He concluded that temperature maxima were higher for conventional tillage than for the direct drilling treatment.

Potter et al. (1985) pointed out that soil thermal properties in the row varied between tillage systems but residue cover seemed to have the dominant effect on soil temperature. Lal (1973, 1974) demonstrated the pronounced effect of mulch and direct drilling on soil temperatures in Western Nigeria. Bare and tilled plots exhibited higher temperatures during the day and larger daily amplitudes. Hay (1977) showed that stubble mulch on the uncultivated soil surface (as a result of direct drilling) insulated the surface soil layers from large temperature fluctuations that occurred with tillage, and this resulted in lower frequency of freezing, but fewer hours above 5 °C. Taylor and Jackson (1965) stated that the heat capacity of natural soils is strongly dependent upon soil porosity and water content.

2.1.5 Soil chemical properties and biological activity

Hallsworth (1969) defined soil fertility as the ability of the soil to produce a commodity that has commercial value. Soil organic matter can influence many soil quality properties including aggregate stability. For most mineral soils, structural stability decreases when soil management methods reduce organic matter content (Greenland, 1981). However, there have been very few studies in Australia in which effects of conservation tillage (direct drilling) on soil chemical properties have been assessed (Robson and Taylor, 1987).

2.1.5.1 Soil nitrogen

Declines in soil nitrogen with wheat-fallow rotations were much greater for tilled soils than for uncultivated soils (Lamb et al., 1985). Soil nitrate levels are often reported higher where the soil is cultivated before sowing rather than left undisturbed (Thomas et al., 1973; Kohan et al., 1966; Dowdell and Cannell, 1975; Blevin et al., 1977). On the other hand, Reeves and Ellington (1974) showed that nitrate levels can be lower in soil that is cultivated before sowing, compared to sowing into undisturbed soil. Similarly, Ellington and Reeves (1978) stated that mean values of soil mineral nitrogen at seeding were 19.0 and 18.3 mg kg^{-1} for cultivation and direct drilling respectively.

2.1.5.2 Soil organic carbon

Larson and Pierce (1991) regarded soil organic carbon as the most important indicator of soil quality and productivity. Depletion of soil organic carbon is associated with an increase in soil compactability, deterioration in soil structure (Soane, 1990) and loss of nutrients.

Conventional cultivation techniques cause a greater reduction in soil organic matter compared to direct drilling systems (Agenbag and Maree, 1989; Carter, 1992). Generally cultivation causes a decline in soil organic carbon content because the amount of organic materials returned to the soil decreases and decomposition rates of organic materials increases (Dalal and Mayer, 1986). Wood and Edwards (1992) found soil organic carbon to be over 60% greater after 10 years of conservation tillage and a relatively high fertiliser input cropping rotation, compared to increases in organic carbon of only 23% in a low-input crop rotation in South Australia (Smettem et al., 1992). In the central Great Plains of USA, after 16 years at a site previously in native pasture, the soil organic carbon content of the top 100 mm in the no-tilled soil was about 80 % of the original level compared with 60 % for tilled soil (Follett and Peterson, 1988). In the south-eastern USA, at Alabama, on a site that had been conventionally tilled for more than 50 years, after 10 years of direct drilling, organic matter increased in the 150 mm surface layer of soil from 10 to 15.5 g kg^{-1} - but was unchanged after continued tillage (Edwards et al., 1992).

2.1.5.3 Soil fauna

Earthworms often have a beneficial influence in soil structure by improving aeration and producing stable aggregates. Edward and Lofty (1972) reported that earthworms brought a considerable quantity of subsoil to the surface and took down decaying organic matter into the soil. Moreover, they created channels which favoured root elongation and helped to improve drainage. Also they reported that the total earthworm population was greater in direct drilled plots than in tilled plots.

Carter et al.(1994) pointed out that the absence of tillage allows the benefit of certain biological processes to occur, such as the formation of stable and continuous macropores by earthworm tunnelling and the restoration of vertical pathways for water movement. Thus under conservation tillage the greater populations of earthworms that form extensive burrows recorded in the surface 100 mm of soil compared with conventional tillage, would have been a major factor in increasing water penetration (Carter et al., 1994). Depending on soil type, direct- drilling can increase or decrease macropore volume relative to conventional tillage practices (Carter 1988; Francis et al. 1988; Chan and Mead 1989; Logsdon et al. 1990). In most cases, macropore continuity is enhanced or more efficient under direct drilling compared with tilled soils, regardless of differences in macroporosity (Ball et al. 1988; Carter 1988). This is attributable to the maintenance of a continuous pore network throughout the soil profile and the cumulative effect of the macrofauna, especially earthworms, on macropore formation in the absence of tillage (Zachmann et al. 1987).

Studies have shown that the microbial biomass of soil under direct drilled conditions was significantly greater than that of soil under conventional cultivation (Lynch and Panting, 1980). Bligh (1994) pointed out that earthworm numbers and size may increase after several seasons under direct drilling. He reported that by the fourth season in a cereal / lupin rotation, there were four times as many earthworms under direct drilling than traditional tillage treatments and the earthworms were twice as large, on average, in mid-August, 1992. There were 500,000 earthworms per hectare under traditional tillage compared with two million per hectare under direct drilling.

2.1.6 Crop establishment and root growth

The use of a narrow seeding point may benefit plant establishment under more adverse soil conditions (Mead et al., 1992).

Optimum crop emergence is essential to achieve maximum crop yields, particularly in direct drilling systems (Tessier et al. 1991). Finlay et al. (1994) found that emergence was riskier when the direct-drill placed seeds onto untilled soil compared with tilled soil. hey concluded that a system of direct drilling which increases the drainage and storage of water and which loosens the soil immediately below the seed would increase emergence on hardsetting soils.

Important factors determining establishment and early growth of crops are depth of sowing, shape of soil opening implement and soil physical condition after sowing.

2.1.6.1 Sowing depth

Lateral variations of seed placement may not effect seedling establishment (Barr, 1981) but seeding depth is one of the most critical factors in which the seeding operation can affect crop yields. Radford (1986) found that a sowing depth of about 55 mm was optimum for wheat establishment when no rain fell between sowing and emergence.

Control of sowing depth is required for optimum seed emergence. Campbell (1981) suggested that sowing depth and its control is important for pasture legumes to achieve high emergence counts. Choudhary et al. (1985) showed that when seeds were sown too deeply, all germinated but some failed to emerge. On the other hand, seeds sown at shallower depths than the optimum were observed to have remained ungerminated because of lower moisture in the surface layer. Observations of uneven seedling emergence and variations in the rates of seedling emergence when comparing various sowing points (Choudhary and Baker, 1980) suggested that seeds were being placed at a range of depths, some of which were not optimum for establishment. It is therefore, possible that some of the reductions in seedling emergence counts which have been observed under favourable conditions and have hitherto remained unexplained, might be related to depth of seed placement within the opener groove.

2.1.6.2 Shape of seeding points

The shape of the seeding points is likely to play an important role in promoting early crop growth and vigour. For example Baker (1976), Choudhary and Baker (1982) and Baker and Mai (1982) reported that sowing point designs have significant effects on seedling emergence. Baker (1976) compared three seeder openers following coulters in tillage bins under controlled moisture conditions. An experimental winged opener achieved significantly higher establishment of wheat in a fine sandy loam soil than either a triple-disc or a hoe opener. Rainbow et al. (1992) tested the effects of seeder point type in different machine configurations and soil types. They concluded that wide 200 mm points maximised emergence and early plant growth rates on all soil types. Spear points significantly increased plant emergence and early growth compared with all other narrow point types on all soils. Lindwall and Anderson (1977) compared five seeding machines direct drilling rotations over a 7-year period under various conditions of residue and soil compaction. Hoe and shovel openers seemed to provide affective seed placement and optimum seed coverage throughout the tests, leading to the conclusion that some form of narrow strip tillage in the furrow may be necessary to assure proper seed placement and germination and to ameliorate the growth retarding effects of hard soils. Ward and Norris (1982) also showed increased crop emergence in clay soils using the Power-Till compared with disc coulter-spear point-press wheel combinations. Bligh (1991) reported that direct drilling using 55 mm-wide narrow-winged points, without cultivating tines, achieved crop establishment comparable to conventional points in loamy soils in medium (greater than 350 mm) rainfall areas.

Choudhary and Baker (1981) pointed out that attempts to categorise point designs by measuring the in-groove micro-environment have been successful in relatively dry soils, but in moist soil and under favourable climatic conditions, only partial success has been achieved in relating crop emergence patterns to the in-groove micro-environments (Choudhary, 1981).

The majority of the work which has been carried out to date on categorising point designs has been concerned by measuring the seed emergence and crop establishment. Also there is some attempts on the calculation of soil and tillage tool behaviour has been concerned with the forces involved in causing the soil to fail. However, there is a lack of knowledge in the literature on point design concerning within the province of the engineering (the efficiency and effectiveness of tillage tools by the draft force, vertical force, lateral failure, critical depth and wear rate), biological (seed placement, establishment and crop yield) and effect on soil physical properties particularly on soil strength.

2.1.6.3 Soil physical conditions

Apart from the genetic character of the plant, soil factors such as moisture, temperature, aeration and soil strength can strongly influence early shoot and root growth of crops. Carns (1934) reported that roots were found flattened or growing in a distorted manner when they encountered severe physical restraints. In direct drilling, the early growth of cereal roots was reported to be usually restricted in their distribution down the soil profile. Apparently larger proportions of the root system than under normal cultivation were in the surface layer, but the total weight of the root systems was little affected (Barber, 1971).

A great deal of work has been published world-wide on the response of roots to soil physical properties and on possible means of ameliorating these conditions (eg. Taylor, et al.; 1966, Arkin and Taylor, 1981). Branching of roots was less when they encountered impedance and roots were often thickened and shortened (Forrestall and Gessel, 1955). Several research reports have shown that where increasing soil bulk density was associated with a decreased porosity, a decrease in root growth usually resulted (Zimmerman and Kardos, 1961; Phillips and Kirkham, 1962).

2.1.7 Crop root diseases

Tillage practice has been shown to have a significant effect on occurrence and severity of a number of cereal root diseases (Rovira, 1987) with the most significant and consistent effect relating to the increase in *Rhizoctonia solani* root rot following direct drilling (Rovira and Venn, 1985).

Rhizoctonia solani has been reported as a pathogen of cereals in Australia since 1928 (Samuel 1928; Samuel and Garrett 1932) and causes patches of poor growth in crops. The findings of Sumner (1977) and Sumner et al. (1981) that there was less *Rhizoctonia* root rot of peas following either subsoiling to a depth of 400-460 mm or tillage to 270-300 mm compared with using a disc to 100-150 mm has little relevance to Australian cereal growing areas, where cultivation for cereals varies from 50-100 mm and is generally conducted with either tines or discs. Damage from *Rhizoctonia* was found to be greatly reduced when soil was tilled to 200-250 mm deep compared with discing of soil to 50-70 mm (Papavizas and Lewis. 1979), although again such ploughing is not usually practical in Australian cereal growing areas. Weller et al. (1986) reported a greater incidence of patches due to *Rhizoctonia* in direct drilled crops than when sown following cultivation. This was the first report of losses due to this pathogen in the Pacific north-west of the United States.

Research in Western Australia by Jarvis (1984) indicated that it may be possible to modify direct drilling practices to reduce damage by *Rhizoctonia*. His experiments indicated the importance of soil disturbance and surrounding the seed with loose soil in reducing damage. The faster root growth in loose soil, higher day time soil temperatures near the surface, and the earlier photosynthesis with shallow sowing could all account for the reduced damage.

The timing and number of cultivation in relation to *Rhizoctonia* incidence were studied by Moore (1983) and MacNish (1985). Moore (1983) stated that one cultivation reduced *Rhizoctonia* patches, but two cultivations were necessary to eliminate the patches. MacNish (1985) reported that the area infected with *Rhizoctonia* in barley was reduced to the same level by a single cultivation 7 or 18 days before seeding as with two cultivations at 7 and 18 days. Jarvis (1984) found that by using a seed drill modified to cultivate 100 mm deep and seed shallow in one pass, disease patches were reduced and grain yields increased by 0.44 t ha^{-1} compared with direct drilling with a triple-disc drill. Even with a modified seed drill yields were 0.57 t ha^{-1} lower than those achieved with conventional cultivation. Direct drilling using modified narrow sowing points that disturbed the soil below sowing depth, such as the McKay modified lucerne point, significantly reduced *Rhizoctonia* root damage when compared to direct drilling with standard points (Roget and Jarvis, 1994). They also pointed out that the control of *Rhizoctonia* following direct drilling with modified points produced grain yields equal to those obtained following cultivation.

2.1.8 Effect of direct drilling on grain yield

2.1.8.1 Introduction

Many reports of yields produced by direct drilled crops compared to crops following conventional cultivation techniques have appeared in the literature. However, the yield comparisons of direct drilled crops with others were not consistent and varied from superior (Van Doren and Triplett, 1969) to equal or less than (Phillips, 1969), yields following conventional cultivation techniques.

Davis and Cannell (1975) reviewed reduced cultivation and direct drilling using sowing points in the U.K. and suggested that yields varied with soil and weather conditions as well as with agronomic experience with the newer techniques and poor performance of sowing points.

Freebairn et al. (1986) found that average yields of winter crops produced under direct drilling were 12 % higher than those following conventional tillage. Jarvis et al. (1986)

reported similar wheat yields under direct drilling using either a conventional combine or a triple-disc drill seeder on loamy soils under continuous cropping in Western Australia. On the other hand Hamblin et al. (1982) reported that on deep, yellow loamy sand at Wongan Hills, the conventionally tilled wheat crop yielded nearly 20 % more than the direct drilled crops.

2.1.8.2 Depth of soil disturbance

Schmidt and Belford (1994) pointed out that increasing depth of soil disturbance increased grain yields of wheat, particularly for depths of disturbance of 10 cm or greater. They found an average increase in grain yield of 3.2 kg ha^{-1} for every millimetre increase in tillage depth below 40 mm. Kirkegaard et al. (1994) indicated that increasing yields under direct drilling may require more soil disturbance around the seed such as with sowing points modified with a blade fitted to rip or fracture a slot in the soil 50-100 mm below the seed. On the other hand Bligh (1991) pointed out that cultivation 50 mm below the seed zone did not increase crop yields in loamy soils in medium (greater than 350 mm) rainfall areas.

2.1.8.3 Type of seeding point

Rowell et al. (1977) found out that direct drilling with a triple disc drill gave significantly lower yields than other methods of direct drilling involving a rigid hoe seeder. This difference was due to poor plant establishment which was possibly emphasised by restricted root growth.

First year yield results of direct drilled winter wheat with several seeding points in North Dakota resulted in no significant differences among narrow hoe-type seeding point (John Deere HZ), spear points, 76 mm shovels and conventional double disc openers used behind large, straight rolling coulters (Diebert et al., 1978). Direct drilling using 55 mm-wide narrow-winged points, without cultivating tines, achieved crop yields comparable to conventional points (Bligh, 1991).

Often there is more water available to direct drilled crops at the end of the growing season (Cornish and Lymbery, 1987), but insufficient root growth and dry matter accumulation early in the season prevents the crop from taking advantage of this available water. For example nil fallow, direct drilled crops where rainfall was 425-450 mm year^{-1} yielded 10-20 % less than cultivated crops owing to poor early growth (Mason and Fischer, 1986; Fischer et al., 1988).

2.2 Development of seeding points for direct drilling

2.2.1 Introduction

Reductions in tillage frequency and soil disturbance by tillage have been achieved through the introduction of modified tillage implements. Many of the original developments were in North America and Canada. Few systematic attempts to develop no till equipment for Australian conditions have been recorded. However, many Australian farmers have modified commercial machinery to suit local conditions.

2.2.2 Machinery development for direct drilling

In Australia inventive farmers have continued a tradition of machinery development using a range of seeder mechanisms. These have included simple modifications such as angled plates behind disc openers to deflect soil back into the seed groove, thereby overcoming the poor seed-coverage characteristics of drills in untilled soils. Lack of machinery specifically for this type of tillage in Australia was another disadvantage of direct drilling (Ellington and Reeves, 1978), but this situation has been remedied with the development of new equipment.

Most, if not all, seeder developments for direct drilling were made as a result of experimental tests. Baker et al. (1979a) pointed out that any other method of development is unlikely to be successful until adequate design criteria are determined. Frye and Lindwall (1986) reported consensus on zero tillage research priorities, that the physical requirements of the seed zone must be better defined for objective seeder design.

The Sirodrill (Stegall, 1979) was an early development of a direct drilling seeder. It featured, in sequence, a scalloped disc coulter, depth wheel, an applicator tine with mouldboard followed by a press-wheel.

Tined seeders have been adapted to sow with reduced soil disturbance. Disc coulters are often used in front of tines in an attempt to slice through stubble, and replacing front cultivating tines on rigid-frame combines with disc coulters, increases stump-jump ability (Mead, 1985). Krall et al. (1979) found that the coulter must be mounted independently of the tine in stony soils, whilst Baker et al. (1979a) observed that a substantial amount of stubble was merely pushed under front coulters rather than sliced, particularly in loose soil.

The Case-I. H. Colta-disc, originally marketed as the Ryan Seeder, is an Australian-developed large disc and sowing boot combination, with an angled steel press wheel. Openers are at 250 mm row spacing, mounted in pairs on combine or air seeder bars, using their own mass for soil penetration (Bligh, 1988). Baker, et al. (1979b) showed that press wheels increase seed-soil contact, and achieve greater control over sowing depth. A disc coulter-spear point-press wheel combination capable of sowing through stubble was developed in Queensland for soil conservation purposes (Freebairn et al., 1986).

Pratley and Rowell (1987) noted that most Australian machinery improvements, have been made by farmers rather than engineers. This appears to have been true in the past but not so much at present. The complexity of plant-soil-machine interactions now frequently requires the covering of a large number of possibilities. The time and expense usually required therefore, largely confines such arrays of tests to technological institutions. Practical criteria however remain essential for commercial acceptance, particularly since direct drilling must be incorporated into a whole farm economic program (Ward et al., 1987).

2.2.3 Seeding point design

Both engineering and biological criteria are used to design sowing points. Slot shape, soil and residue cover of the seed furrow are the most important factors from a biological point of view in sowing point design (Baker, 1976). Existing tined seeders may be converted for reduced soil disturbance by removing cultivating tines, if any, and fitting narrow points to sowing tines. A satisfactory sowing depth may be achieved by positioning the sowing boot behind the tine in an appropriate place.

Most points are designed to create V and U slot shapes, and more recently, inverted T-shaped points have been developed. Double or triple disc openers create V- shaped slots whilst U-shaped slots are made by various hoes, flat-angled discs, dished discs, and power-till openers. An ability to physically handle surface residue without blockage and to incur low machinery maintenance are the greatest advantages of the seeding points producing V-shaped slots. Baker et al. (1988) described these characteristics as an ability to optimise the seed-zone microenviromment, especially water retention and oxygen movement in both dry and wet soils.

Narrow seeding points which leave a minimal slot in the sown row include the Triple disc drill (Karonka, 1973), the Bioblade - though surface disturbance increased rapidly when the replaceable winged components became worn (Baker et al., 1979b). Similar three-point-linkage seeders available include the Connor-Shea "Baker Boot" Drill and the John Shearer Coulter Drill.

The U shape seeding points produce seed-zone microenvironments more optimal than V-shape slots, but yet increase soil disturbance, moisture loss, and randomised seed-soil contact. The residues are often swept aside as a prerequisite to avoiding opener blockage and this can result in loss of moisture control (Choudhary and Baker, 1993).

The 'Cross Slot' seeding point results in conditions where the wide top, narrow base features of V-shaped slots are reversed to produce a narrow top, wide base inverted T shape. The inverted T shape slot created by the 'Cross Slot' point has increased emergence of seeds sown into soils that are too dry or wet. Choudhary and Baker (1981) showed that the dry soil performance of the Cross Slot is a function of moisture retention within the slot.

Wet soil performance has also been linked to the residue retention over the slot. In this case the residue greatly influenced mobility and earthworm activity which provided more oxygen diffusion and water infiltration into the seed zone than other opener types (Baker et al. 1988).

The trash handling characteristics of approximately fifty different opener modifications, and several machine improvements were tested in New Zealand (Baker et al. 1979a). A scalloped disc-winged point-press wheel opener (Baker et al., 1979b), known as the Bioblade, combined most of the desirable agronomic characteristics of the winged opener (Baker, 1976). Improved trash handling, wear characteristics, depth control and seed coverage with reduced maintenance requirements were observed.

Ward and Norris (1982) screened 34 seed placement techniques considered likely to be successful in heavy clay soils. Emergence of wheat at 14 days and seedling vigour at 28 days was measured at five sites. The John Deere Power-Till, which prepares a seedbed using a 300 mm diameter powered cutting disc in front of a narrow sowing point, was the most effective opener at all sites under all conditions. Doubts about its suitability in stony soils, and its potentially high wear rate, led to development of a smooth coulter in front of a spear point and single-rib press wheel as the most practical mechanism for sowing into stubble.

2.2.4 Seeding point operation

When a narrow tine passes through the soil there exists a critical depth (d_c) below which the soil is not loosened and uplifted but is compacted sideways (Godwin and Spoor, 1977). This critical depth is dependent on the tool geometry and on the stiffness of the soil

(McKyes, 1985). The attachment of wings to the tine foot and the use of shallow tines to loosen the surface layers ahead of the deep tine increases soil disturbance. The critical depth was reported by McKyes (1985) to be a function of :

- Rake angle (angle of tool from horizontal): reducing the rake angle increases the critical depth, reduces the draft force and increases penetration.
- Soil moisture content: increasing the moisture content will reduce the soil strength and the critical depth is increased. Drier and more brittle soils have a much larger critical depth.
- Soil type: the more plastic soils (higher clay content) have a shallower critical depth.

Mathematical solutions for calculating forces are available for two dimensional soil failure by wide tines (Osman, 1964), and for three dimensional soil failure by narrow tines (Payne, 1956). The soil failure patterns modelled in the earlier tine theories included the actual observed failure of surface boundaries and simplified patterns involving both vertical and horizontal deformations (Hettiaratchi and Reece, 1967). Godwin and Spoor (1977) reported that the tine force prediction model, based upon the observed soil failure pattern with narrow tines, has been shown to give useful agreement with experimental data for a range of tine shapes operating in two soil conditions. Fielke, et al. (1994) pointed out that the mechanics of soil failure need to be understood. They concluded from their experiment that the shape of the narrow point was observed to influence how the tool fractures the soil and how the soil flows over the tool and back into the furrow. Also the addition of wings and a slotted blade to a basic narrow point can be used to enhance the performance of the point to prepare a wider seed bed and break up hard pans, respectively.

Chisel points on a combine equipped with sowing tines only, cover the entire surface with loose soil (Bligh, 1987). Krall et al. (1979) observed that the John Deere HZO opener, the spear point and 100 mm-wide lister openers moved considerable amounts of soil. Tessier et al. (1991) reported that hoe-type openers can be characterised by higher superficial soil disturbance (furrow roughness), and predictable furrow compaction profiles. As narrow double disc openers seeding in untilled soil can produce less superficial soil disturbance, effective compaction of soil near the seed depends on soil conditions at seeding.

Baker (1976) tested different openers and concluded that the draft (horizontal force) requirement of the Bioblade was more than double that of the triple-disc drill, because of its considerable sub-surface soil disturbance in the seed zone. The vertical force required to penetrate a dry silt loam (6-7 % moisture content) and enable the press wheels to function adequately, was also higher than that for the triple-disc drill.

Studies by Mead et al. (1992) in New South Wales, Australia showed that there was a significant interaction between seedbed condition and share design ($P< 0.05$) on penetration force. Compacted seedbeds required substantially greater downward vertical force for the combine point to penetrate the soil but, following cultivation had the least vertical force on the compacted seedbed. A vertical downward force, which increased with increasing compaction, was required to hold the winged point in the soil under all seedbed treatments.

Riley and Fielke (1986) measured draft and penetration forces required on a front disc coulter mounted at various depths in front of a cultivator share set at 75 mm. They reported increased soil build-up on the upper part of the share and tine using the coulter.

Wear occurs when material is lost or displaced from surfaces that are in relative motion. In agricultural tools this loss of material occurs mainly through the process of abrasive wear caused through contact with hard soil particles (Quirke, 1988). Large areas used for grain and pasture production in Australia have soils which are very hard-wearing on ground-engaging components. On many of these soils, the working life of shares may be less than 6 hours. Not only do farmers have to purchase replacement shares on a regular basis, but time to remove and replace worn points decreases the time available for tillage operations. This is particularly crucial when farmers are working in very narrow tillage and seeding 'windows' (Fielke et al. 1993). Wear of the points may also change the seeding depth of the machine over a period of time.

Riley et al. (1990) reported that wear rates on a selected range of representative South Australian soils under dry conditions were significantly higher than under moist conditions. They also pointed out that draft force had no distinguishable effect on wear rate.

The material which seeding points are manufactured can also inference wear rates. For example, Fielke et al.(1993) compared Australian produced pressed steel and cast steel cultivator shares. This report showed that the wear rate of cast shares was 0.48 of the wear rate of pressed shares, irrespective of the soil type and condition. They concluded that the cast share had initially 2.1 times more mass, an extrapolation of expected life difference would indicate that the cast share should last 4.4 times longer than the pressed share.

Bligh (1990) used narrow-winged points for sowing with minimal soil disturbance. High wear rates were experienced using the deep-bladed points cultivating 110 mm below the surface in a loamy sand soil. Leading points wore sharp, and were shortened by approximately 2 mm for each hectare sown.

Baker and Budger (1979) concluded that substantial improvements can be made to reduce wear of a winged opener in undisturbed soil. Lundy (1987) also suggests that a considerable reduction in wear of points and discs is metallurgically possible.

2.3 General discussion and conclusions

Direct drilling has the potential to maintain better soil structure for intensive and sustainable agricultural cropping but there is a little knowledge of the performance of narrow sowing points used in direct drilling, on soil physical properties, early crop growth and resultant grain yields. To enhance soil quality and therefore increase the potential yield of the product, continued effort is needed to identify tillage methods and appropriate sowing tools that will augment productivity at the same time as soil resilience and stability.

The literature shows that tillage practices have a significant effect on occurrence and severity of cereal root diseases particularly *Rhizoctonia spp*. Direct drilled crops show a greater incidence of *Rhizoctonia* than crops grown under conventional cultivation. There are reports in the literature which show that direct drilling using modified narrow seeding points that disturbed soil below the sowing depth, such as the McKay modified lucerne point, significantly reduced *Rhizoctonia* root damage. Measures to control *Rhizoctonia* using direct drilling with modified narrow points produced grain yields equal to those obtained following conventional cultivation.

Several research reports have shown that an increase in soil bulk density, soil strength and decrease of soil porosity resulting from direct drilling can restrict crop establishment and root growth. However, much of this research was done using conventional seeders to direct drill the crop. Few reports exist on the use of narrow sowing points for direct drilling. There is a need for more effort to examine the effect of direct-drilling with narrow sowing points on soil strength and soil physical qualities particularly immediately after seeding.

Pratley and Rowell (1987) reported that most Australian machinery improvements in the past have been made by farmers rather than engineers. Some research is now being done by scientists and engineers and a number of empirically developed commercial sowing points are available. However, the literature shows there is still a lack of scientific basis for seeding point design for conservation tillage systems, especially for direct drilling. In particular, there is a need to characterise the performance of narrow sowing points with respect to soil physical quality and crop establishment. The task of testing the large number of commercially-available seeding points is likely to be beyond the resources of most research institutes and a more achievable project would be to test a small number of points that embody the most important design features. These features should include the shape, width and rake angle of points, shape and size of wings for loosening soil around the point, and also the use of extended blades for loosening the soil under the seedbed. The investigations need to evaluate and examine the effects of these narrow seeding points on seed placement, crop establishment, early growth and grain yield, soil physical properties and soil quality immediately after sowing.

CHAPTER 3

DRAFT FORCE, UPWARD FORCE, SOIL FAILURE AND WEAR RATE CHARACTERISTICS OF THE EXPERIMENTAL NARROW SEEDING POINTS

3.1 Introduction

For over 100 years the Australian farming industry has largely depended on the wide scarifier point to disturb the soil and cut the roots of weeds. However, by moving towards simple narrow seeding points for sowing crops, and substituting herbicides instead of tillage for weed control, it became possible to plant directly into soil without cultivation (Rovira, 1993).

A single-pass operation with narrow points is a move towards a more sustainable system which reduces fuel usage, but increases herbicide use. There is concern amongst farmers that the greater use of herbicides with narrow points may not be sustainable in the long term, but it is accepted that the proper use of herbicides is less damaging to soil than cultivation. Despite the need for change to a conservation farming system the rate of adoption has been slow (Walters and Rovira, 1993). Hurley et al. (1985) pointed to some of the major problems with conservation tillage techniques were that the necessary equipment is too costly, existing equipment becomes redundant and suitable equipment is often not available for some environments and soil conditions.

Selecting appropriate tillage machinery and tools is one of the major costs of cereal farming. However, the cost can be minimised using research and development data. For seeding, farmers endeavour to select a seeding point that will give long life and undergo minimum change in shape during use. Most importantly, farmers require an operational draft force that leads to a reduction in fuel usage and tractor size without reducing effectiveness in seed placement.

The purpose of the research reported here was to determine the mechanical effects of soil on 4 narrow seeding point designs (Fig. 3.1). The engineering efficiency and effectiveness of the tillage tools was evaluated by the draft force (horizontal), vertical force (upward), lateral failure (side crescent), wear rate and critical depth. The critical depth of a seeding point refers to the depth below which, during operation, soil is not lifted toward the soil surface but is compressed to the sides of the tool and moved in a horizontal plane.

3.2 Materials and Methods

3.2.1 Point design

Four different types of narrow-seeding point were designed and constructed (Fig. 3.1). The point 45-0-0 is similar to those commonly used by farmers practicing direct-seeding in southern Australia. It comprises the 45° rake angle of a typical point (Godwin and Spoor, 1977). The point 45-W-0 is similar to 45-0-0 but includes a 40 mm wide wing at the bottom of the point which produces more soil loosening around the point. For disturbing the soil under the seed bed the 45-W-S point was constructed by welding a 5 mm wide blade on the front of the point 45-W-0 cultivating soil 50 mm below the seed zone. As the number of farmers using a 90° rake angle seeding point was increasing (Reeves, T. G., personal communication), it was decided to also evaluate the point 90-0-0.

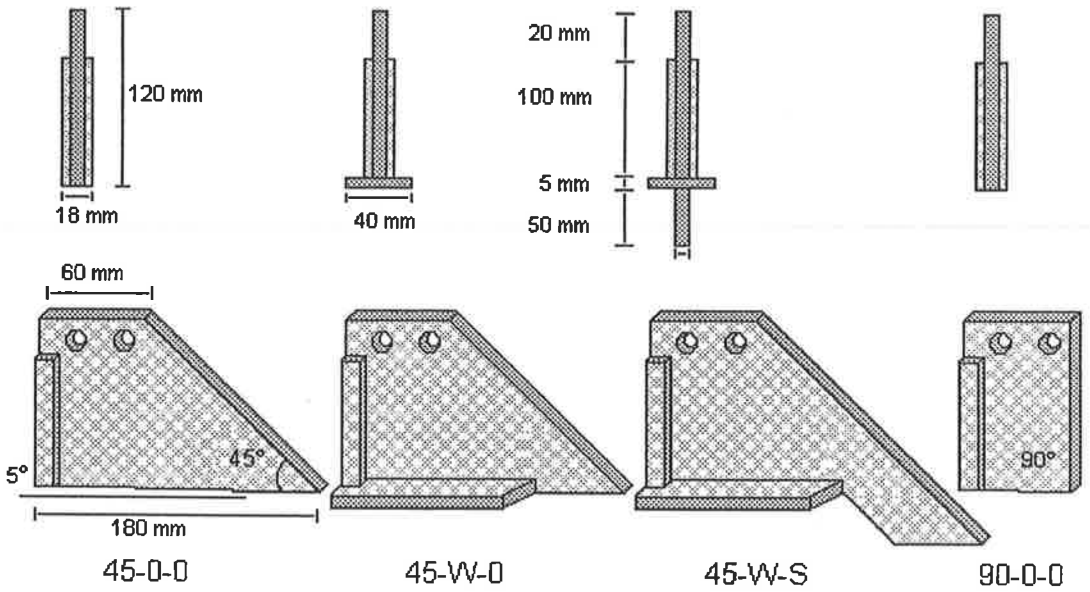


Figure 3.1 Front and side views of experimental narrow seeding points.

The four experimental narrow points are briefly described as:

45-0-0: 45° rake angle,

45-W-0: 45° rake angle with wings,

45-W-S: 45° rake angle with wings and blade,

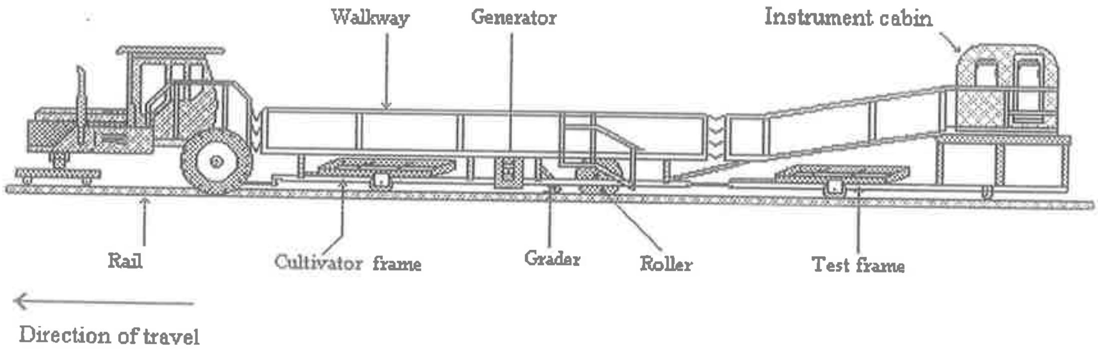
90-0-0: 90° rake angle.

The material used to construct the points was K1073 steel (0.7 % carbon content) of 8 mm thickness. After construction, the points were heat treated (oil quenched) and hardened to 42-45 Rockwell 'C'. This material was based on current pressed steel share manufacturing procedures which are designed to minimise wear so ensuring a minimum mass loss during testing. The 8 mm thickness of steel ensured adequate rigidity and strength. The 40 mm width of wings and 5 mm thickness were designed with a 5° relief under the point or point wing giving a constant clearance angle. The maximum selected sowing depth was 80 mm, so the length of 120 mm was selected for all points (20 mm is for connecting purposes).

3.2.2 Draft force, upward force and wear rate

To evaluate the draft and upwardforce characteristics, and the wear rate of the selected four narrow seeding points, tests were conducted at the University of South Australia's Tillage Test Track facility (Fig. 3.2).

Side view



Front view

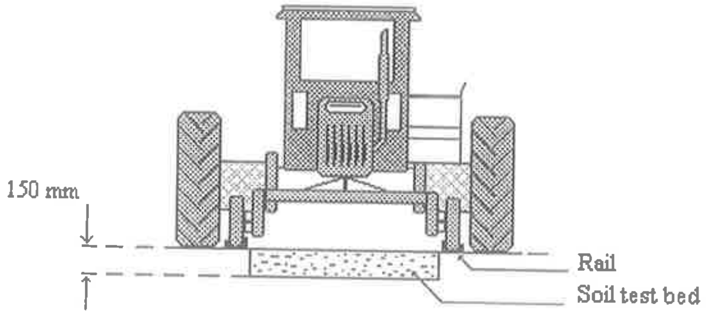


Figure 3.2 Schematic representation of the Tillage Test Track facilities at the University of South Australia.

The Tillage Test Track (Fielke and Pendry,1986) is a unique outdoor oval shaped soil bin of 2.5 m width which permits continuous and repeatable testing under controlled conditions. The track consists of two parallel 50 m lengths (used for measurement) which are joined by two 50 m diameter curves to give 250 m of travel per lap. The sandy loam test soil is 2.5 metres wide and 0.3 metres deep. An 80 kW tractor pulls two trolleys around the track at a speed of up to 12 km h^{-1}. The photograph of the tillage test track (TTT) is shown in Figure 3.3.

Figure 3.3 Photograph of the Tillage Test Track .

To control the moisture of the test soil in the Tillage Test Track, water is added using a boom extended over the soil of track. Before each test the soil water content was measured by oven drying of the samples at 105° C within the 0-100 mm soil depth. Force measurement for the tillage testing facility is achieved by a micro-processor controlled data acquisition system. The instrumentation system consists of strain gauged force transducers, analogue strain gauge excitation and signal conditioning, analogue to digital conversion, micro-processor based data logging and recording to the data recovery and processing.

3.2.2.1 Soil type

The Test Track was filled with loamy sand soil; soil particle size was described by Fielke and Pendry (1986) and particle size distribution data are shown in Table 3.1. This soil is typical of large areas of southern Australia.

Table 3.1 Sieve analysis of loamy sand soil (adapted from Fielke and Pendry, 1986).

Particle size distribution (%)				
Clay < 2 μm	Silt 2-20 μm	F. Sand 20-200 μm	C. Sand 200-2000 μm	Texture class
5	8	45	42	Loamy sand

3.2.2.2 Force measurements

The tests were conducted at depths of 25, 50 and 80 mm to obtain information on depth effects. Prior to the commencement of each test 4 clean points were bolted to standard tines attached to the standard stump jump mechanisms which were mounted on the two force frame. The travelling speed was 8 km h^{-1} for all tests. Draft force (the measure of the force required to pull the ground engaging tool through the soil) and upward force (the measure of the ground engaging tool's ability to hold itself at the given depth) measurements were taken on both of the straights giving 2 laps × 2 readings per lap using an instrumentation system described by Fielke and Pendry (1986). There were three replications for each test. At completion of the integration period which was selected to record a distance of 40 m on each straight section of the track, the outputs of depth, draft force and upward force were copied onto a tabulated results sheet and saved for analysis.

3.2.2.3 Soil failure and critical depth

To calculate the soil failure pattern (McKyes, 1985), the ultimate width of each side crescent (S), was determined using Equation 1as follows:

$$\mathrm{s} = f\sqrt{1-(d\cot\alpha/f)^2} \qquad [1]$$

where f is the forward distance of soil failure (the distance ahead of the tine at which the distinct shear plane broke the surface) which was estimated from Figure.3.4 (Godwin and Spoor, 1977) for both 45° and 90° rake angle, d is the sowing depth (mm) and α is the rake angle.

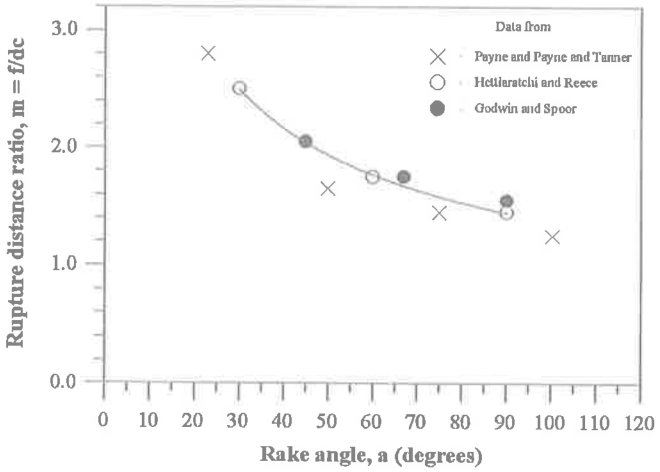


Figure 3.4 Experimental relationship between rupture distance ratio and tine rake angle (after Godwin and Spoor, 1977).

The critical depth, d_c (above a certain critical depth, the soil displace forwards, sideways and upwards, and below it no upward movement occurs) was estimated from the data (Fig. 3.5) in relationship between crescent aspect ratio (critical depth/tool width) and aspect ratio (working depth/tool width) for 90° and 45° rake angle tines. Where d is working depth, d_c is critical depth and w is the tool width.

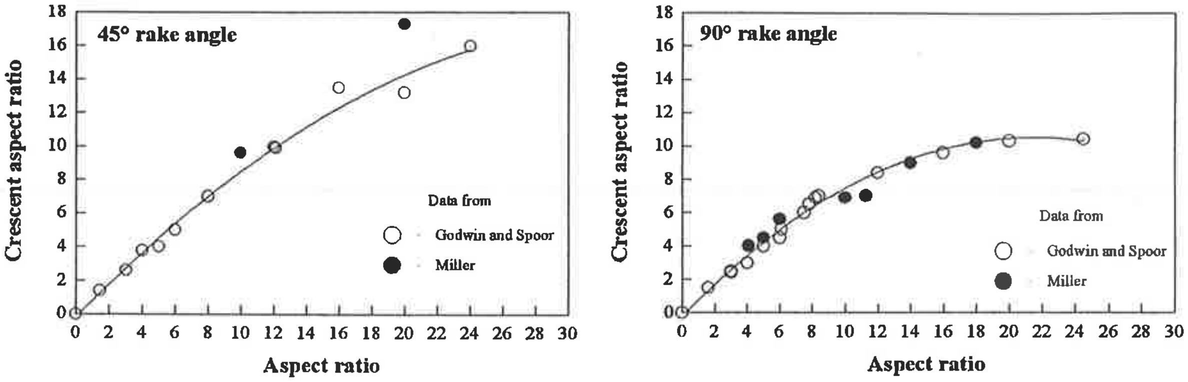


Figure 3.5 Relationship between crescent aspect ratio and aspect ratio for 45° and 90° rake angle tines (after Godwin and Spoor, 1977).

3.2.2.4 Wear rate measurement

To give an indication of the life of the point, the weight loss (g km^{-1}) as a function of travel distance through the soil bin of the Tillage Test Track was measured on 14 April 1993. Three replicate measurements were made at an accuracy of 0.001 g before and after each test and run, and the seeding points were cleaned thoroughly and then weighed.

3.2.3 Statistical analysis

The statistical analysis was performed in Genstat 5 Release 3 (Genstat 5 Committee, 1993). The experimental design for force measurements was a Factorial Block Design (Table 3.2). Three seeding point treatments (45-0-0, 45-W-0 and 90-0-0), three depth intervals (25, 50 and 80 mm) in two straights have randomly allocated with three replicates. However, only the 25 mm sowing depth was tested for the seeding point 45-W-S because for deeper sowing depths the blade (see Fig. 3.1) would have penetrated to a depth greater than the soil bin depth.

Table 3.2 Analysis of variance table for force measurements using a factorial block design with 3 treatments, 3 sowing depths and 3 replicates for 2 straights.

Source of variation	Degree of freedom
Replication	2
Tool type	2
Depth	2
Straight	1
Tool type. Depth	4
Tool type. Straight	2
Depth. Straight	2
Tool type. Depth. Straight	4
Residual	34
Total	53

The statistical analysis was performed for wear rate with four treatments and three replicates. The least significant difference (LSD) was calculated for pair wise comparisons of treatments at the 5 % level of significance. The Analysis of Variance table is shown for wear rate in Table 3.3.

Table 3.3 Analysis of variance table for wear rate using a RCBD with 4 treatments and 3 replicates for 4 tool positions.

Source of variation	Degree of freedom
Replication	2
Tool type	3
Tool position	3
Tool type. Tool position	9
Residual	30
Total	48

3.3 Results and Discussion

3.3.1 Draft and upward forces

Results of the tests showed a significantly higher draft force (Fig. 3.6) and upward force (Fig. 3.9) for the 45-W-S point compared to other points, whilst the point 45-0-0 had the lowest value of draft and upward force compared to 45-W-0 and 90-0-0 points. Having a blade on the point ie. 45-W-S resulted in the point operating deeper and touching the bottom layer of the track. Consequently the Tillage Test Track was not suitable to obtain the measurements of draft force and upward force for point 45-W-S except at 25 mm depth.

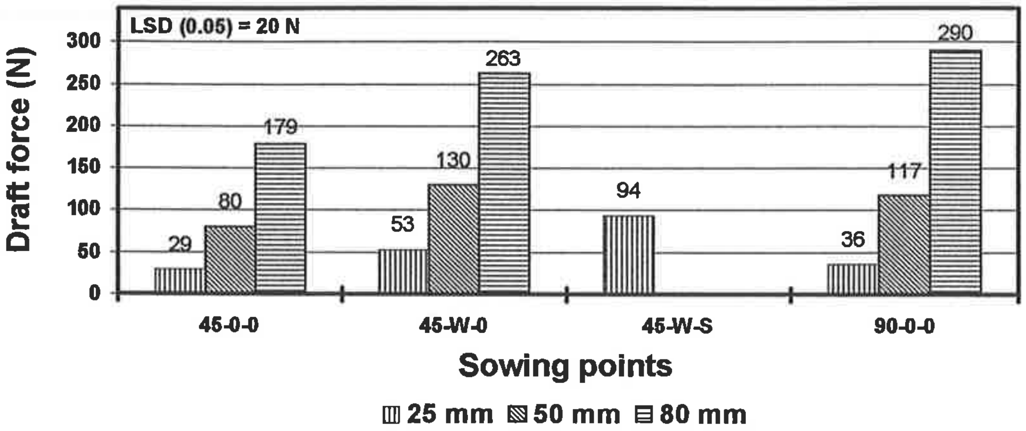


Figure 3.6 Draft force (N) for four narrow seeding points at sowing depths of 25, 50 and 80 mm. Only one depth (25mm) was used to test seeding point 45-W-S.

Fig. 3.7 shows that there is a linear relation between draft force and tillage depth over the depth range tested, as the tillage depth increased the draft force increased.

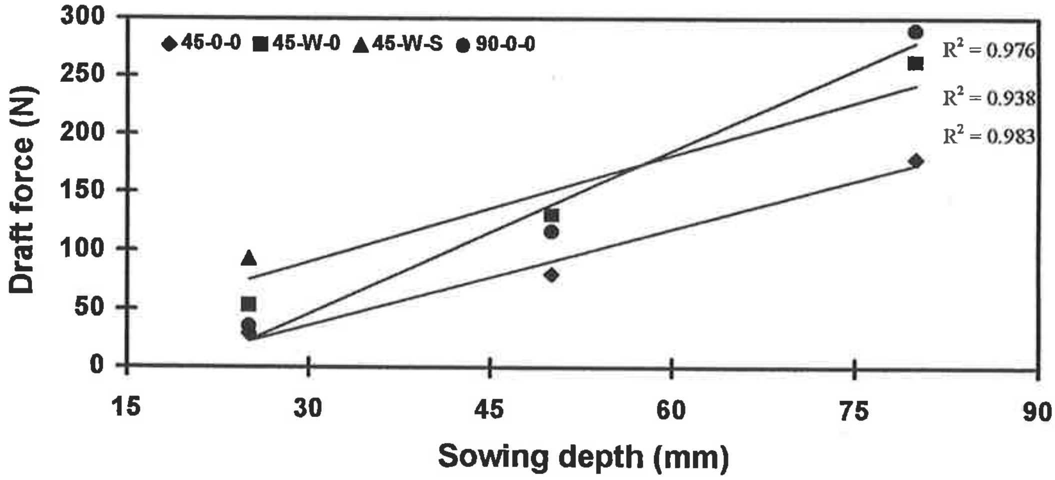


Figure 3.7 Trend lines of draft force over sowing depth for the four narrow points. Only one depth (25mm) was used to test seeding point 45-W-S.

The draft forces resulting from variation of the rake angle are given in Fig. 3.8 and showed that force increased with an increase of the tool rake angle. This result is similar to that predicted by the modified model for soil cutting resistance proposed by Zhang and Kushwaha (1995).

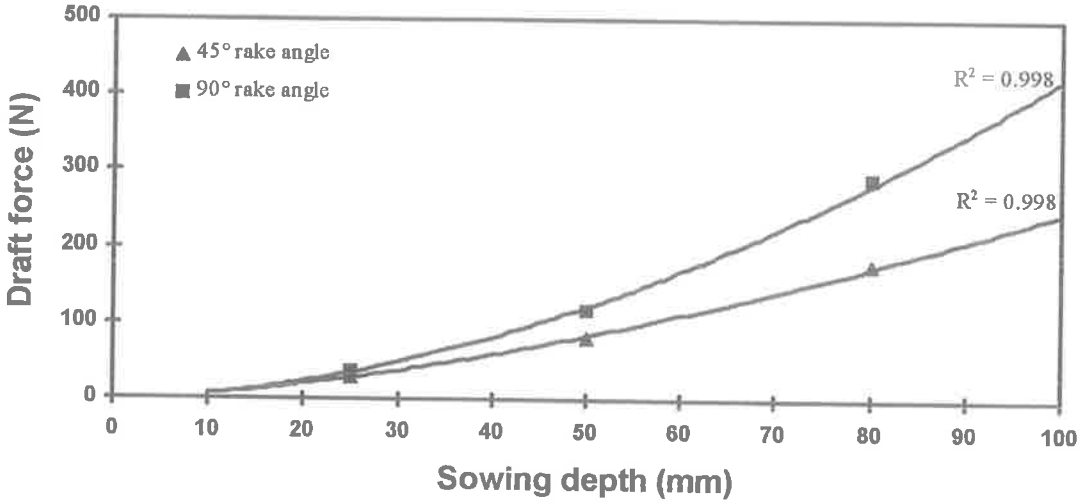


Figure 3.8 Effect of rake angle on draft force at 3 sowing depths.

The point 45-W-S had a significantly higher upward force at 25 mm tillage depth (Fig. 3.9) compared to other seeding points. The result also showed that the point 45-0-0 (with 45° rake angle) had the lowest upward force compared to other points at 50 and 80 mm but was similar to 90-0-0 at 25 mm tillage depth.

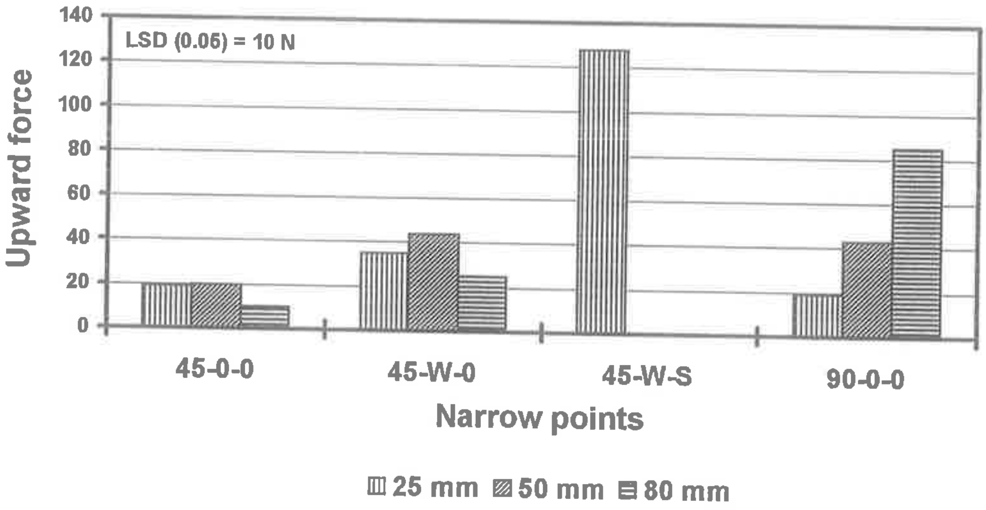


Figure 3.9 Upward force (N) for four narrow seeding points at sowing depths of 25, 50 and 80 mm. Only one depth (25mm) was used to test seeding point 45-W-S.

The trend line of the upward force (Fig. 3.10) for varying tillage depth shows that for points 45-0-0 and 45-W-0 with 45° the upward force had a polynomial relationship, but for the point with a 90° rake angle (90-0-0), upward force behaved linearly, that it is increased with increasing tillage depth as shown in Fig. 3.10.

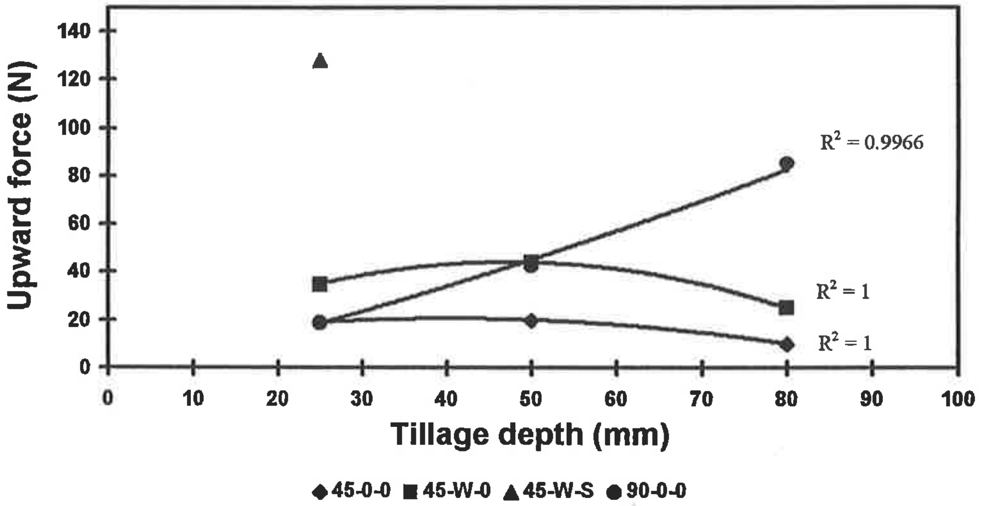


Figure 3.10 The relationship between upward force as a function of tillage depth for the four narrow seeding points.

The results showed that important factors which influence draft and upward forces are tools working depth (tillage depth), cross sectional area of tool/soil engagement and tool cuting angles (rake angle). These results are suported by the Buckingham's Pi-theorem which were presented by Koolen and Kuipers (1983). The theorem shown that the draft force is a function of:

$$F = f(\lambda, b, z, \alpha, \mu, \ldots)$$

where F is the draft force, λ is tool length, z is tool opertaing depth, α is cutting angle and μ is the coefficient of soil to metal friction.

3.3.2 Soil failure pattern

Table 3.4 shows the calculated values of the ultimate width of each side crescent (s), the forward distance of soil failure (r) and the critical depth (d_c) for the narrow seeding points 45-0-0, 45-W-0, 45-W-S (45° rake angle) and point 90-0-0 (90° rake angle) with three sowing depth intervals (25, 50 and 80 mm). Working depth was greater for seeding point 45-W-S than other points because of 50 mm extended blade below the sowing depths. Therefore 50 mm was added to sowing depth when the values of r and s was calculated.

Table 3.4 Calculated values of s, r and d (mm) for the four narrow seeding points with three depth intervals.

Treatment	Sowing depth (d)	Width of side crescent (s)	Forward distance of soil failure (r)	Critical depth (d_c)
45-0-0	25	40	50	24
	50	78	100	46
	80	124	160	64
45-W-0	25	56	50	24
	50	94	100	46
	80	140	160	64
45-W-S	25	108	150	63
	50	146	200	80
	80	190	260	99
90-0-0	25	44	40	20
	50	84	80	44
	80	132	128	56

The soil failure patterns from calculated values are shown in Figure 3.12 for the four narrow seeding points operating at 50 mm depth.

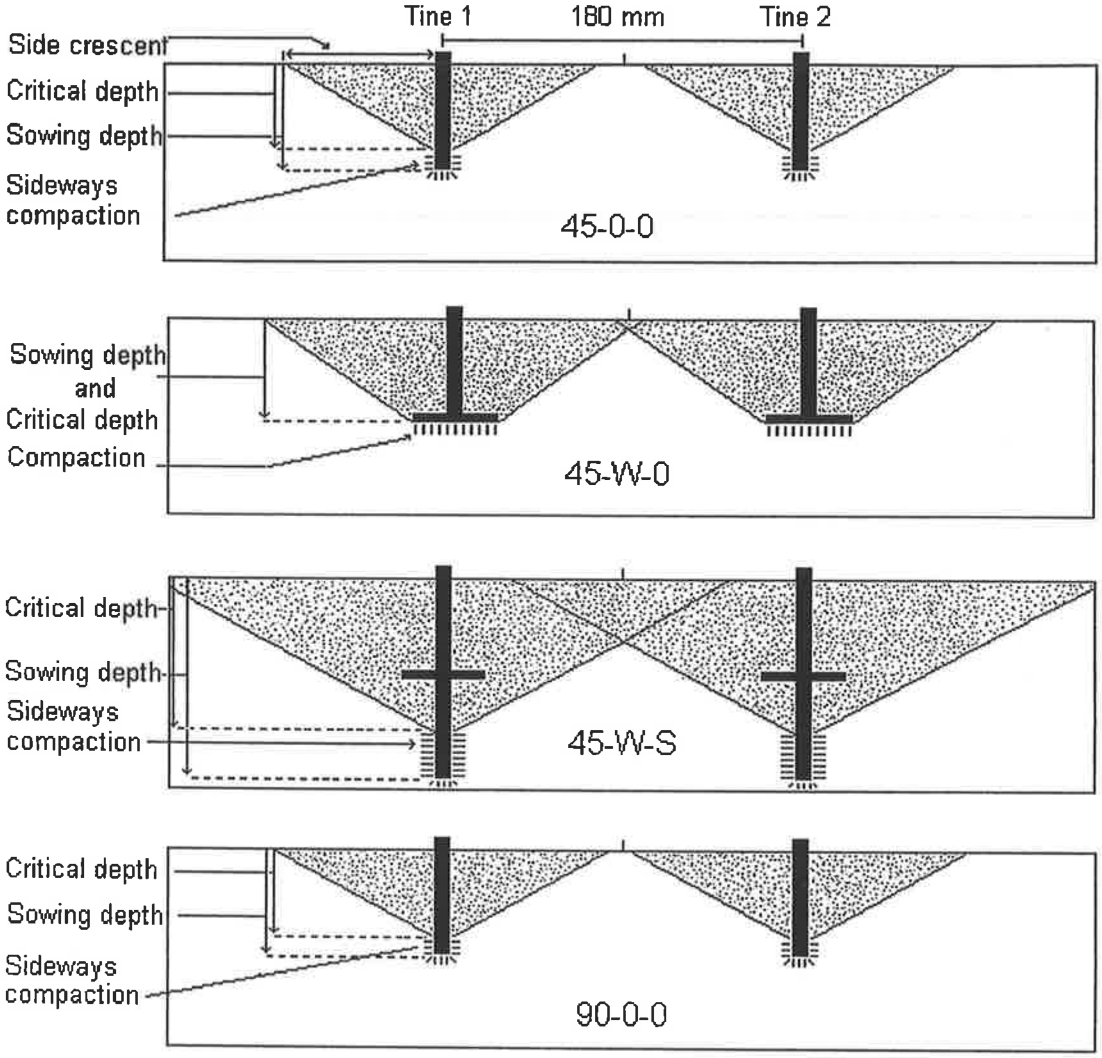


Figure 3.11 Soil failure pattern for four narrow seeding points (45-0-0, 45-W-0, 45-W-S and 90-0-0) at 50 mm sowing depth.

Comparing the critical depth positions, it can be seen that the critical depth is closer to the surface in the seeding point 90-0-0 with 90° rake angle (Fig. 3.11) than for the point 45-0-0 with 45° rake angle. The addition of wings to narrow point 45-W-0 resulted in an increase in the effective width of the point hence increasing the critical depth and the volume of the loosened soil. The point 45-W-S with wings and deep blade produced a slot below the critical depth with noticeable soil disturbance under the seed bed. The addition of wings to this point did not increase width of the soil disturbance but they seemed to fill the slot under the wings (produced by deep blade), to level the seed beds and let the seeds spread more horizontally.

3.3.3 Wear rate

Figure 3.12 shows that the seeding point 90-0-0 suffered a significantly lower mass loss, or wear due to point shape which allowed less point surface and soil contact, compared to other points, whilst significantly highest wear occurred on point 45-W-S due to larger surface area (extra wings and blade) which was touching the soil during operation.

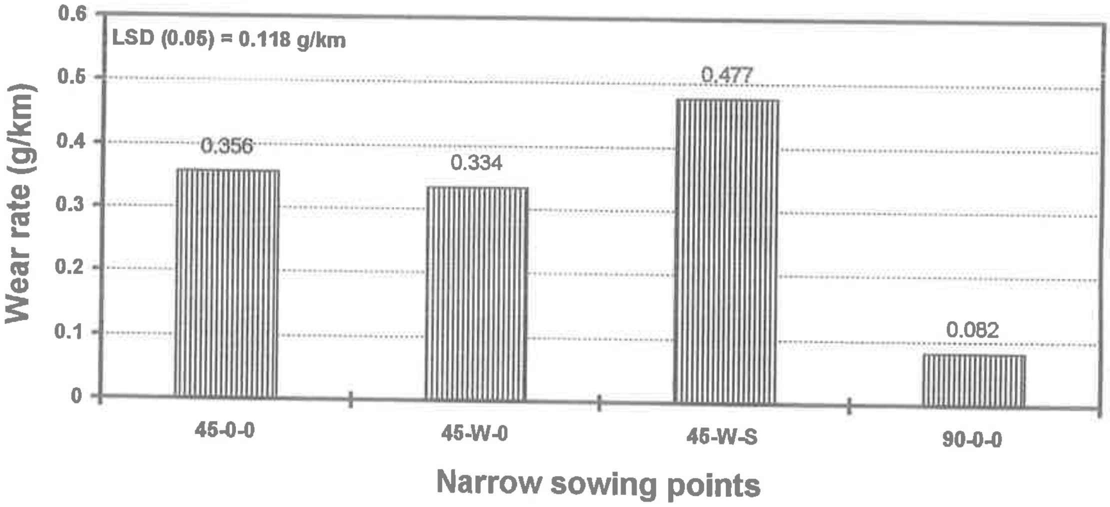


Figure 3.12 Wear rate of narrow seeding points (g km^{-1}).

3.4 Conclusions

The performance of the four experimental narrow points varied significantly in draft, upward force and wear rates. The results showed that for the four seeding points, 45-W-S produced higher draft force and wear rate because this point was working deeper than other points and disturbing more soil under seedbeds with the extended blade (Fig. 3.1). As the depth of sowing was increased the draft force and wear rate were increased. The point 45-W-0 showed a slight increase in draft force and upward force as expected due to its wings but a decrease in wear rate. The 90° rake angle (90-0-0) resulted in higher draft force and upward force but lower wear rate than the 45° rake angle (45-0-0).

Comparing the critical depth positions, it can be seen that the critical depth is closer to the surface in the seeding point 90-0-0 with 90° rake angle than for the points with 45° rake angle which is a disadvantage for this seeding point (90-0-0). The addition of the wings (45-W-0) resulted an increase in the effective width of the point and increasing its critical depth. When wings and deep blade added to the narrow point (45-W-S) resulted a slot below the critical depth with soil disturbance under the seedbed and increase in the effective width of the point hence increasing its critical depth and the volume of the loosened soil.(Fig. 3.11). The addition of wings to this point did not increase in width of the soil disturbance but they pressed the soil under the wings which resulted to fill the slot and leveled the seedbed.

CHAPTER 4

EFFECT OF THE NARROW SEEDING POINTS ON SEED PLACEMENT

4.1 Introduction

Attainment of high crop yields demands optimal crop emergence, early crop vigour and uniform subsequent development of the plants. Apart from soil and seed limitations, seed placement is an important determinant of crop establishment. Norris (1988), found that better seeder ground working components and better control of sowing depth can increase early plant growth by 10 to 50%, and grain yields by at least 10%. An ideal seeder will maintain a constant mean depth of soil cover with a minimal variation in depths of cover as well as a uniform seed distribution within each row. Heege (1993) noted that a precise sowing depth is an important prerequisite for seeding methods whilst Palmer et al. (1988) pointed out that uneven sowing depth can be a major problem for crop emergence. They suggested that the ultimate solution to accurate depth control was a tool which did not throw soil onto adjoining rows. Choudhary et al. (1985) and Barr (1981) also found that optimum sowing depth is required for good seedling emergence, but showed that lateral variation of seed placement may not influence crop establishment.

The aim of the work reported here was to measure the depth and lateral variation of seed placement and also depth of soil cover in relation to original soil surface and soil profile after wheat was sown, using four different narrow seeding points.

4.2 Materials and Methods

The artificial seed bed (soil bin) system described by Slattery et al. (1993) was used to complement agronomic results obtained from field trials. Whilst field experimentation takes place in conditions similar to those encountered by farmers it has disadvantages in measuring seed placement and related establishment when compared to soil bin evaluation.

4.2.1 Seed Placement Test Rig

To investigate the effects of the shape of narrow seeding points on seed placement, experiments were conducted using the University of South Australia's Seed Placement Test Rig (Slattery and Rainbow, 1991). This allowed a range of seeding point shapes to be compared under controlled conditions as the facility provides a method of accurately measuring seed placement (Fig. 4.1).

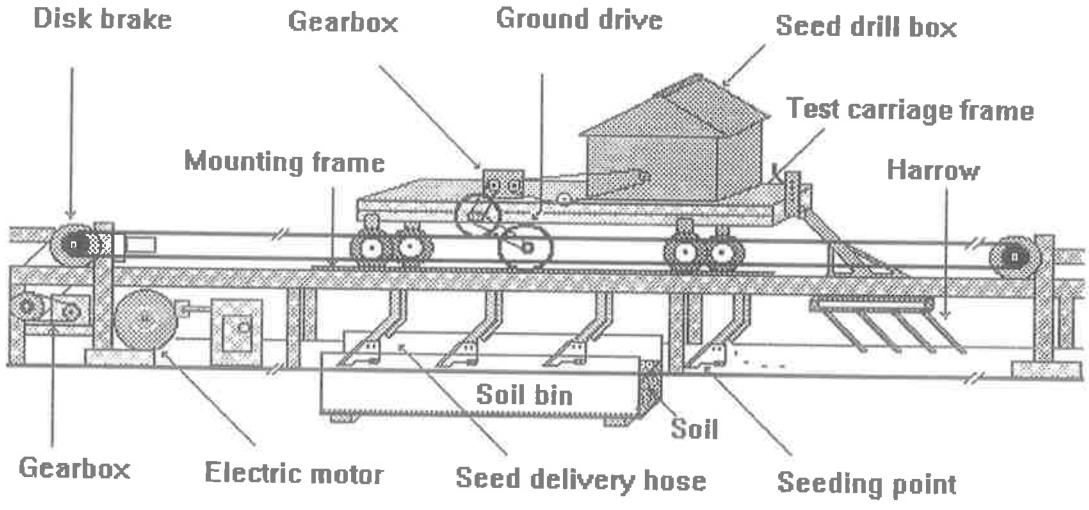


Figure 4.1 Seed Placement Test Rig.

The test carriage main frame was 3.7 m long and 1.3 m wide. Two conveyor chains were used to drive the carriage back and forth. Tines of a selected seed drill were mounted on the adjustable frame hanging from a parallel linkage to enable level height adjustment. A thirteen outlet John Shearer seed drill box was mounted at the rear of the carriage and above the mounting frame. Three row spring tine harrows were clamped at the rear most part of the main carriage frame. Two four speed automotive gear boxes provided a range of operating speeds and a main drive shaft was connected by roller chain to the output of the two gear boxes coupled in series to an automotive clutch. Automatic control of the brake and power to the motor was provided by micro switches at either end of the rails.

4.2.2 Seed bed

The facility could accommodate four seed beds housed in soil bins 1.5 m wide and 3 m long which were inserted under the test carriage rails (Fig.4.1 and 4.2). The central 1.5 m width and a selected 1.2 m length of the seed bin was available for steady state seeding and subsequently for seed and soil profile recording purposes. Removable plastic covers were fitted to the open soil bins to provide an enclosed environment to facilitate germination and emergence. Two metal sheets were used after sowing to close both ends of the bins to protect seeds from mice damage (Fig. 4.2).

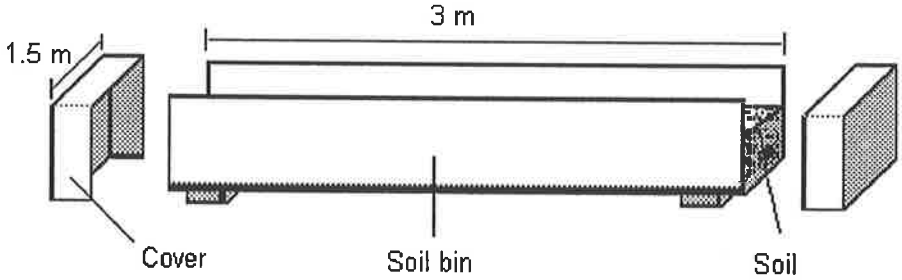


Figure 4.2 Soil bin and end covers

The soil used for the tests was a sandy loam red-brown earth collected from the Roseworthy Campus of the University of Adelaide (the same soil used later for field experiments, Section 7.2.1). After collecting soil from the field, native seeds were removed by air drying the soil, sieving through 2.3 mm mesh and then transferring it into the bins. The soil was irrigated in the bin by a sprinkler system to raise the water content to 0.08 kg kg^{-1}. After covering the bins, five days were allowed to elapse before applying the seeding point treatments.

4.2.3 Seeding point treatments

Four narrow seeding points (45-0-0, 45-W-0, 45-W-S and 90-0-0) were used to sow wheat seeds cv.(Machete) at three depths (25, 50, and 80 mm) into the artificial seedbeds in the bins of the seed placement Test Rig. Speed of sowing was 6 km h^{-1} or 10 km h^{-1}. Following sowing the seedbed was smoothed with a 3 row spring tine set 20 mm below the pre-sowing soil level. A random selection process was used to determine which set of variables was sown in which bin to alleviate any bin bias to the data.

4.2.4 Measurements

At sowing time, measurements of soil water content, soil bulk density and shear strength were obtained to evaluate reproducibility of seedbed conditions (data not presented here). Following sowing, soil furrow profiles were measured at five set intervals across each bin. Furrow profiles were also obtained after the post sowing operation. The soil profile was measured using a 40 mm T-bar fitted to the pointer of the three dimensional digitiser. The T-bar was mounted parallel to the direction of tillage with the soil height recorded when half of the bar came into contact with the soil surface. Germination and emergence of sown seed were encouraged by covering the bins for four to five days after sowing. Seedling emergence were counted daily until the end of seedling emergence. At the end of the seedling emergence the young wheat plants and seeds were carefully excavated and each seed position recorded with the three dimensional digitiser. A manual excavation method was used to find the seeds. Seeds were located using a spatula and a vacuum gun was then used to carefully excavate the soil and expose the seed in the drill rows. A three dimensional digitiser (optical shaft encoder) with a moveable pointer within a fixed reference frame (Fig. 4.3) was used to electronically record the individual seed locations and soil profiles and the information was logged to a computer file. The measuring frame was located on the test carriage rails to provide an accurate and repeatable measurement reference.

Figure 4.3 Photograph of the seed locations and soil profiles measuring frame.

Seeding point performance was analysed by comparing seed distribution in the horizontal plane relative to the direction of the seeding point path and the vertical plane relative to the

original soil surface and seed mean depth of cover below the average soil profile. Figure 4.4 defines these seed and soil measurements.

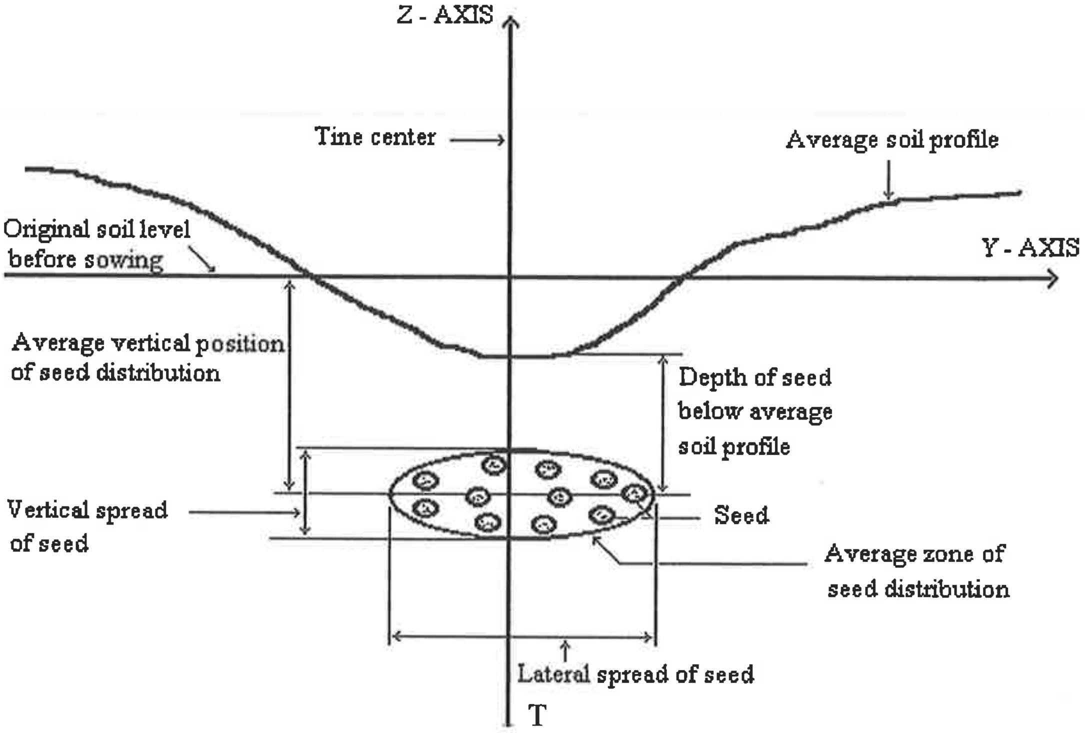


Figure 4.4 Dimensions referred to in seed placement analysis. Direction of travel (X-Axis) is into the plane of the paper.

Depths of cover should fall within the recommended depth for a particular seed and soil type. Visual information of the seed distribution within the soil is obtained by plotting cross sections of seeds and soil as viewed in the direction of travel.

4.3 Statistical analysis

Genstat 5 Release 3 (Genstat 5 Committee, 1993) was used to perform analyses of variance of seed depth, lateral variation of seeds and depth of the soil cover data. A randomised block design was used with four block replicates for three sowing depths. The least significant difference calculated for paired comparisons of mean values with the 95%

confidence level. Table 4.1 shows the degrees of freedom available for statistical analysis of the data.

Table 4.1 The ANOVA table for statistical analysis of seed placement.

Source of variation	Degree of freedom
Tool type	3
Replicates	3
Residuals	9
Total	15

4.4 Results and Discussion

Averages of seed distribution obtained from the four narrow seeding points at two speeds (6 and 10 km h^{-1}) and three sowing depth (25, 50 and 80 mm) are shown in Table 4.2.

Table 4.2 Narrow seeding point seed placement at two speeds (6 and 10 km h^{-1}) and three sowing depth (25, 50 and 80 mm).

Seeding point	Sowing speed km h^{-1} ↓	Lateral seed spread mm			Vertical seed spread mm			Depth of soil cover mm		
	Sowing depth mm→	25	50	80	25	50	80	25	50	80
45-0-0	6	14.9	23.2	20.0	14.8	15.5	14.4	22.3	51.3	78.0
	10	20.3	19.8	19.7	16.8	16.0	14.5	21.5	51.8	84.5
45-W-0	6	31.1	27.1	27.8	14.3	22.7	15.4	24.8	54.7	83.8
	10	29.5	30.1	29.9	12.2	16.4	17.3	24.5	56.6	89.8
45-W-S	6	33.6	26.9	35.2	29.0	23.0	35.1	43.3	67.8	93.0
	10	39.7	32.4	28.4	23.3	18.3	18.9	38.0	70.8	96.8
90-0-0	6	19.3	21.0	19.0	17.3	16.3	16.6	22.5	52.3	83.5
	10	21.6	23.0	22.8	19.7	15.1	15.8	25.5	53.8	82.8

An indication of the seed scatter relative to the final surface of the soil as shown in examples of seed and soil cross-section diagrams (Figures 4.5 and 4.6). These diagrams show the typical cross-section of some of the soil bin experiments which provides seed distribution and the soil profile before and after using a harrow for variation of narrow seeding points. The examples are at 6 and 10 km h^{-1} sowing speed with 50 mm sowing depth. The broken line passing through 0 depth is the original soil surface.

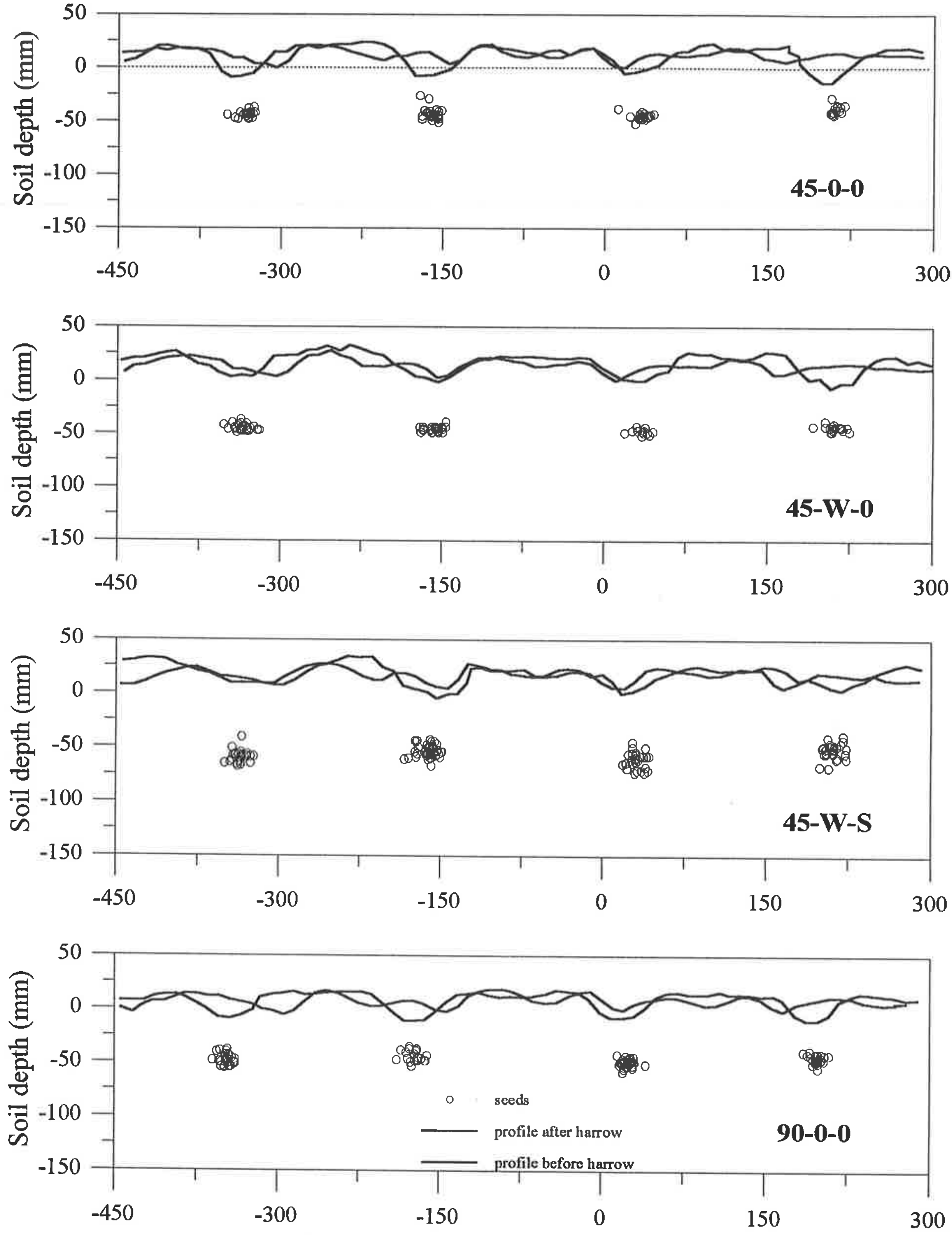


Figure 4.5 Cross section of seeds at 50 mm sowing depth with 6 km h^{-1} sowing speed for the four narrow point treatments.

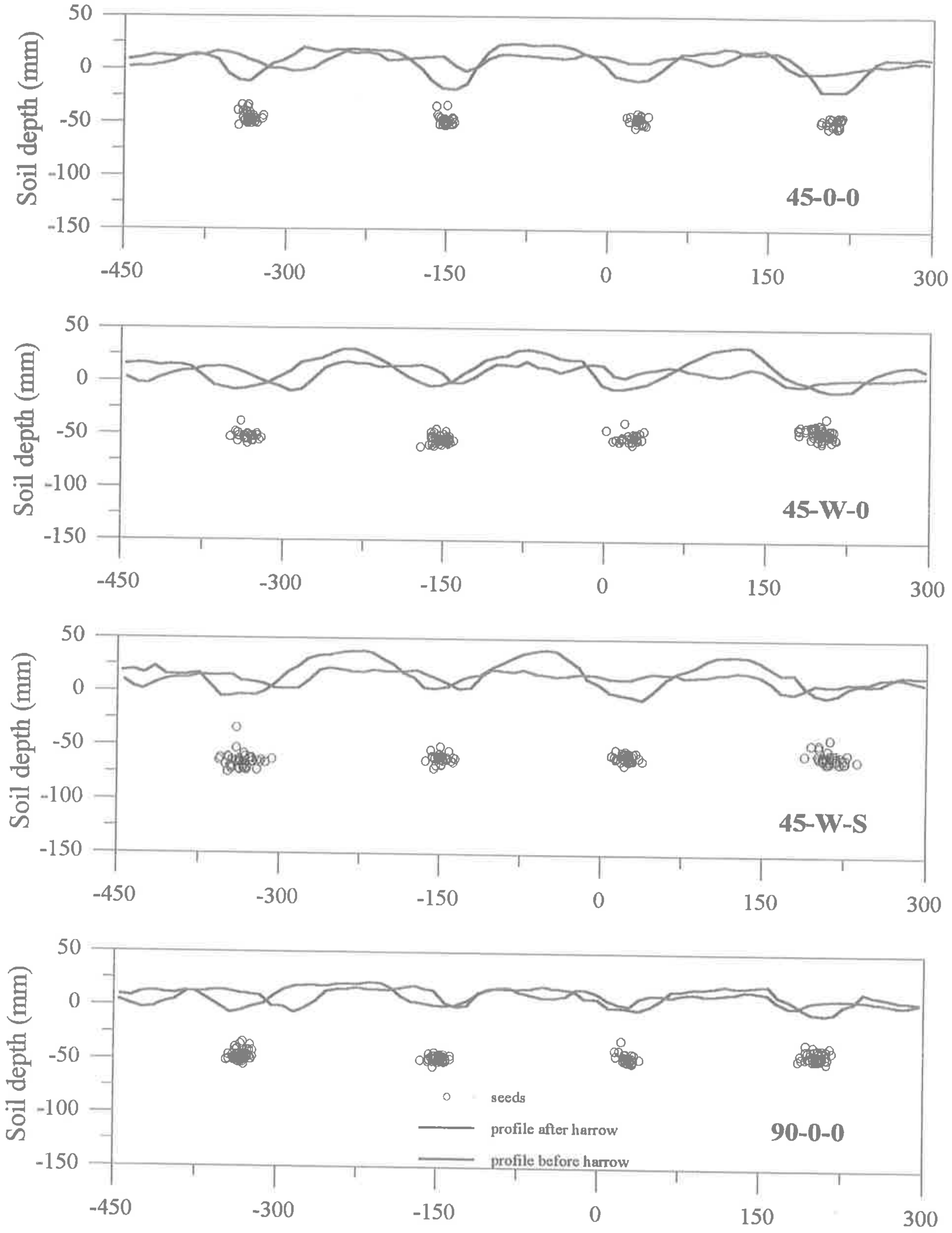


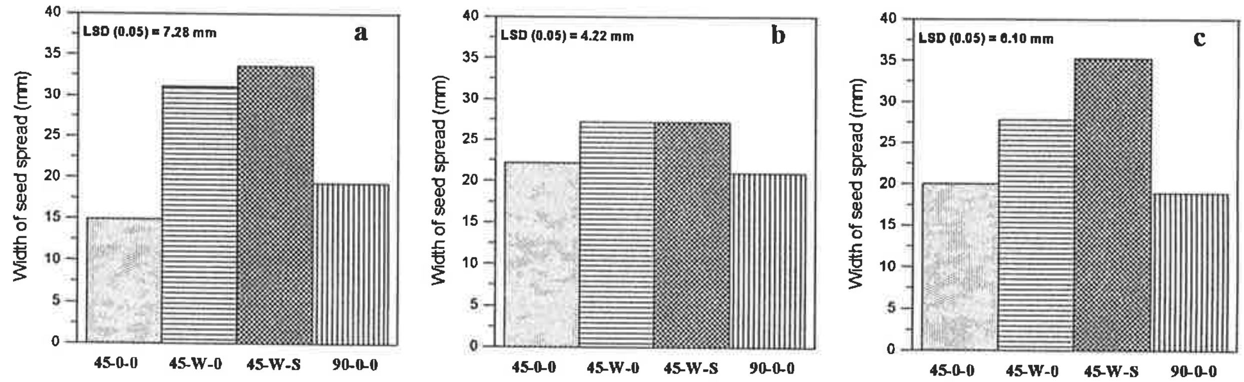
Figure 4.6 Cross section of seeds at 50 mm sowing depth with 10 km h^{-1} sowing speed for the four narrow point treatments.

4.4.1 Width of seed spread

Lateral variation of seed placement may not be a problem for establishment. However the wings caused more loosening of soil laterally than others (see section 3.3.2), therefore seeds had an opportunity for lateral movement during placement for winged points.

The seed distribution produced by the four seeding points were generally significantly ($P<0.05$) different in lateral spread as shown in Figure 4.7. The points 45-W-S and 45-W-0 had significantly higher lateral spread of seed than 45-0-0 and 90-0-0, and points 45-0-0 and 90-0-0 produced less lateral spread. The result did not show any significant difference in lateral spread of seed between sowing depths and sowing speeds.

6 km h^{-1} sowing speed



10 km h^{-1} sowing speed

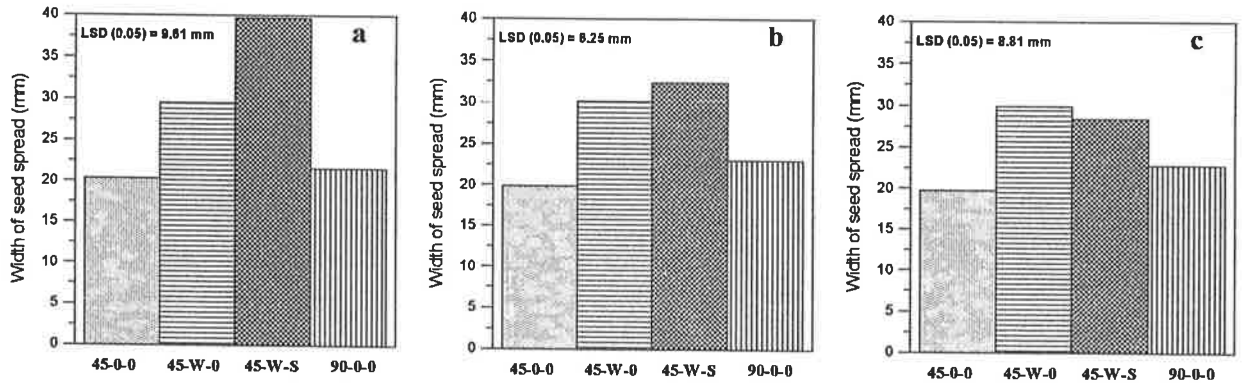
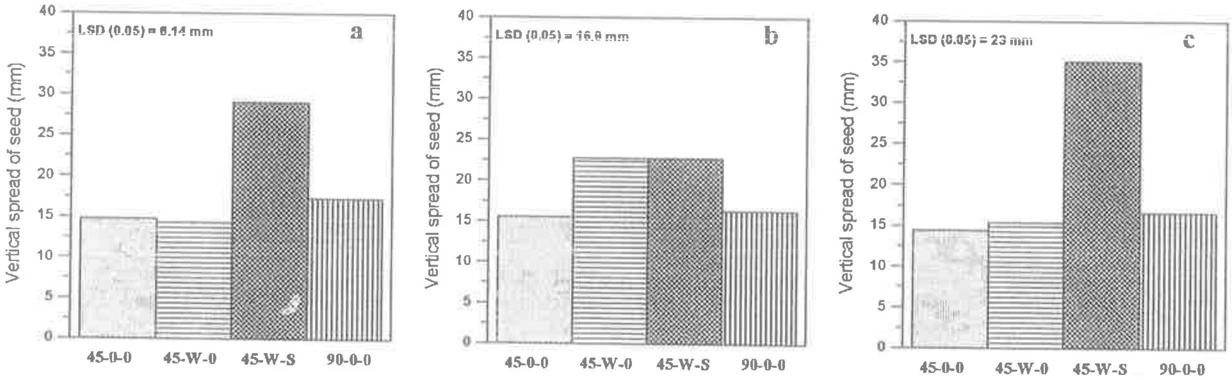


Figure 4.7 Variation in width of seed distribution spread for the seeding points (45-0-0, 45-W-0, 45-W-S and 90-0-0) for three sowing depths (a 25; b 50 and c 80 mm) and two speeds (6 and 10 km h^{-1}).

4.4.2 Vertical seed spread

The vertical spread of seeds for the four seeding points is shown in Figure 4.8. The seeding point 45-W-S showed significantly larger vertical spread of seeds than other points at the 25 mm sowing depth, but with 50 and 80 mm sowing depths, there was no significant difference. Large LSD values were observed for the 50 and 80 mm sowing depths at the slower sowing speed (6 km h^{-1}).

6 km h^{-1} sowing speed



10 km h^{-1} sowing speed

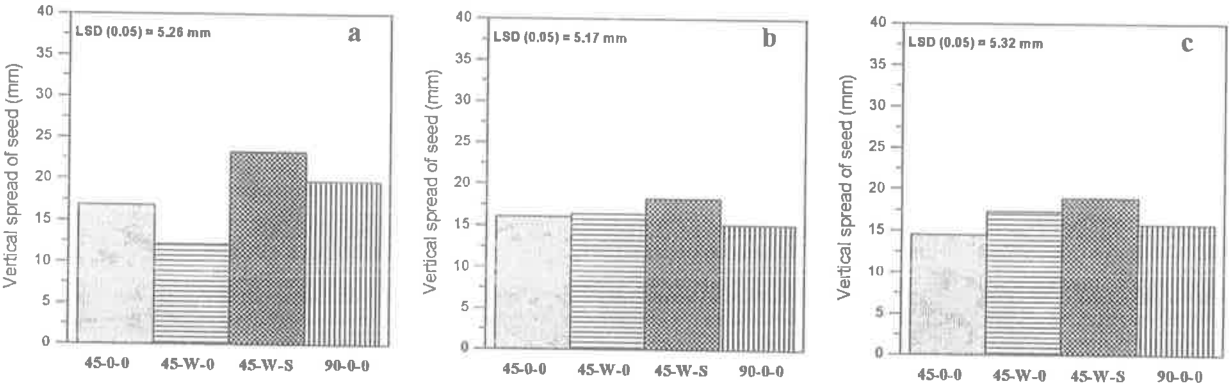


Figure 4.8 Variation in vertical spread of seed for sowing depths of 25, 50 and 80 mm (a, b and c respectively) with 6 and 10 km h^{-1} sowing speeds.

Increase in the depth of sowing from 25 mm to 50 mm resulted in a decrease in the vertical seed spread for point 45-W-S and from depth of 50 mm through to 80 mm, results showed increase in vertical seed spread. There was no significant difference in vertical spread of seeds placed by points 45-0-0 and 90-0-0 as the depth increased. Point 45-W-0 had a significantly larger vertical spread of seeds as depth increased from 25 mm to 50 mm and slightly decreased from 50 mm to 80 mm operating depth (Fig. 4.9).

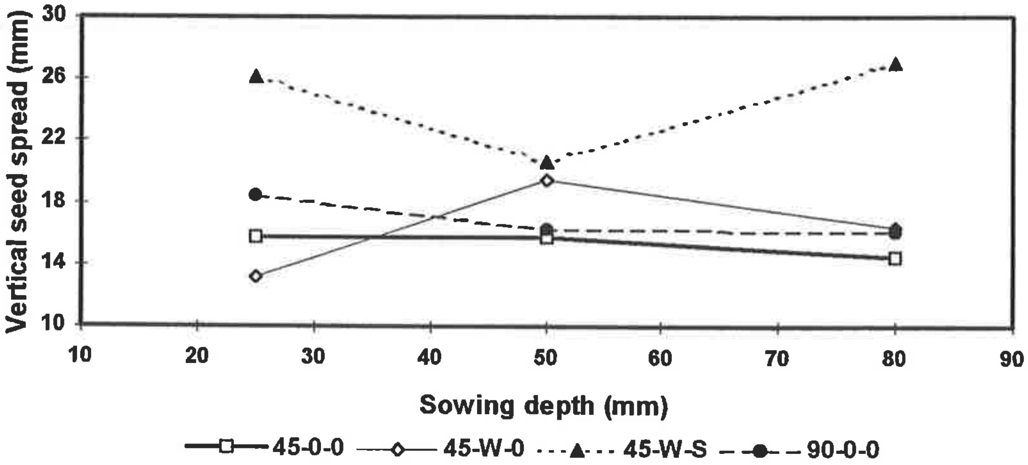


Figure 4.9 Vertical spread of seeds for the four narrow seeding points with a range of sowing depth.

There was no significant difference with an increase of speed from 6 km h^{-1} to 10 km h^{-1} in the vertical spread of seeds (Fig. 4.10) for the points 45-0-0, 45-W-0 and 90-0-0 but for point 45-W-S, there was a significant decrease in vertical spread of seeds as speed increased from 6 km h^{-1} to 10 km h^{-1}.

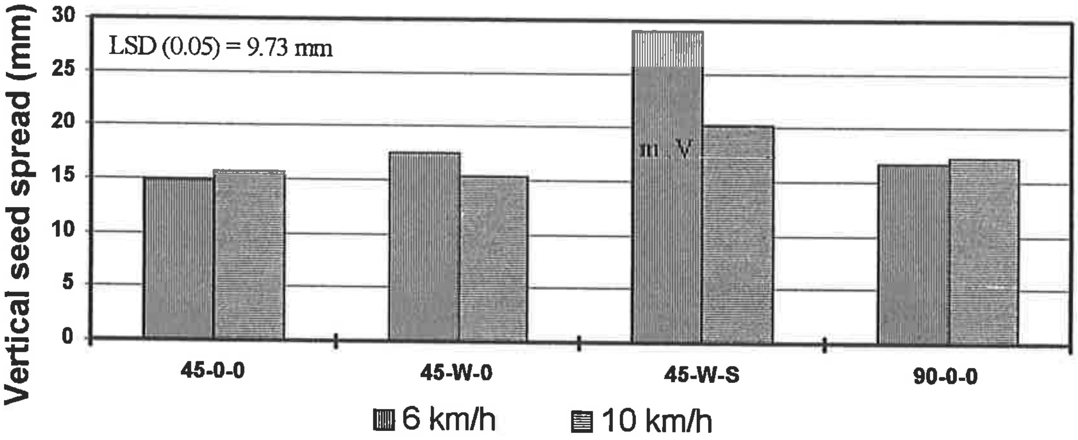
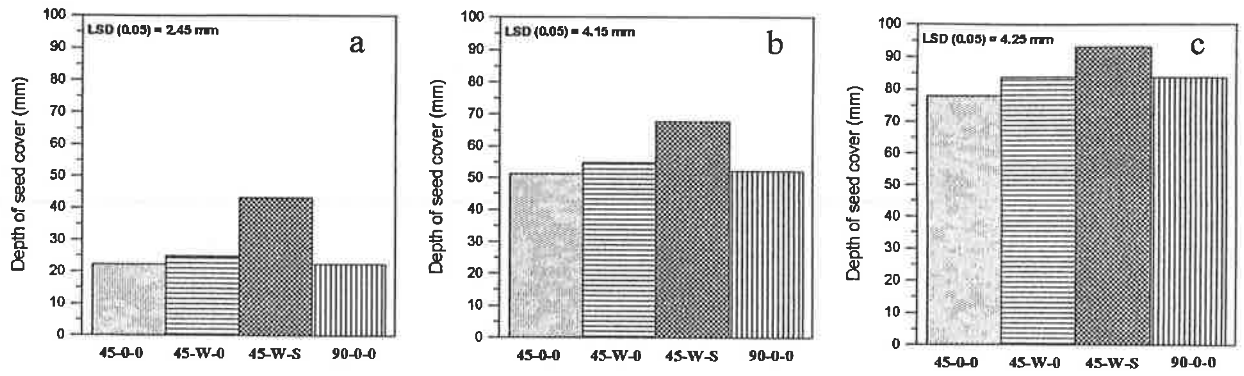


Figure 4.10 Vertical spread of seeds for the four narrow seeding points with two sowing speed.

The sowing point 45-W-S with extended blade had greater vertical seed spread with shallow and deep sowing depths (25 and 80 mm) but there was less variation in vertical seed spread with optimum sowing depth (50 mm) and also with higher sowing speed (10 km h^{-1}). Slot closure was presumably better at high speed than low speed and disturbance caused by the wings could fill the slot under the seedbed better at high speed than at low speed.

4.4.3 Depth of soil cover

The depth of soil cover over the seeds for a range of sowing depths of 25, 50, and 80 mm and for sowing speeds of 6 and 10 km h^{-1} are shown in Figure 4.10. The only notable response was for the seeding point 45-W-S which showed significantly higher depth of soil cover than other seeding points for both 6 and 10 km h^{-1} speeds. Point 45-W-S operating at a depth of 80 mm or more, might cause restricted seedling emergence as a result of excessive soil cover.


6 km h^{-1} sowing speed

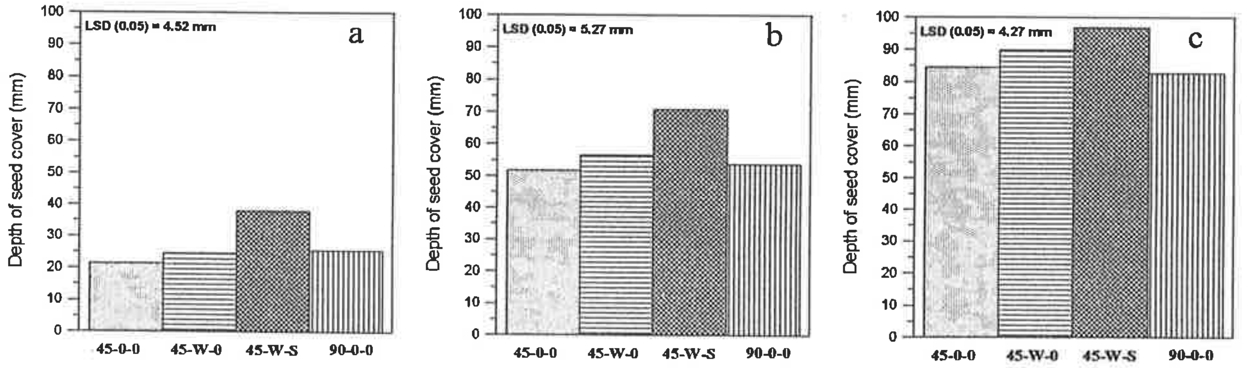

10 km h^{-1} sowing speed

Figure 4.11 Depth of the soil cover for four narrow seeding points (45-0-0, 45-W-0, 45-W-S and 90-0-0) and sowing depths of 25, 50 and 80 mm (a, b and c respectively) and 6 and 10 km h^{-1} sowing speeds.

4.5 Conclusions

The performance of four narrow points varied significantly in horizontal and vertical spread of seed, and the seed depth of cover. The results showed that points with wings resulted in a greater lateral spread of seed whilst point with extended blade gave a greater vertical spread of seed. As a result the point 45-W-0 (with wings) produced a greater lateral seed distribution, and the point 45-W-S (with wings and blade) showed higher seed spread in both lateral and vertical positions. The point 45-W-S also produced a greater soil cover of seed than other points. However, the variation of lateral and vertical seed spread generally declined by increasing sowing depth from 25 mm to 50 and then to 80 mm for these narrow points. There was no significant difference with an increase of sowing speed from 6 km h^{-1} to 10 km h^{-1} in the vertical spread of seeds for the points 45-0-0, 45-W-0 and 90-0-0 but for sowing point with wings and extended blade, 45-W-S, there was a significant decrease in vertical spread of seeds as speed increased from 6 km h^{-1} to 10 km h^{-1}.

CHAPTER 5

EFFECT OF NARROW SEEDING POINTS ON SOIL PHYSICAL PROPERTIES

5.1 Introduction

Reducing cultivation may improve many properties of red-brown earths, which are widespread in Australian cereal- growing areas. Under intensive cropping the surface of this soil type is commonly structurally unstable, prone to slaking and dispersion, sets hard after wetting and drying (Mullins et al., 1990) and forms crusts under high intensity rainfall (Moran, 1988).

Cultivation of the structurally fragile topsoils of Australian red-brown earths, specially under the wrong conditions (Tisdall and Adem, 1986), can have a deleterious effect on soil physical properties. Each tillage operation, regardless of the particular tillage implement or power source, alters soil physical properties. Depending on conditions, the soil may be loosened, granulated, compacted, crushed, inverted, sheared or shattered. Several of these effects may occur simultaneously. Rovira (1993) and many others have shown that under intensive cultivation organic matter declines and aggregates are destroyed by the repeated tillage. This leads progressively to poorer soil structure conditions and land degradation by hardsetting (Mead et al., 1992) crusting (Moran, 1988) and erosion (Auerswald et al., 1994). Emerging crop shoots may be restricted by hardset layers or crusts and rate of seed germination and primary shoot elongation are affected because imbibition of water is restricted when the seed is enclosed by soil of high strength (Collis-George and Williams, 1968).

Compact layers below the seedbed may limit root growth due to strength impedance. Roots of plants may not grow into a dense subsoil or through a tillage pan and high soil strength may halt root penetration completely, but more generally it reduces the rate of elongation of roots and alters the preferred direction of growth (Greacen et al., 1968). Soil strength has been shown to increase with an increase in bulk density (Taylor and Ratliff, 1969) and clay content (Gerard, 1965) whereas soil strength decreases with increasing water content (Gerard, 1965: Taylor and Ratliff, 1969).

With development of herbicides it has been possible to reduce cultivation to a minimum (ie at sowing only), since there is no further need to control weeds by tillage (Rovira, 1993). Reduced cultivation can improve the properties of many soils (Auerswald et al., 1994) but productivity of crops on red duplex soils may be lowered because of unfavorable seedbed conditions in direct drilling systems (Chan et al., 1987). Mead et al., (1992) and others have pointed out to the need for some disturbance of poorly structured soils to insure an adequate seedbed for establishment and early vigour of crops. Chaudary and Baker (1980) have shown that important soil physical characteristics can be considerably modified by tillage during sowing with drill coulters. The design (shape) of the narrow seeding points is important in creating ideal soil physical conditions at sowing. However, very little published work on the effects of narrow seeding points on soil physical properties is available.

Apart from soil physical conditions, soil temperature is an important factor in crop establishment. Different soil tillage systems have different effects on the soil temperature regime, because they leave different amounts of mulch on the soil surface or because they affect soil physical properties such as porosity and water content differently. Soil surface configuration and plant residue cover, both influenced by tillage, have a significant influence on soil heat flux and therefore, soil temperature (Cruse et al., 1982). On the basis of theoretical calculations and field measurements, Van Duin (1956) reported that loosening the top soil reduced the heat uptake and heat loss of a soil and caused more of the heat exchange to take place in the surface soil. As a result when soil temperatures are increasing, soils are warmer near the surface when tilled, and colder near the surface when left undisturbed.

Use of a direct drilling system and appropriate tillage points may reduce the adverse effects of tillage on soil structure, create better soil physical conditions for germination and emergence and improve crop establishment. The hypothesis of the work reported here is that narrow seeding points of appropriate shape can be used to reduce soil structural damage associated with more intensive forms of tillage and improve the physical properties of soil in the seedbed. The aim of the work reported in this chapter was to measure the bulk density, penetration resistance, soil porosity, soil temperature and soil water content after seeding of wheat, using four differently shaped seeding points.

5.2 Materials and Methods

5.2.1 Field treatments

In June 1993, a tillage experiment was carried out on a red-brown earth soil (SL93) at the Roseworthy Campus of the University of Adelaide (34° 32' S, 138° 41' E) . Wheat was sown into uncultivated soil with a John Shearer seeder fitted with one of the four designated narrow points as described in Chapter 3, (45-0-0, 45-W-0, 45-W-S, 90-0-0). Sowing depths for these treatments were 25, 50, and 80 mm with four replicates. There was also a conventionally cultivated treatment (CT) which comprised two passes of a standard commercial sweep cultivator followed by sowing with the 45-0-0 points. This latter treatment was only sown at 50 mm depth.

In July 1994, the field treatments were applied at two sites, one on a similar soil type to SL93, a sandy loam (SL94) and the other on a heavier soil type, a clay loam (CL94). In July 1995 the same treatments were applied and some experimental work was carried out on the sandy loam (SL95) site. The two sites were less than 4 km apart, both on the Roseworthy Campus. The treatments at both sites were similar to those in 1993, but only one sowing depth was used, 50 mm. Sowing speed was 8 km h^{-1} for both field experiments. The crop rotations for both sites were similar: in the 5 years preceding the experiment, the cropping systems was faba beans, wheat, peas, wheat, faba beans.

5.2.2 Soil chemical properties

Ten duplicate samples from 0-100 and 100-200 mm depth of soil were analysed by a routine laboratory analyses in the South Australian State Chemistry Laboratories for routine analysis of chemical properties (nitrogen, sulphur, phosphorus, potassium, organic carbon, alkaline earth carbonates, pH, salinity) of the soils on the two experimental sites.

5.2.3 Soil physical properties

Before sowing in 1993 and 1994 particle size distribution, texture, soil moisture (at 0-150 and 150-300 mm), wilting point, penetration resistance, soil pore attributes and bulk density at 0-50, 50-100 and 100-150 mm was measured. Times and method of sowing are described in Section 7.2.2. After sowing, the soil water content, penetration resistance, pore attributes and bulk densities were measured over the same depth intervals before and after emergence.

5.2.3.1 Bulk density

Soil bulk density (ρ_b) is nearly always altered by tillage operations. Before sowing, bulk density of the sites (SL93; SL94 and CL94) was determined by direct measurement of soil mass and volume using undisturbed cores that had been oven-dried at 105 °C for twenty-four hours (Blake, 1965). Ten samples at random locations across the experimental site and at three depths, 50, 100, and 150 mm, were extracted using stainless steel sleeves 75 mm diameter, 50 mm high and 2 mm wall thickness (McIntyre, 1974). One week after sowing four replicates of undisturbed cores were taken at three depths in each plot.

5.2.3.2 Field capacity and wilting point

Soil that had been sown to wheat using the narrow sowing points was wetted as described in Section 6.2.1 and sampled after 48 hours drainage, under cover. Replicate (3) cores were taken (thin walled sleeves 36 mm diameter, 25 mm high) centred at 50, 100 and 150 mm depths, weighed and dried to determine water content. Wilting point was determined on duplicate samples collected from each treatment and each site (CL and SL) using a soil core sampler (45 mm diameter, 25 mm high and 2 mm wall thickness) at depth intervals of 0-50, 50-100, and 100-150 mm. The air-dried soil samples were gently crushed and passed through a 2 mm sieve. Small samples were placed on a ceramic plate, wetted by flooding the plate and drained in a pressure chamber. A positive air pressure of 1500 kPa was used in the pressure chamber and the permanent wilting point calculated by weighing the samples before and after oven drying at 105° C (Cassel and Nielsen, 1986). There were no significant differences between the treatments sampled and average wilting point was calculated for each depth, and for two sites (CL and SL) at three depth intervals 0-50, 50-100, and 100-150 mm.

5.2.3.3 Penetration resistance

The penetrometer resistance of the soil from the surface to a depth of 150 mm was measured before sowing and periodically after sowing and after crop emergence. The force (F) on a stainless steel cone (American Society of Agricultural Engineering, 1983) was measured using a calibrated load cell as the cone was pushed into the soil. Force was measured at frequent intervals in the passage of the cone through the soil. Penetration resistance (P_r) was calculated

$$P_r = 10^{-6}\, {}^{F}\!/_{A} \qquad [1]$$

where F is force (N), A is area of the base of the cone (m^2) and the factor 10^{-6} converts units of P_r from Pa to MPa.

Penetration energy (P_E) was calculated to reduce the large number of penetration resistance values to a single value, characteristic of the site and depth penetrated. This quantity has units which may be interpreted as penetration energy per unit area

$$P_E = \Sigma_1^n (Pr_i \times z_i) \times 10^{-3} \qquad [2]$$

where P_E is penetration energy in kJ m^{-2}, Pr_i is the i th penetration resistance in MPa corresponding to z_i the i th depth interval (m) and 10^{-3} is used to obtain units of kJ m^{-2}.

Wherever penetration resistance (P_r) measurements were made, three samples were taken at the same locations, at depths of 50, 100, and 150 mm for water content and bulk density.

In 1993 soil strength was measured with a Rimik CP10a penetrometer fitted with a 1000 N strain gauge and a 12.7 mm diameter, 30° included angle stainless steel cone on a 10 mm diameter shaft. The Rimik penetrometer records force on the cone at 15 mm intervals. These data are stored in a memory module for later transfer to a computer. Penetrometer resistance was recorded at five random positions over the experimental sites prior to sowing. Soil penetration resistance was again measured to 150 mm depth on two occasions, on the day after sowing and then after emergence, at five random positions along the sowing rows and at five random positions between the rows in each plot with four plot replicates. The Rimik cone penetrometer proved to be insensitive to differences in treatment strength and standard errors of means were too large to generally distinguish treatment differences. Accordingly a different penetrometer was constructed for use in 1994 (Fig. 5.1).

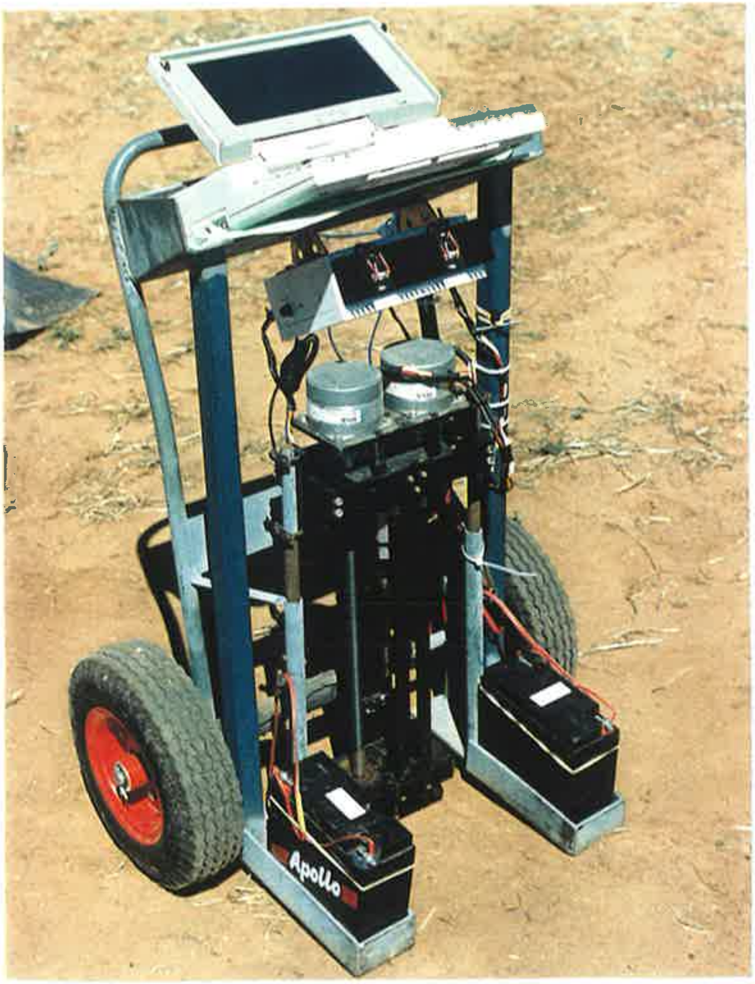


Figure 5.1 Photograph of the motorised pnetrometer.

The penetrometer was motorised and had a cone of 6.25 mm diameter and 30° internal angle. The penetrometer had three major components: (1) mechanics (trolley, worm drives, two stepper motors and load cell 450 N), (2) electronics (stepper motor controller and data logger), (3) portable personal computer and software program.The load cell and penetrometer shaft and cone are guided along twin worm drive shafts at 1.66 mm s^{-1} recording force on the cone at 2 mm intervals from 0-150 mm depth which is immediately transferred to the computer.

Before sowing, the penetrometer resistance was recorded at five random positions over the experimental sites. After sowing, measurements were again made at five random positions along the middle of the sowing-line in each treatment (4 replicated treatments) on the day after sowing and then after emergence. The penetration resistance between the rows was not measured. Results from 1993 showed that soil strength between the rows in the treatments was unaffected by the tillage treatments.

5.2.3.4 Soil temperature

In 1995, at the Sandy loam site (SL95), during the period from seed germination to seedling emergence, soil temperature was measured with copper-constantan thermocouples inserted horizontally in each plot at seeding depth (50 mm). A data logger was used to read the output voltages from the thermocouples at one minute intervals and store the 15 minute average value. Data was downloaded to a computer every day and converted to °C using previously determined thermocouple calibration factors. Air temperature was measured simultaneously with soil temperature by inserting the thermometer into a cylindrical PVC shield of 40 mm diameter and 100 mm length, painted white on top and black on the bottom and mounted horizontally on a wooden stalk1.20 m above the soil surface.

5.2.3.5 Soil surface properties

In 1995, at the Sandy loam site (SL), soil surface roughness and the amount of organic surface residues were measured after sowing at the soil surface above the location of the thermocouples. The 480 Rimik Profilemeter with depth sensors 300 mm in length was used to measure the soil surface roughness. The frame of the instrument was placed at a reference height higher than the highest point of the profile. Four soil surface roughness measurements from each plot were stored in a data logger and downloaded to a computer. The mean and standard error of means was calculated for each plot.

A quadrant of 500×500 mm was used to collect soil surface residues with four replicates from around the thermocouples sites. The weight of residues was calculated after oven drying at 85 °C for 48 hours.

5.2.3.6 Soil pore structure

In 1994, at the Sandy loam site (SL94) site, three undisturbed soil monoliths (150×150×40 mm) were taken from each treatment for resin impregnation, photography and image analysis using the methods of Koppi et al. (1992). Figure 5.2 shows the sequence of procedures involved. Ciba-Geigy Araldite epoxy resin was used for impregnation. The mixture contained resin LC191 (170 g), diluent DY026 (170 g), hardener LC249 (160 g), opacifier DW0131 (5 g) and oracet (0.5 g). The resin mixture was poured onto a horizontally exposed vertical face of each monolith and left to harden for 48 hours. A small industrial milling machine was then used to expose the profile surface for photography under ultraviolet light.

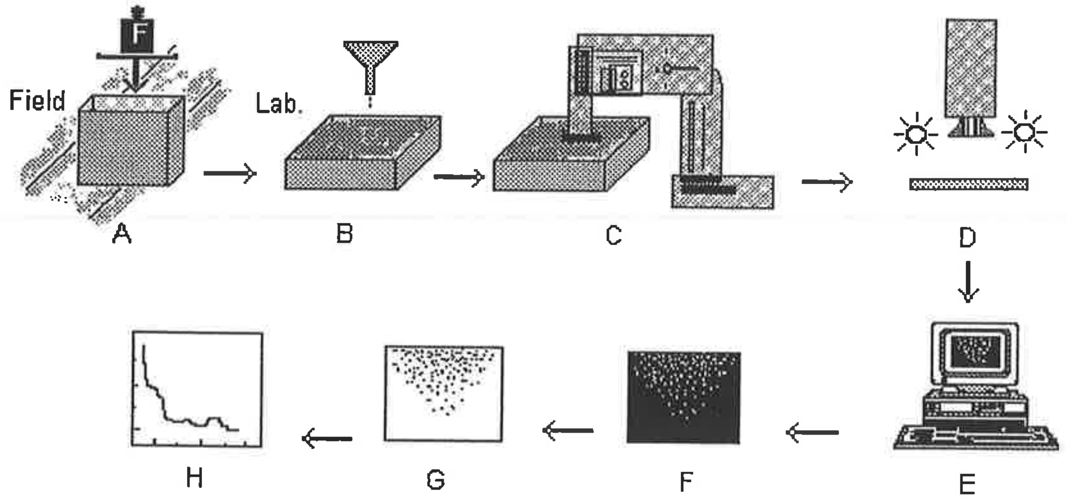


Figure 5.2 Diagram of soil porosity procedure. A sampling, B epoxy impregnation, C surface preparation, D photography, E and F scanning, G inverting, and H rapid analysis.

The methods of McBratney and Moran (1990) were used for statistical analysis of features on the photographic images. Mean pore-structure attributes (porosity, pore surface area per unit volume of soil and mean pore size) were calculated.

5.2.3.7 Water content

In 1994, at both sites, the soil volumetric water content was monitored during the period between sowing to anthesis using a Trase (Soil Moisture Equipment Corp.), time domain reflectometer (TDR). Two parallel stainless steel wave guides of the TDR were inserted over the center row at two locations on each plot. At each location a 150 mm and 300 mm length set of wave guides were used to obtain volumetric soil water contents every day from sowing, through to seed emergence and then at weekly intervals until anthesis. The wave guides were used to obtain mean volumetric moisture content (m m^{-1}) for depth intervals of 0-150 and 0-300 mm. The moisture content of the150-300 mm depth interval was calculated as

$$\theta_{(150\text{-}300)} = 2\theta_{(0\text{-}300)} - \theta_{(0\text{-}150)}. \qquad [3]$$

Actual available water capacity (mm) to a depth of 150 mm (W_{avail}) was determined from water contents measured during growing season using TDR. The actual available water capacity values were calculated as the difference between measured water contents (θ) and a lower limiting water content (θ_x) which was the greater value of either the water content at wilting point or at a penetration resistance of 3 MPa (θ_{pr}), multiplied by depth interval ($\Delta z = z_1 - z_0, z_2 - z_1, \ldots$), summed to 150 mm depth:

$$W_{avail} = \Sigma(\theta - \theta_x) \times \Delta z \times 1000 \qquad [4]$$

In several cases water content measured on the experimental plots exceeded field capacity or water content at which $\theta_a = 0.1$ m m^{-1}. Then following Letey (1985) and Cass et al. (1994), it was assumed that this water was not available for plant uptake and the upper limit of available water was adjusted accordingly.

When penetration resistance measurements were made, soil was sampled at the same time using a thin walled tube to extract a core of soil which was sectioned into depth intervals of 30, 60, 90, 120 and 150 mm. The core samples were weighed, dried at 105 °C and mass water content (kg kg^{-1}) calculated as

$$\theta_m = (D - W)/D \qquad [5]$$

where W is wet sample mass and D is oven dry (105 °C) mass of soil and converted to volume units by multiplying by relative bulk density.

5.3 Statistical analysis

Genstat 5 Release 1.3, (Genstat 5 Committee, 1993) was used to perform analysis of variance of soil bulk density, penetration energy, soil temperature, soil surface roughness, surface residues, and soil water content data. A randomised block design was used with four block replicates. The least significant difference was calculated for paired comparisons of mean values with the 95% confidence level. Table 5.1 shows the degrees of freedom available for statistical analysis of the data.

Table 5.1 The ANOVA table for statistical analysis of soil physical properties.

Source of variation	Degree of freedom
Tool type	4
Replicates	3
Residuals	12
Total	19

5.4 Results and Discussion

5.4.1 Site characteristics

Prior to sowing, experimental sites (CL and SL) were characterised in terms of particle size distribution, chemical properties and wilting point water contents. These data are shown in Tables 5.2, 5.3 and 5.4.

Table 5.2 Soil particle size distribution on the CL94 and SL94, before sowing.

Depth intervals (mm)	Mass % of oven dry soil			
	Coarse sand 2000-200 μm	Fine sand 200-20 μm	Silt 20-2 μm	Clay < 2μm
	Clay loam site			
0-50	15	48	9	26
50-100	17	38	17	23
100-150	14	50	4	30
150-300	10	43	5	41
300-450	9	40	12	37
	Sandy loam site			
0-50	28	56	5	8
50-100	23	58	3	12
100-150	17	55	7	18
150-300	20	54	5	20
300-450	24	42	10	23

Table 5.3 Soil chemical characteristics on the CL and SL, before sowing. All results calculated on air dry basis.

Site	Soil depth mm	Kjeldahl Nitrogen (N) %	Sulphur (S) mg kg^{-1}	Available Phosphorus (P) mg kg^{-1}	Available Potassium (K) mg kg^{-1}	Organic Carbon (OC) %	Alk. Earth Carbonate (CaCO3) %	pH (Ca Cl_2)	Salinity EC 1:5 dS m^{-1}
CL	0-100	0.11	4.8	33	520	1.0	3	7.7	0.14
	100-200	0.06	2.1	7	280	0.5	4	8.8	0.16
SL	0-100	0.13	3.3	17	300	1.2	6	8.5	0.11
	100-200	0.08	2.5	8	190	0.8	12	8.7	0.10

Table 5.4 Wilting point water content (wp) for two sites (CL94 and SL94) at 0-50, 50-100, 100-150,150-300 and 300-450 mm depth intervals. n (wp) = 10.

Depth intervals	Wilting point			
	SL		CL	
(mm)	kg kg^{-1}	m^3 m^{-3}	kg kg^{-1}	m^3 m^{-3}
0-50	0.040	0.057	0.087	0.123
50-100	0.052	0.079	0.111	0.170
100-150	0.060	0.087	0.135	0.194
150-300	0.105	0.151	0.171	0.247
300-450	0.095	0.136	0.160	0.230

5.4.2 Soil bulk density

Tables 5.5 and 5.6 show the mean bulk density (details are on page 73) before sowing and one week after sowing at the SL93, SL94 and CL94. Particle density (ρ_p) was assumed to be 2.65 Mg m^{-3} (Blake and Hartge, 1965).

Tables 5.5 shows that the point 45-W-S produced significantly lower bulk densities than other treatments at 0-50 mm depth for all three sowing depths, at 50-100 mm for sowing depths of 50 and 80 mm, and also at 100-150 mm soil depth for 80 mm sowing depth. Seeding points 90-0-0 and 45-0-0 showed higher bulk densities than other treatments. Cultivated treatment (CT) at 0-50 mm soil depth produced a lower bulk density than 45-0-0, 45-W-0, and 90-0-0 for 50 mm sowing depth, but this result was not significant.

Table 5.5 Mean bulk density values of the SL93 at 50, 100 and 150 mm depth intervals with sowing depth of 25, 50 and 80 mm using four narrow point treatments, before sowing (n=10) and one week after sowing (n = 4).

25 mm sowing depth

	Treatment	Bulk density, ρ_b (Mg m^{-3})		
	Depth intervals (mm) →	0-50	50-100	100-150
Pre sowing		1.393 a	1.560 a	1.450 a
Post sowing	45-0-0	1.275 b	1.459 a	1.457 a
	45-W-0	1.240 b	1.446 a	1.472 a
	45-W-S	1.125 c	1.383 b	1.460 a
	90-0-0	1.360 a	1.461 a	1.465 a
LSD (0.05)		0.069	0.114	0.090

50 mm sowing depth

	Treatment	Bulk density, ρ_b (Mg m^{-3})		
	Depth intervals (mm) →	0-50	50-100	100-150
Pre sowing		1.393 a	1.560 a	1.450 a
Post sowing	45-0-0	1.240 b	1.415 b	1.449 a
	45-W-0	1.180 bc	1.348 b	1.461 a
	45-W-S	1.108 c	1.235 c	1.428 a
	90-0-0	1.240 b	1.493 a	1.443 a
	CT	1.120 c	1.423 b	1.447 a
LSD (0.05)		0.106	0.093	0.078

80 mm sowing depth

	Treatment	Bulk density, ρ_b (Mg m^{-3})		
	Depth intervals (mm) →	0-50	50-100	100-150
Pre sowing		1.390 a	1.560 a	1.450 a
Post sowing	45-0-0	1.187 b	1.360 b	1.441 a
	45-W-0	1.085 c	1.340 b	1.477 a
	45-W-S	1.082 c	1.235 c	1.255 b
	90-0-0	1.240 b	1.413 b	1.453 a
LSD (0.05)		0.077	0.091	0.088

Mean followed by unlike letters in a column show significant difference at $P \leq 0.05$.

Table 5.6 shows the mean value of the soil bulk density (ρ_b) in the CL94 and SL94 sites with 50, 100 and 150 mm depth intervals one week after sowing. The result shows that seeding point 45-W-S produced lower soil bulk density values than other treatments at 0-50 and 50-100 mm soil depth in both CL and SL soils.

Table 5.6 Mean bulk density values (n = 4) of the CL94 and SL94 at 50, 100 and 150 mm depth intervals using five narrow seeding point treatments, before sowing and one week after sowing.

Site		CL			SL		
Soil depth (mm)		0-50	50-100	100-150	0-50	50-100	100-150
Treatment ↓			ρ_b (Mg m^{-3})			ρ_b (Mg m^{-3})	
Pre sowing		1.298 a	1.603 a	1.545a	1.398 a	1.568 a	1.463 a
Post sowing	45-0-0	1.240 a	1.565 a	1.550 a	1.253 b	1.538 a	1.440 a
	45-W-0	1.215 ab	1.545 a	1.517 a	1.237 bc	1.545 a	1.465 a
	45-W-S	1.080 b	1.202 b	1.485 a	1.162 c	1.360 b	1.435 a
	90-0-0	1.295 a	1.627 a	1.528 a	1.280 ab	1.567 a	1.448 a
	CT	1.273 a	1.512 a	1.462 a	1.335 a	1.517 a	1.482 a
LSD (0.05)		0.136	0.116	0.093	0.089	0.080	0.088

Mean followed by unlike letters in a column show significant difference at $P \leq 0.05$.

Higher bulk density resulted in 0-50 mm depth with seeding points 45-0-0 and 90-0-0 due to less soil disturbance (see Section 3.3.2 and Pictures 5.10a and 5.10d). Wings on seeding points produced more soil loosening and resulted lower bulk density at 0-50 mm depth. Seeding points without wings tended not to disrupt soil as much as points with wings, and below the point depth compaction occurred although the effect was not significant. 45-W-S produced lower bulk density in 50 -100 mm depths because of the extended blade, which disturbed soil to this depth (Section 3.3.2 and Picture 5.10c).

5.4.3 Penetration energy and resistance

Penetration energy is a bulk property of soil obtained by integrating the penetration resistance profile from the surface to a given depths, in this case 150 mm. It is an index of the restriction that soil strength may impose on an emerging seedling or growing root, although no critical limit criteria have been published in the literature. In this study penetration energy has simply been used to compare different seeding point treatments and provide a quantitative index for the degree of soil disturbance caused by different seeding points.

Penetration energy (P_E) in 1993 was calculated (Eq. 2) for the 0-150 mm depth interval for four narrow point treatments at three sowing depth intervals of 25, 50 and 80 mm (Table 5.7). The CT treatment was sown only at 50 mm depth. Pre-sowing penetration energy was 259 kJ m^{-2} from 0-150 mm soil depth. The result shows that there was no significant difference in the penetration energy between the treatments at a sowing depth of 25 mm except point 45-W-S which produced significantly lower penetration energy than other treatments. At a sowing depth of 50 mm, the CT and point 45-W-S had a significantly lower penetration energy compared with other treatments. There was no significant difference at a sowing depth of 80 mm except point 45-W-S which had a significantly lower penetration energy than other treatments. The conventional treatment at a sowing depth of 50 mm and 45-W-S at all sowing depths (25, 50 and 80 mm) caused more soil weakening than other treatments.

Table 5.7 After sowing, penetration energy (P_E) from 0-150 mm soil depth at 25, 50 and 80 mm sowing depth intervals using five narrow seeding point treatments. n (PE) = 12

Sowing depth (mm) →	25	50	80
Treatment		Penetration energy P_E (kJ m^{-2})	
45-0-0	169.0 a	152.4 a	137.4 a
45-W-0	171.1 a	166.6 a	138.1 a
45-W-S	139.0 b	108.6 b	97.1 b
90-0-0	169.1 a	141.8 a	135.0 a
CT	—	110.5 b	—
LSD (0.05)	29.3	19.4	34.9

Mean followed by unlike letters in a column show significant difference at $P \leq 0.05$.

Penetrometer resistance values and associated water content profiles on the SL94 are shown in Figure 5.3. These data are shown with field capacity and wilting point water contents and penetration resistance limits of 1 and 3 MPa. Wilting point water contents are assumed not to vary with treatment, but field capacity values reflect treatment differences. The measurement of penetration resistance and water contents are also shown at three occasions in each plot; before sowing, after sowing and after emergence.

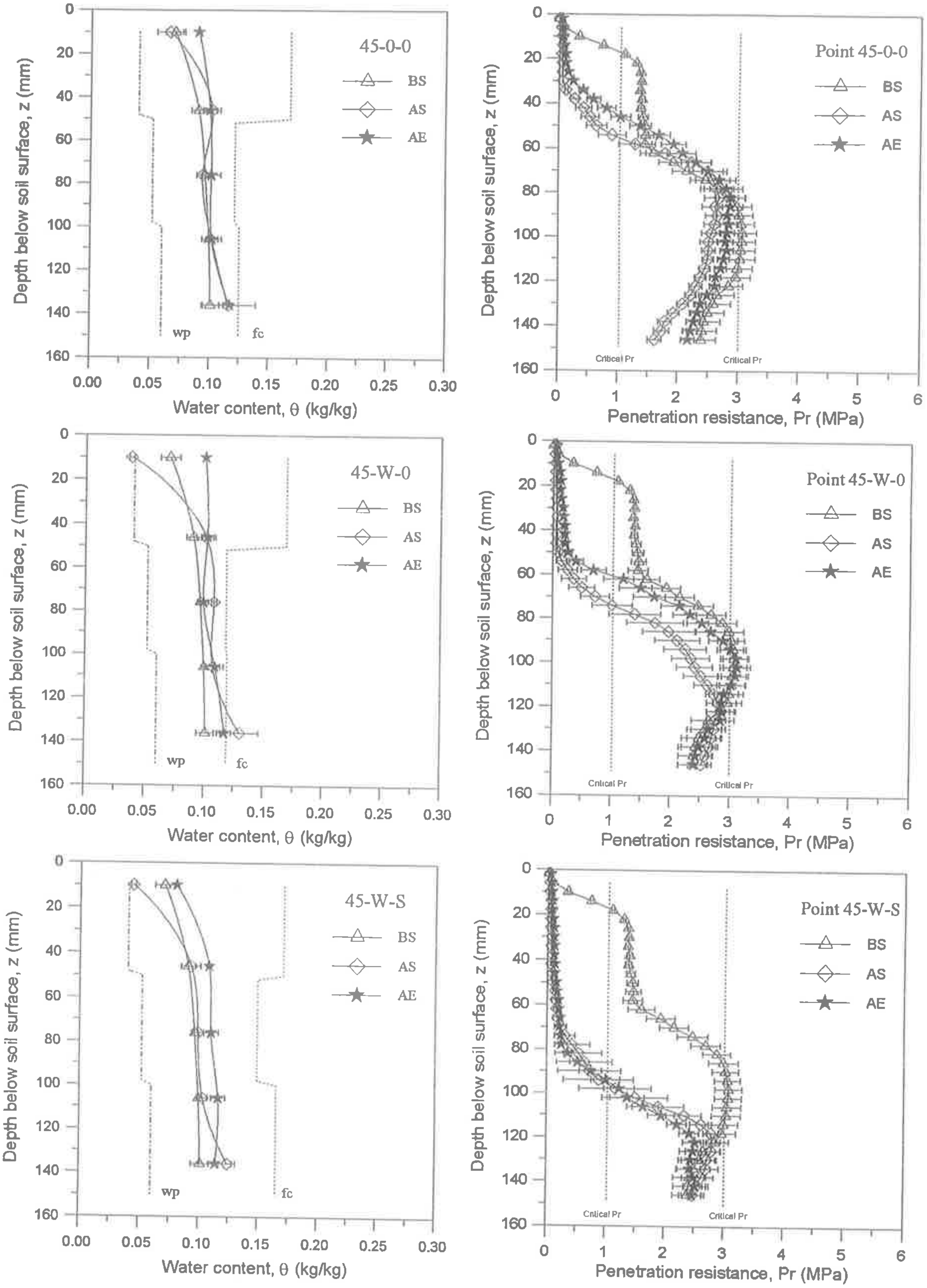


Figure 5.3 continued

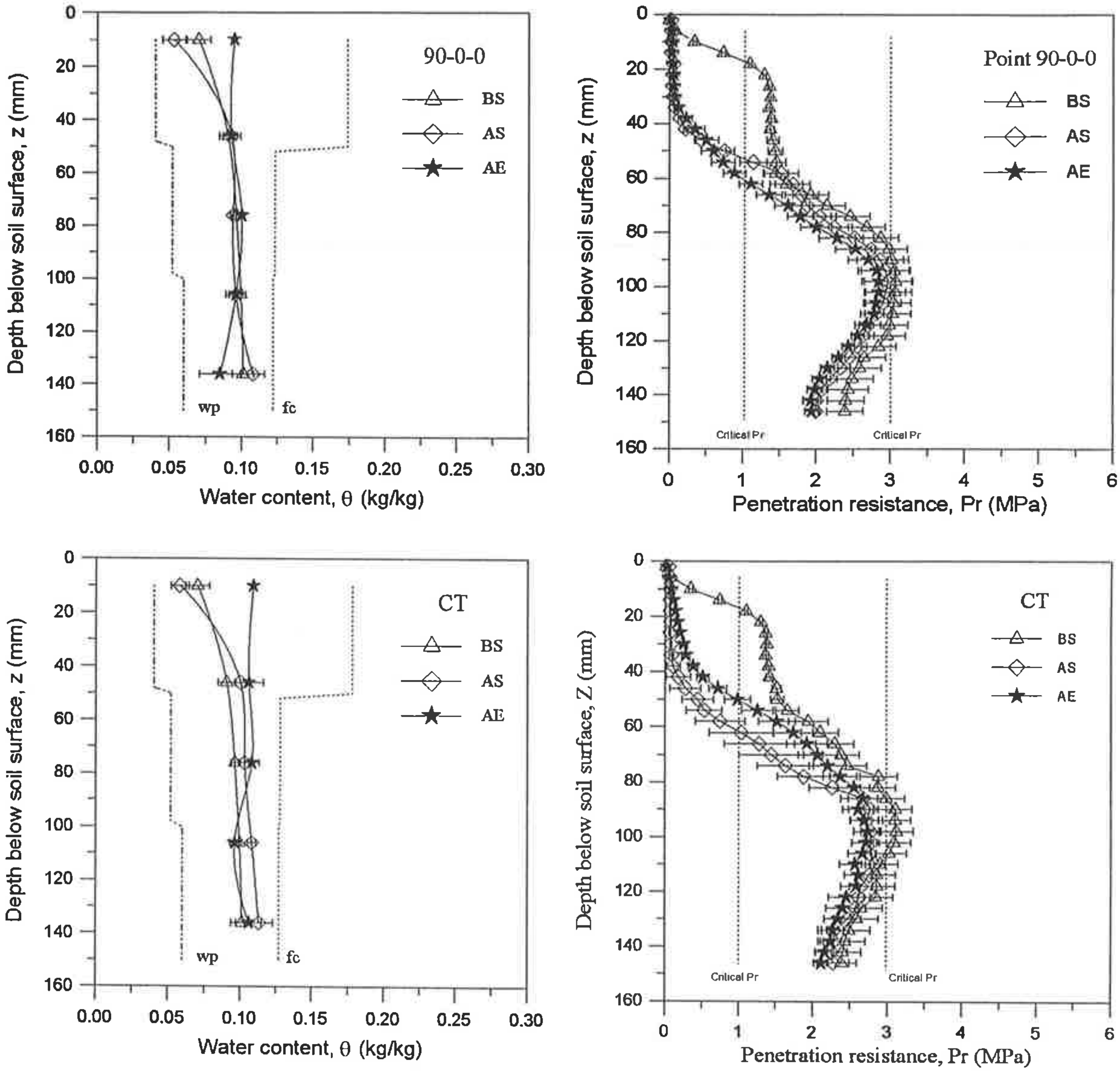


Figure 5.3 Water content (right) and penetration resistance (left) as a function of soil depth for five narrow seeding point treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0, and CT) on the SL95 site. Penetration resistance was measured on three occasions; before sowing (BS), after sowing (AS), and after emergence (AE). (wp) and (fc) are 'wilting point' and 'field capacity' for three depth intervals: 0-50, 50-100, and 100-150 mm. Broken lines show critical penetration resistance ($Pr_{critical}$) and error bars are 2× standard error of mean, n (Pr) = 12; n (θ) = 12; n (wp) = 4 and n (fc) = 3.

Before sowing, the penetration resistance of the soil at the SL94 was low up to about 50 mm depth below the surface, i.e just above 1 MPa even though water content was well below field capacity. Penetration resistance values between 1 and about 3 MPa over the available water content range (field capacity to wilting point) are regarded as indicative of acceptable soil physical quality (Letey, 1985; Cass et al., 1994).

Below about 60 mm, soil strength increased substantially, reaching or exceeding 3 MPa even though the water contents were close to field capacity values. Root growth in this layer would have been periodically restricted by high penetration resistance (Letey, 1985). There was evidence of a tillage pan at 90 to 120 mm.

After seeding, soil strength decreased in both the upper layers (0-50 mm) and the lower layers (> 60 mm) to less than 1 MPa. The lower depth to which this change occurred was dependent on the type of seeding point. For most of the seeding points this change did not extend to depths in excess of about 80 to 90 mm and below this the soil remained as hard as before sowing and the tillage pan at 90 to 120 mm was not generally weakened.

The exception to the above observation was noted for seeding points 45-W-0 and particularly 45-W-S. The latter point in operating to greater depths, weakened the soil to about 120 mm and reached the tillage pan. Below 120 mm the physical quality of the soil was good, with $1 < Pr < 3$ MPa in the range $\theta_{wp} < \theta < \theta_{fc}$. It should be noted that water content did not vary markedly from before sowing to after emergence (Fig. 5.3).

Measurement of penetration resistance after emergence showed that the soil remained weak over the depth of disturbance. Points 45-0-0 and 45-W-0 showed increased soil strength at depths from 40-70 and 60-120 mm, which may be explained by a change in water content (Fig. 5.3).

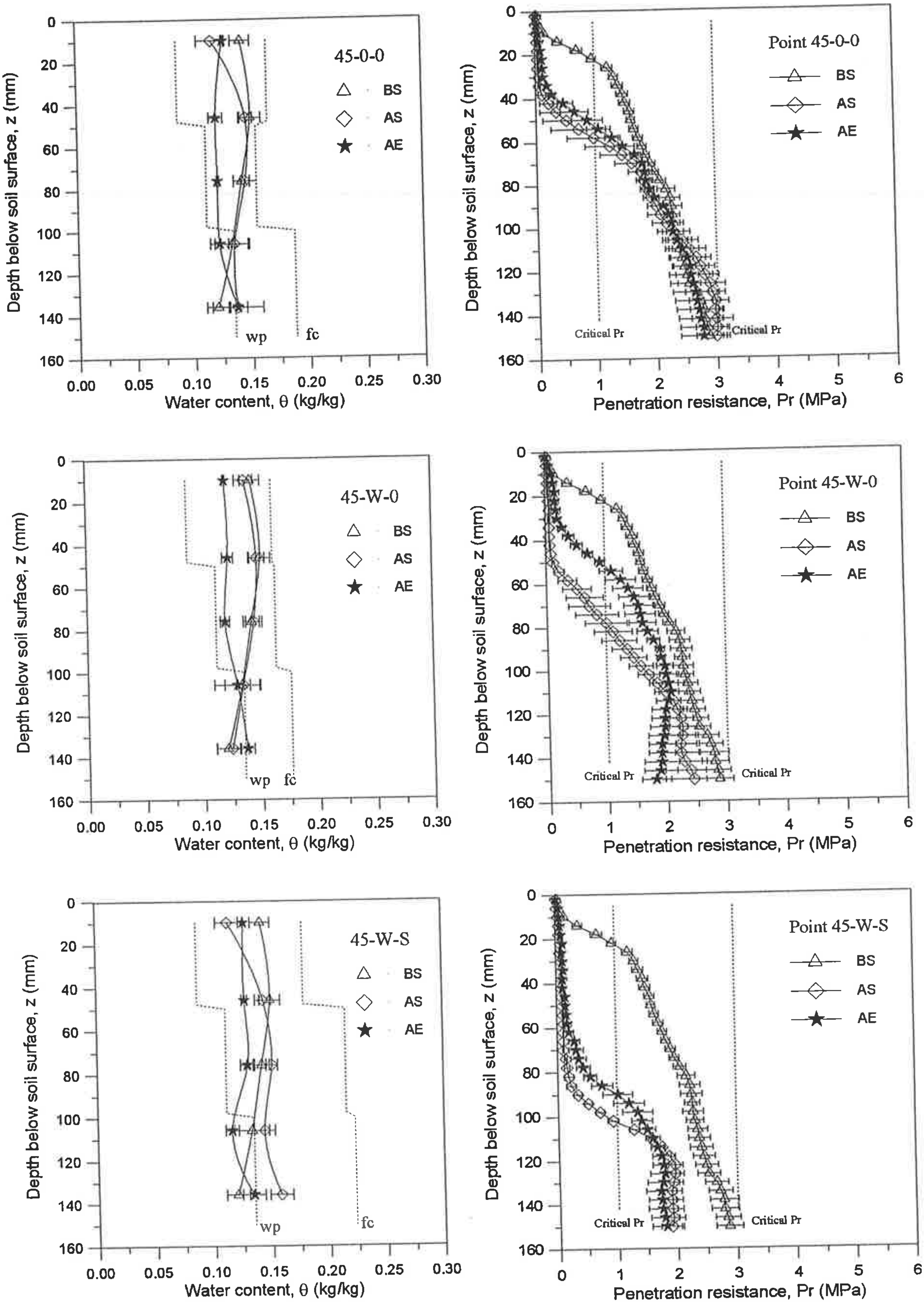


Figure 5.4 continued

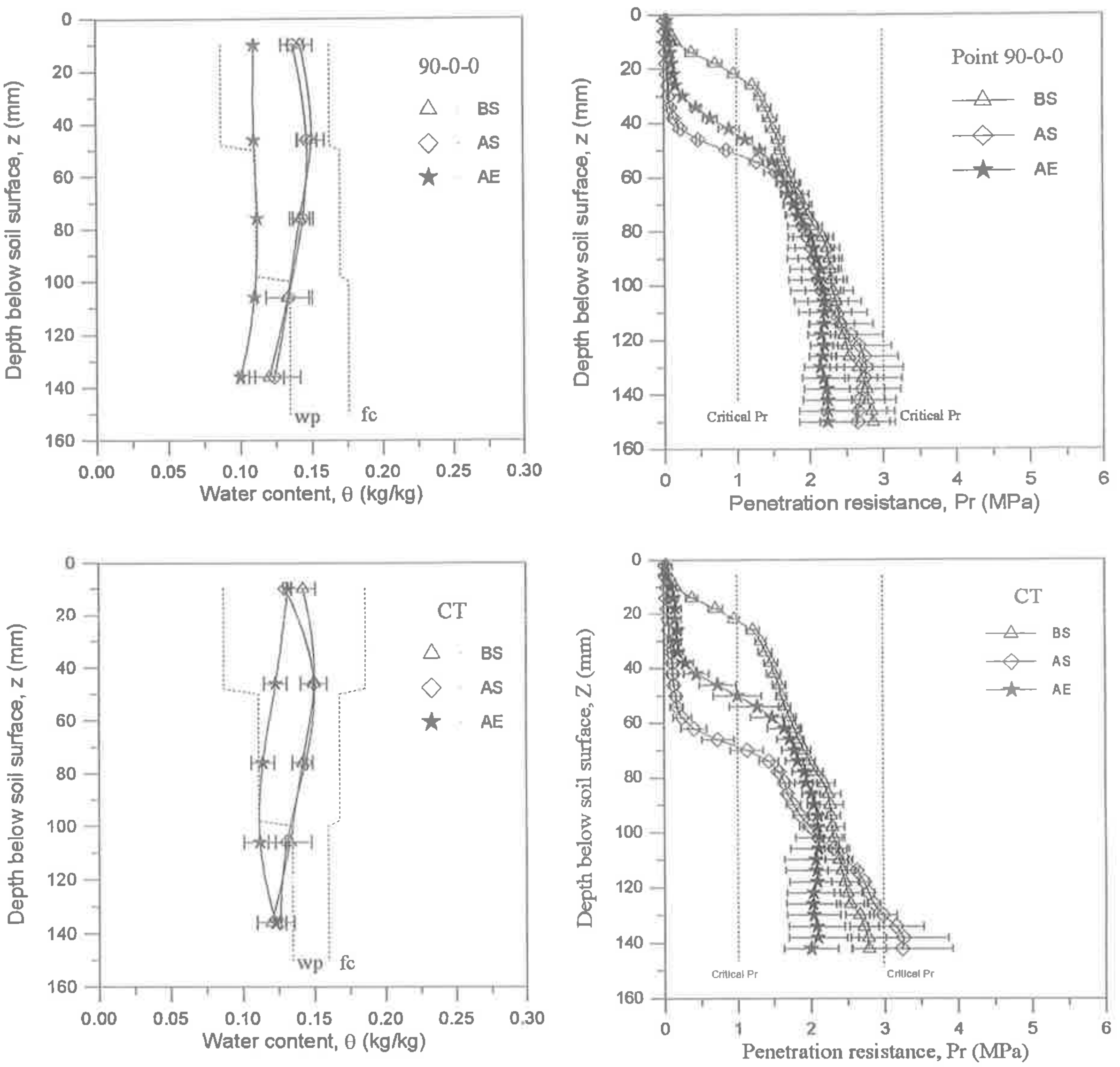


Figure 5.4 Water content (right) and penetration resistance (left) as a function of soil depth for five narrow seeding point treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0, and CT) on the CL94. Penetration resistance at three occasions; before sowing (BS), after sowing (AS), and after emergence (AE). "wp" and "fc" are 'wilting point' and 'field capacity' for three depth intervals: 0-50, 50-100, and 100-150 mm. Broken lines show critical penetration resistance (critical p_r) and error bars are 2× standard error of mean, n (Pr) = 12; n (θ) = 12; n (wp) =5 and n (fc) = 3.

Penetrometer resistance values and associated water content profiles on the CL94 are shown in Figure 5.4. These data are shown with field capacity and wilting point water contents and penetration resistance limits of 1 and 3 MPa. The measurements of penetration resistance and water contents are also shown at three occasions in each plot; before sowing, after sowing and after emergence on the five seeding point treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0, and CT).

Similar results were obtained for penetration resistance at the CL94 as were described for the SL94 (compare Fig. 5.3 and 6.4). However, three main differences were evident. Firstly at the CL94, there was no tillage pan in the top 150 mm. Secondly, after sowing, soil of most seeding point treatments appeared to have become stronger at depths of up to about 100 mm. Conventional tillage (CT) appeared to be weaker below 100 mm after emergence. The third major difference between the two sites was that the CL site was drier. Water content was close to wilting point at depths below 100 mm and had become even drier by the time of emergence.

In order to reduce the extensive data set shown in Figures 5.3 and 5.4, penetration energy was calculated for the depth interval 0-150 mm from the penetration resistance profiles (Eq. 2). Mean penetration energy values are listed in Table 5.8 for the CL94 and SL94 sites on two occasions after sowing and after emergence for the 5 narrow seeding point treatments.

Table 5.8 Penetration energy (P_E) in kJ m^{-2} to a depth of 150 mm, after sowing and after emergence on two sites (CL94 and SL94) for five narrow seeding point treatments.

Treatment	Penetration energy (kJ m^{-2}) after sowing		Penetration energy (kJ m^{-2}) after emergence	
	CL94	SL94	CL94	SL94
	mean P_E	mean P_E	mean P_E	mean P_E
45-0-0	223 a	211 a	210 a	253 a
45-W-0	166 ab	194 a	192 a	227 b
45-W-S	108 b	148 b	122 b	141 c
90-0-0	208 a	217 a	223 a	243 ab
CT	171 a	164 a	197 a	213 b
LSD (0.05)	61	60	41	20

Mean followed by unlike letters in a column show significant difference at $P \leq 0.05$.

Table 5.8 showed that the point 45-W-S produced a significantly lower penetration energy compared to other treatments at both sites (CL94 and SL94) and on both occasions (after sowing and after emergence) whilst points 45-0-0 and 90-0-0 showed higher penetration energy. Other notable responses were with the CT treatment and point 45-W-0 which showed lower penetration energy than points 45-0-0 and 90-0-0 at the SL94 after emergence.

5.4.4 Soil temperature

Soil temperature may have an important effect on wheat germination and emergence in cool area. Soil temperature for over different seeding points was measured because these treatments may influence soil temperature and therefore germination and emergence. This information, although of possible limited value in South Australia, may have greater importance elsewhere.

Figure 5.5 shows an example of the temperature variation logged over a 36 hour period during four days after sowing for the narrow seeding point treatments at SL95. This example and the other data, show that the seedbed in the CT treatment had warmer soil temperature and seeding point 45-W-S was consistently second warmest at seeding depth (50 mm). Soil tilled with point 45-0-0 responded more to variation in air temperature and was higher than for points 45-W-0 and 90-0-0 during the day time and lower than all points at night time. This trend was consistent during the two weeks that data has recorded.

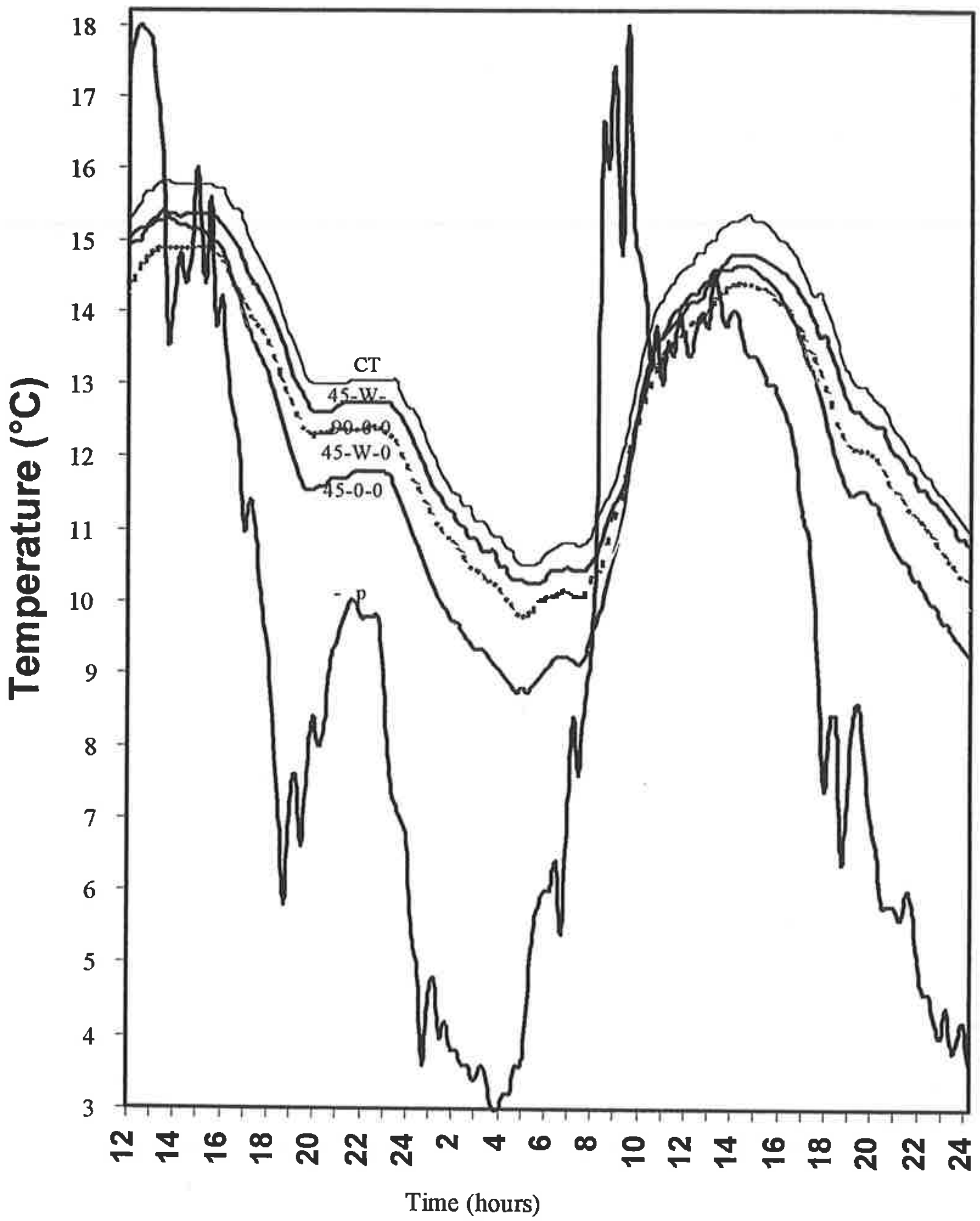


Figure 5.5 Variation of air temperature above the soil surface and soil temperature at sowing depth of 50 mm with time for five seeding point treatments; 45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT at SL.

Mean soil temperatures were calculated for each of the treatments over the period from sowing to emergence at 3 am, 9 am, 3 pm and 9 pm (Fig. 5.6). These means show that soil where CT treatment and point 45-W-S were used was significantly warmer than that of any other treatment. The only other notable response was with point 45-0-0 at 3 PM which showed a higher soil temperature than 45-W-0 and 90-0-0. These differences could be due to a number of factors, namely difference in surface cover, producing variable insulation effects, difference in surface roughness producing different radiation absorbency effects and differences in surface porosity producing different radiation conductivity effects. These parameters were investigated.

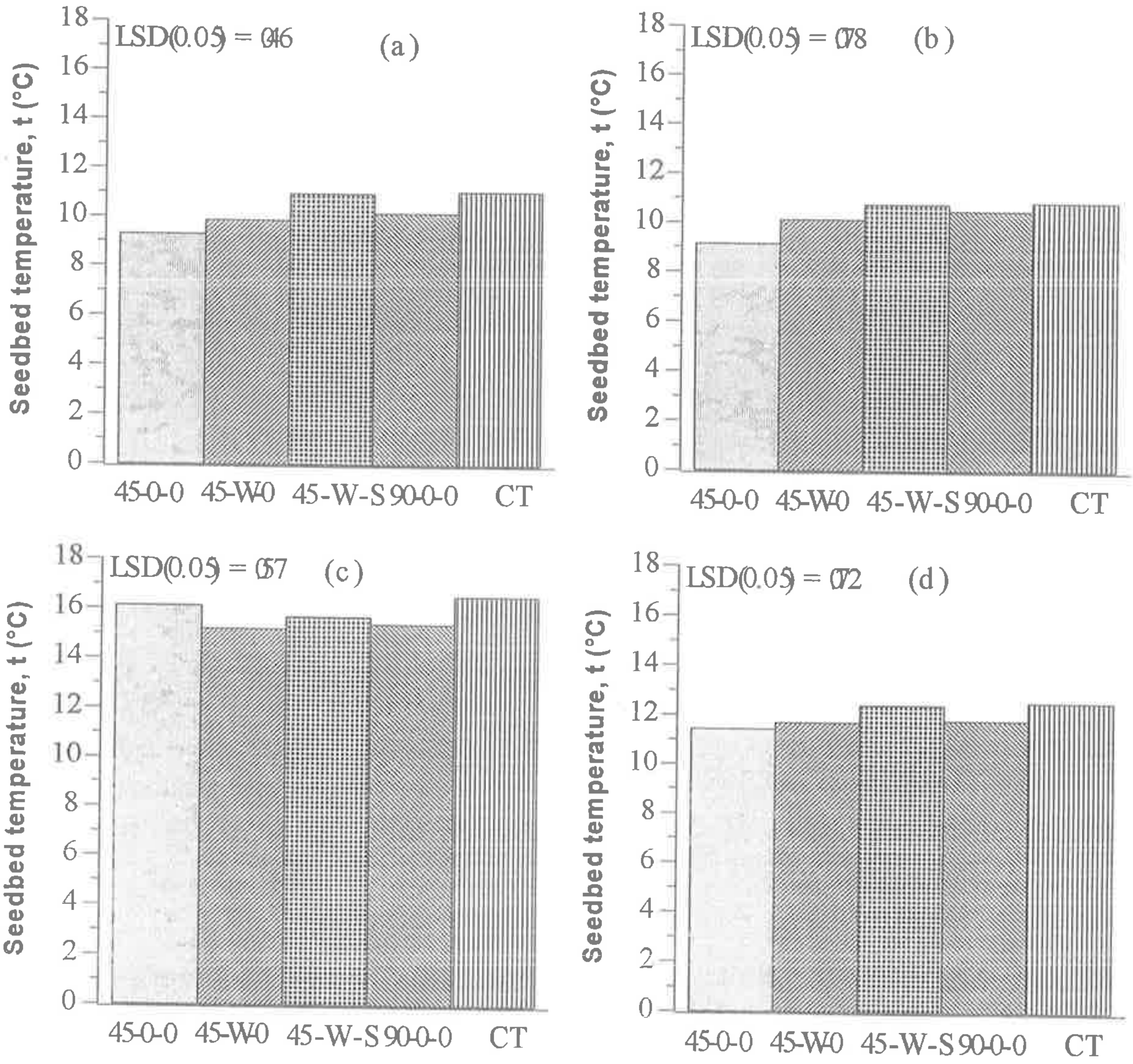


Figure 5.6 Mean soil temperature for each of the treatments over the period from sowing to emergence at 3 am (a), 9 am (b), 3 pm (c) and 9 pm (d) on a sandy loam soil.

Soil temperature and its associated surface attributes are shown in Table 5.9.

Table 5.9 Mean soil temperature, surface residues, surface roughness, and total porosity for five narrow seeding point treatments on the SL95 site.

Treatment	Soil temperature °C	Surface residues t ha^{-1}	Surface roughness (mm)	Macroporosity (m^3 m^{-3})
45-0-0	11.69	0.67	23.56	0.0364
45-W-0	11.96	0.49	24.75	0.0936
45-W-S	12.58	0.51	29.81	0.1442
90-0-0	12.20	0.83	22.13	0.0581
CT	12.89	0.34	19.19	0.1739

5.4.4.1 Surface residue

The amount of surface residue around the locations at which thermocouples were installed was measured to investigate the effect of surface cover on soil temperature. The results show that the seeding points 45-0-0 and 90-0-0 had significantly larger surface cover whilst CT had a smaller amount of residues (Fig. 5.7). These results show that the residues pushed in the soil when the points had more soil disturbance, and probably high amount of residues in the soil caused a warmer seedbed which resulted on the CT treatment and the point 45-W-S.

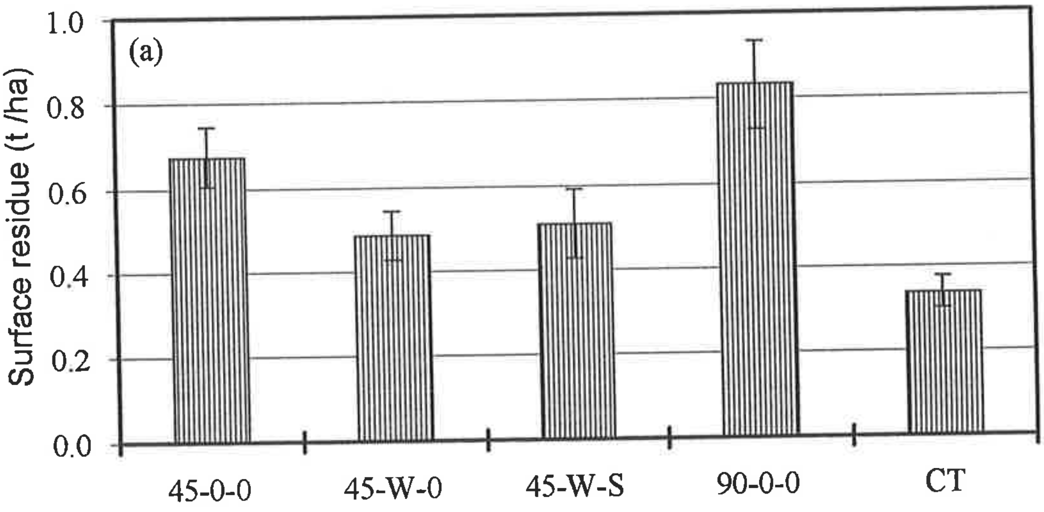


Figure 5.7 Mean values of soil surface residue (t ha^{-1}) associated with five seedingpoint treatments at SL95 site.

5.4.4.2 Surface roughness

Surface roughness was measured above the locations where thermocouples were installed to investigate the effect of surface configuration on soil temperature. The mean values for five narrow point treatments are shown in Figure 5.8.

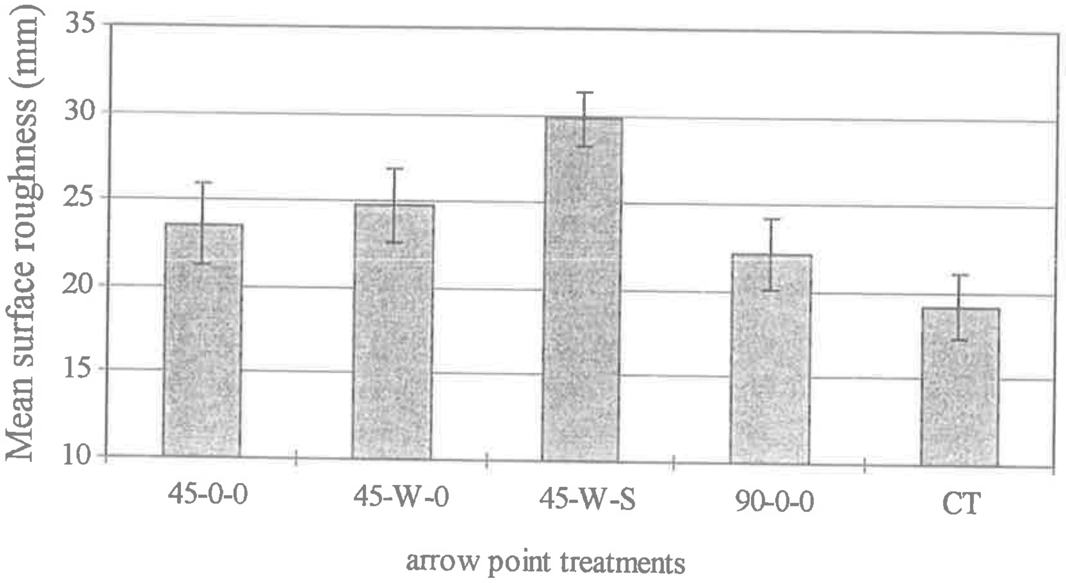


Figure 5.8 Mean value of soil surface roughness (mm) for the five seedingpoint treatments at SL95 site.

The results show that there was no significant difference between treatments except point 45-W-S which had significantly higher surface roughness than other treatments. The surface of soil tilled with point 45-W-S would intercept more radiation during daylight hours. Accordingly a higher daytime soil temperature could be expected for this treatment. Figure 5.9 shows this to be true for mean 24 hour temperature, but also shows that CT is equally high although it has a low surface roughness.

Figure 5.9 shows the trend lines of soil temperature (°C) as a function of total porosity. The trends show that there is a linear relation between temperature vs porosity.

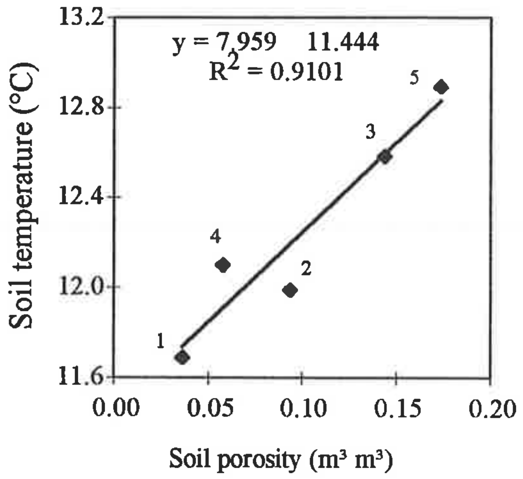


Figure 5.9 Trendline of soil temperature with total porosity. The numbers (1, 2, 3, 4, 5) represent the sowing treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT treatment) respectively.

5.4.5 Soil pore structure

Photographs of the soil samples from the vertical section of the soil surface are shown in Figure 5.10 for five narrow point treatments with three replicates. Results of the estimation of total porosity of soil monoliths impregnated with resin on the SL94 site are shown in Figure 5.11 as a comparison between the control seeding point (45-0-0) and the other points. The probability that the control porosity is similar to that of the other treatments is also shown in Figure 5.11.

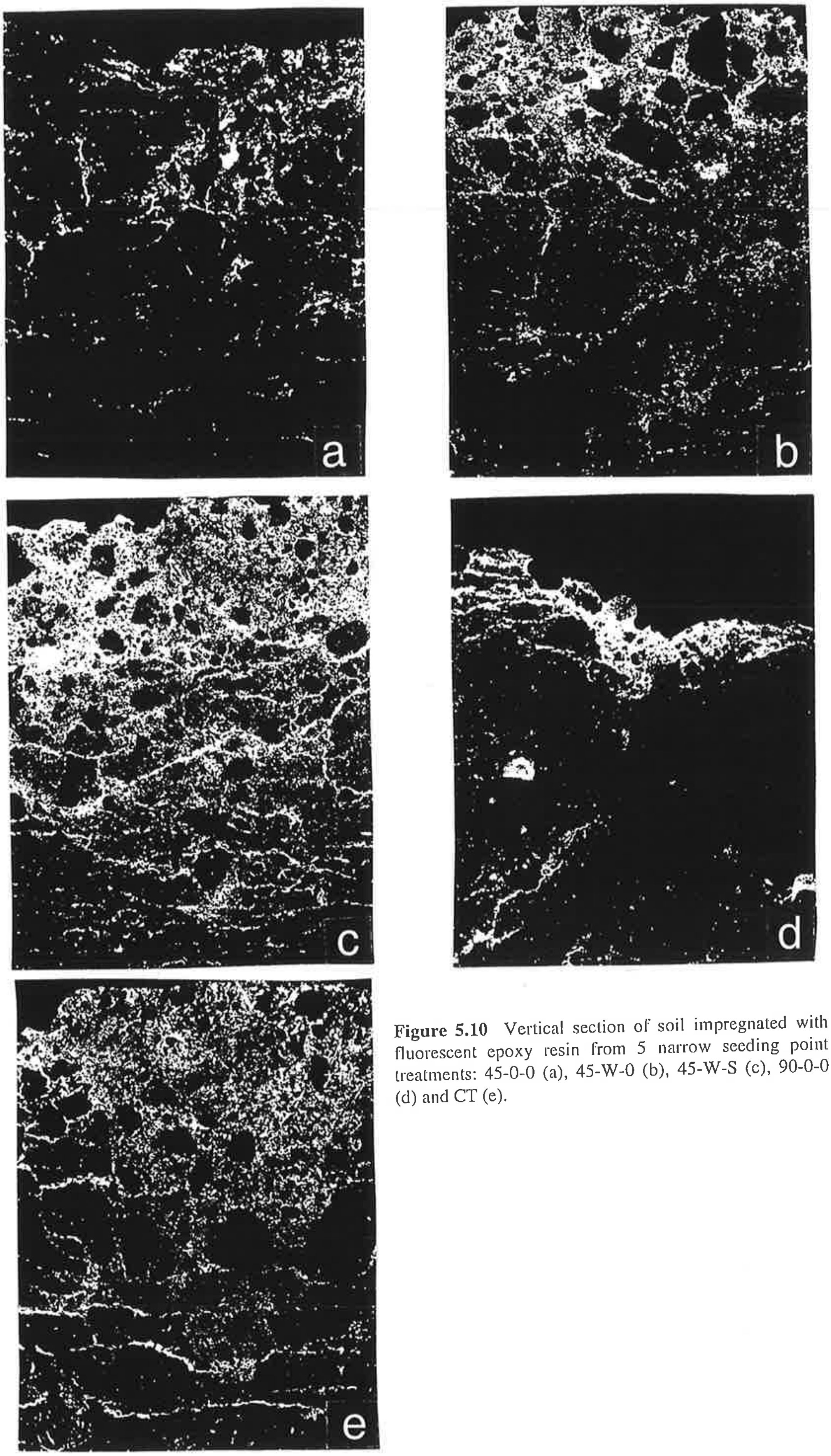


Figure 5.10 Vertical section of soil impregnated with fluorescent epoxy resin from 5 narrow seeding point treatments: 45-0-0 (a), 45-W-0 (b), 45-W-S (c), 90-0-0 (d) and CT (e).

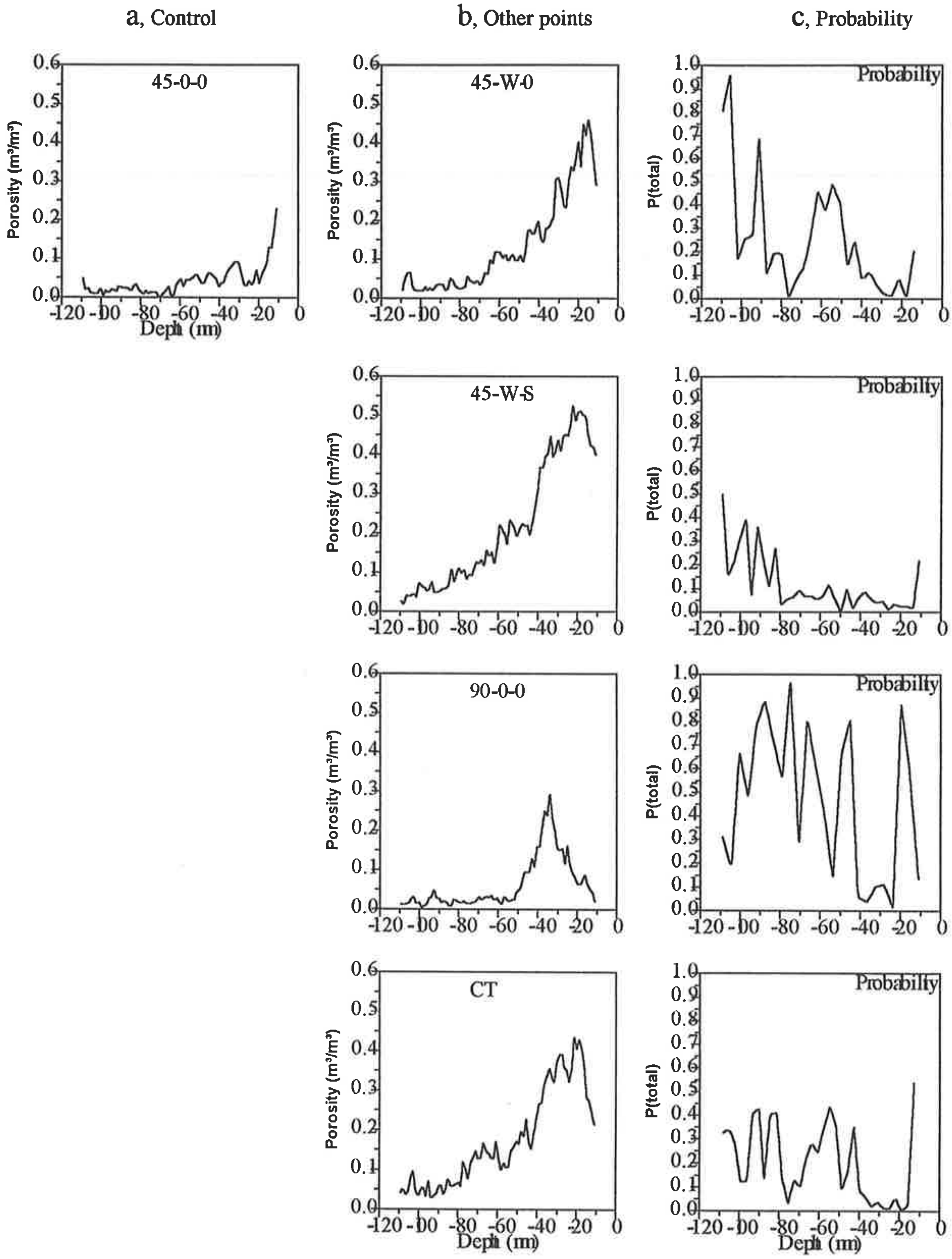


Figure 5.11 The variation of porosity (m³ m^{-3}) as a function of depth below the surface of the soil (mm) for (a) the control seeding point, 45-0-0; (b) seeding points 45-W-0, 45-W-S, 90-0-0 and CT; (c) the probability that (a) and (b) are the same.

A summary of the comparison shown as an example in Figure 5.11 is provided for all the attributes measured on the resin impregnated monoliths in Table 5.10. Structural attributes for different treatments were judged to be similar provided the probability of the difference was less than 10 % (see Fig. 5.11 for example).

Table 5.10 indicates that the pore attributes which were affected by different seeding points were porosity and surface area of pores, but not average pore size. This means that soil disturbance by the seeding points did not create a significantly different system of pore sizes, but a significant different numbers of pores of a narrower range of sizes.

Table 5.10 Soil pore structural attributes for four tillage treatments compared to those after direct seeding with the 45-0-0 point on the SL soil. Significant differences were judged to be present if the probability that the attribute was the same as that of 45-0-0, was < 10 %.

Pore- structural attributes	CT	90-0-0	45-W-0	45-W-S
Average pore size	Similar	Similar	Similar	Similar
Total porosity	Greater 20-30 mm	Similar	Greater 10-30 mm	Greater 10-50 mm
Surface area of pore space	Greater 20-40 mm	Similar	Greater 20-30 mm	Greater 20-50 mm

The data shows that 90-0-0 did not affect pore-structural attributes compared to 45-0-0. Seeding points 45-W-0 and 45-W-S produced a more favourable seedbed (greater porosity and pore surface area) than 45-0-0 and 45-W-S improved pore attributes to a greater depth than 45-W-0. The cultivated treatment (CT) which involved 2 pre-sowing tillage passes, also produced more favourable pore attributes than 45-0-0.

5.4.6 Soil water content

Figure 5.12 and 5.13 show soil water content as a function of time (days after sowing) on the CL94 and SL94 sites, respectively, at 0-150 and 150-300 mm soil depth together with rainfall.

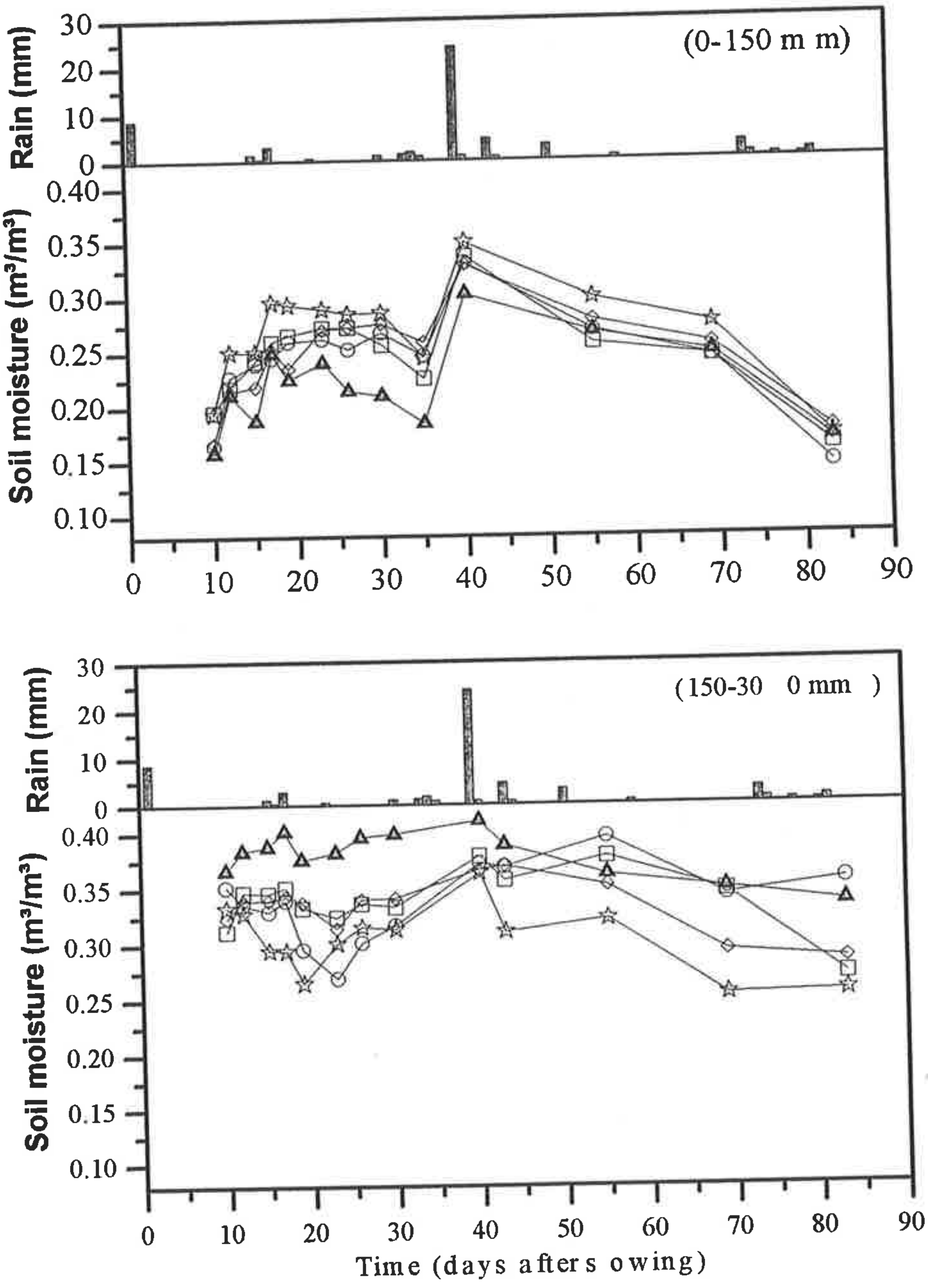


Figure 5.12 The variation of soil moisture (m³ m^{-3}) as a function of time (days after sowing) at two depth intervals of 0-150 and 150-300 mm on the CL94, for five sowing treatments, CT (○), seedingpoint 45-0-0 ( ), 45-W-0 (◊), 45-W-S (Δ) and point 90-0-0 ( ).

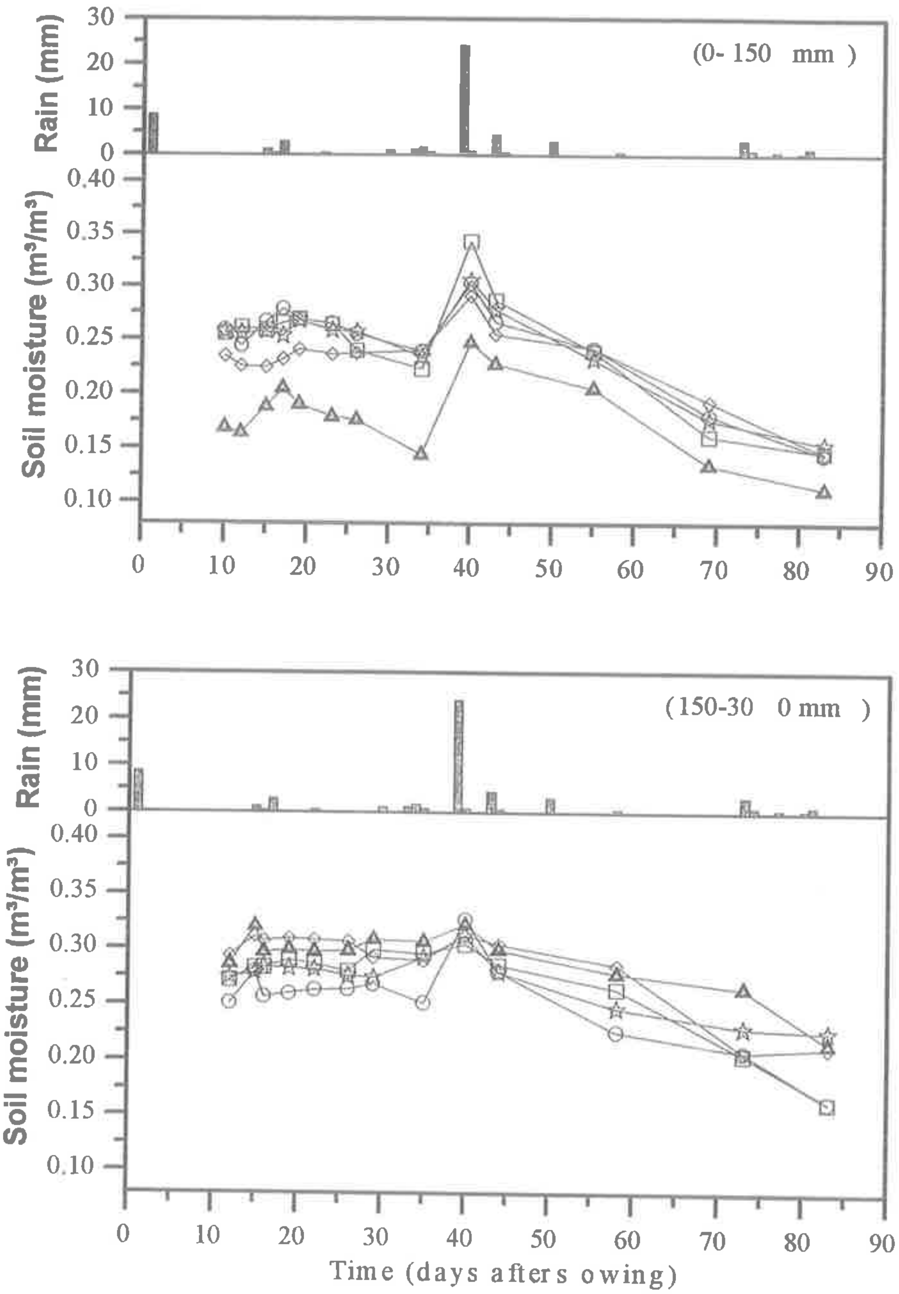


Figure 5.13 The variation of soil moisture ($m^3 m^{-3}$) as a function of time (days after sowing) at two depth intervals of 0-150 and 150-300 mm on the SL94, for five sowing treatments, CT (O), seedingpoint 45-0-0 (□), 45-W-0 (◊), 45-W-S (Δ) and point 90-0-0 ( ).

Figure 5.14 summarises data over three months from Figures 5.12 and 5.13 as the mean water content ($m^3 m^{-3}$) at two depth intervals of 0-150 and 150-300 mm on the CL and SL sites, for five narrow point treatments from seeding to anthesis in 1994. Seeding point 45-

W-S had a significantly ($P \geq 0.05$) lower water content than other treatments at 0-150 mm soil depth, but it

produced higher water content at 150-300 mm soil depth. Also the figure shows that the CL94 had higher water content than the SL94 at 150-300 mm depth.

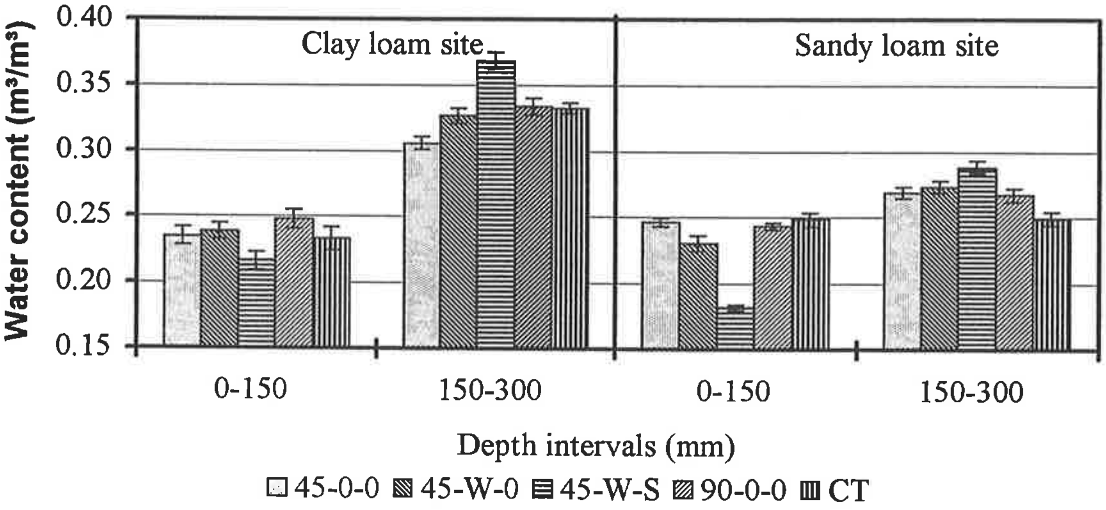


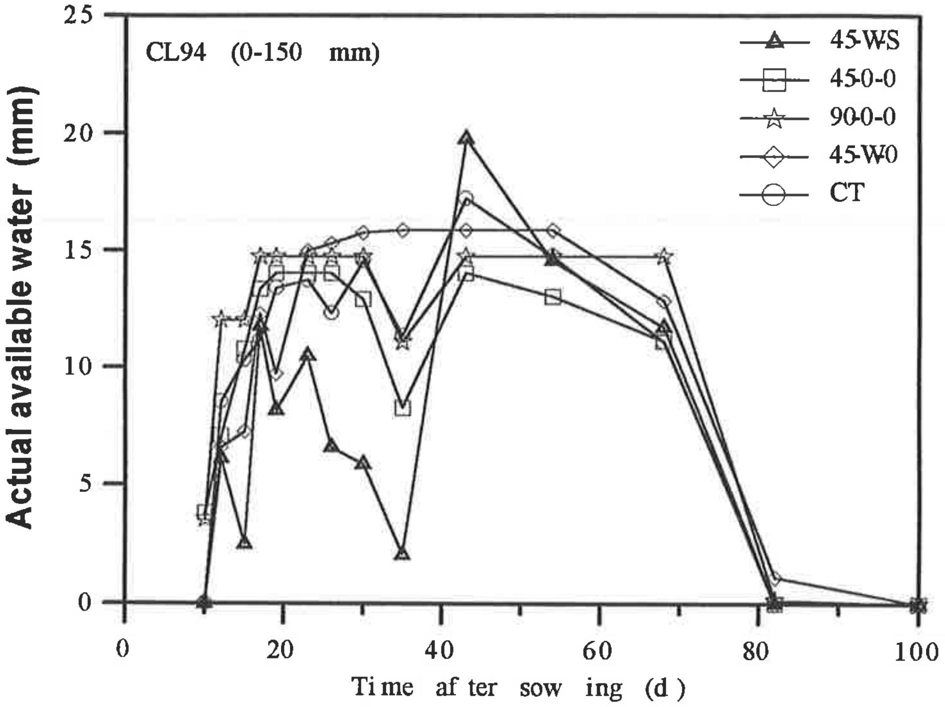
Figure 5.14 Mean soil moisture (m^3 m^{-3}) for the period seedling to anthesis (July to Oct.) at two depth intervals of 0-150 and 150-300 mm on the CL94 and SL94, for the five seeding point treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT).

Greater soil disturbance at surface and depth may result better rain penetration, better drainage and possibly higher evaporation. However, the low air temperatures during the early part of the season probably resulted in only small evaporation losses of water for the top 150 mm of soil.

The data suggest that limitations to water uptake may have been imposed by development of an anaerobic condition in the early part of the season. Later in the season, limitations to water availability could have arisen from strength limitations to root growth. For these reasons it is important to examine the effect of these factors on water availability.

Figure 5.15 shows actual available water capacity, (mm, Eq. 4) to a depth of 150 mm, calculated from water content measured after sowing throughout the wheat growing season at the CL94 and SL94, for five sowing treatments. The actual available water represents total water content adjusted for field capacity, aeration, strength or wilting point constraints as discussed in Chapter 6.

Figure 5.15, in comparison to Figures 5.12 (0-150 mm) and 5.13 (0-150 mm) show that 45-W-S had larger reserves of available water and that this water was used more rapidly and replace more readily from rainfall by the growing crop than that of other treatments. In the seeding point treatments other than 45-W-S point much of the water reserve in the soil was potentially unavailable because strength developed very rapidly (later season, SL site). Figure 5.15 relies on theory developed in Chapter 6. The actual available water shown in this figure is calculated from the range of water content at field capacity and wilting point but reduced by the limitations imposed by either poor aeration at field capacity or high strength before wilting point is reached. Actual available water therefore takes account of poor soil structure on water availability.



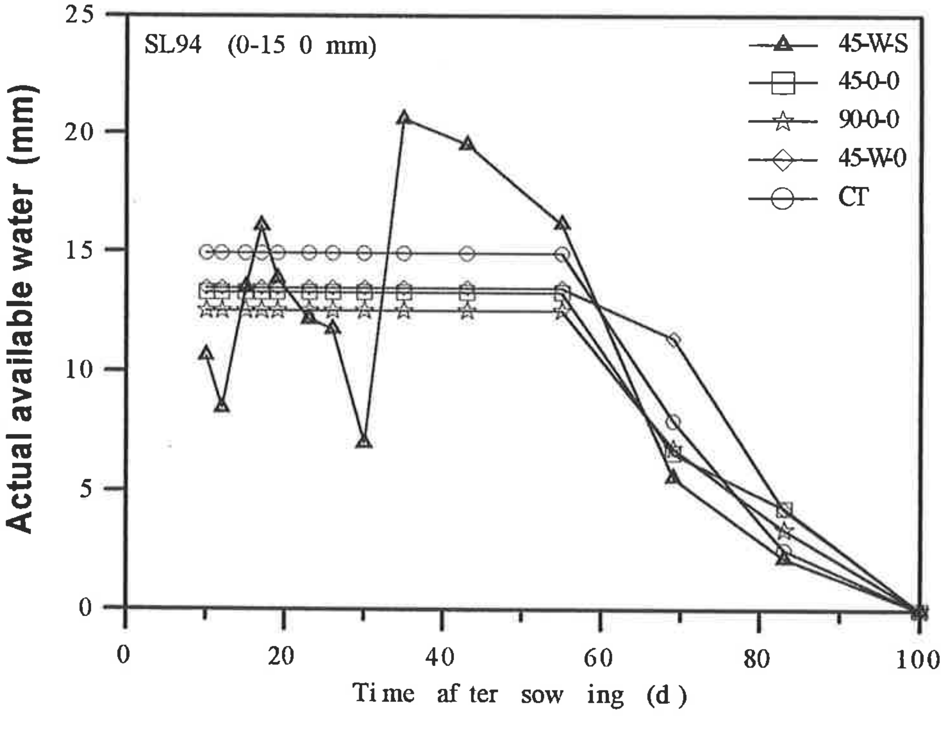


Figure 5.15 Actual available water capacity, (mm, Eq. 4) to a depth of 150 mm, calculated from water content measured after sowing throughout the wheat growing season at the CL94 and SL94, for five sowing point treatments, 45-0-0 (◊), 45-W-0 ( ), 45-W-S (Δ), 90-0-0 ( ) and CT (o).

5.5 Conclusions

After sowing wheat with four different shaped sowing points and also following conventional cultivation, sowing point 45-W-S produced lower soil bulk density values than other treatments at 0-50 and 50-100 mm soil depth at two sites with the CL and SL soil respectively.

Seeding point 45-W-S operated deeply to loosen soil up to 120 mm and ameliorate tillage pans or hard layers to this depth. Soil strength decreased to less than 1 MPa at water contents below field capacity and even close to wilting point in the case of the CL site.

Conventional sowing at a depth of 50 mm and 45-W-S at depths of 50 and 80 mm had lower penetration energy indicating more soil disturbance than other treatments.

Seeding point 45-W-S which loosened the soil below the seedbed, produced the lowest penetration energy at both sites (CL and SL) whilst points 45-0-0 and 90-0-0 had higher penetration energies. The CT treatment and point 45-W-0 had lower penetration energy than points 45-0-0 and 90-0-0 at the SL site.

A warmer seedbed was created by using CT treatment and the point 45-W-S from germination to the end of emergence.

Seeding points 45-W-0 and 45-W-S produced a seedbed with potentially more favourable soil physical properties for plant growth (greater porosity and pore surface area) than other treatments, whilst point 45-W-S improved pore attributes (total porosity and surface area of pore space) to a greater depth than 45-W-0. The cultivated treatment (CT) also produced more favourable pore attributes than 45-0-0 and 90-0-0.

Sowing point 45-W-S had a lower water content at 0-150 mm soil depth, but produced a higher water content at 150-300 mm soil depth compared to other treatments during the growing season at both the CL94 and SL94. This was because 45-W-S had larger amounts of actual available water than other treatments which was used more readily available to the growing crop and replaced more effectively by rainfall.

CHAPTER 6

EFFECTS OF NARROW SEEDING POINT SHAPE ON NON-LIMITING AVAILABLE SOIL WATER

6.1 Introduction

Soil strength is a critical factor controlling shoot and root growth in plants. In particular, soil strength is often an important impediment to seedling emergence in hardsetting soils (Arndt, 1985; Mullins et al., 1990). Weaich et al., (1992) pointed out that the rapidity with which soil strength is developed was the crucial factor influencing the success of emergence, which is often a race between seedling shoot growth rate and rate of soil strength development as the seedbed dries. The rate of soil strength increase is determined by the slope of the soil strength characteristic. The strength characteristic is an intrinsic soil property, usually defined as the relationship between penetration resistance and water content, the latter most appropriately expressed as degree of saturation, θ_v / θ_s where θ_v is volumetric water content ($m^3\ m^{-3}$) and θ_s is saturated water content (Weaich et al., 1992).

In the case of pre-emergent seedlings, development of high soil strength after sowing may cause complete or partial failure of crop establishment. If a critical value of penetration resistance is reached before the emergence of the shoot from the soil surface, then emergence will have failed. The penetration resistance values which are likely to limit seedling growth and emergence have been defined for several crops. Ball and O'Sullivan (1982) reported that emergence of spring barley was reduced in soils with cone penetrometer resistances greater than 2.5 MPa. Weaich, et al. (1992) reported that penetrometer resistances values in excess of 1.1 MPa were inhibitory to maize shoot growth and by 2 MPa, all shoot growth had ceased.

Soil strength is the critical factor controlling root penetration (Taylor et al. 1966). Critical values of penetration resistance at which root growth is inhibited vary, depending on the species. Taylor and Gardner (1963) used soil strength measurements as an indicator of resistance encountered as seedling cotton taproots penetrated soil. They found that the percentage of cotton taproots penetrating through cores decreased progressively as penetrometer soil strength increased until, at about 3 MPa strength, root penetration ceased. In general, root elongation in most species is reduced by 50% when penetration resistance is 0.7 to 1.5 MPa and is restricted completely at penetration resistances greater than 3 (Taylor and Gardner, 1963) to 4 MPa (Kirkegaard, 1990).

The overall consequence of increased strength and reduced air filled porosity under direct drilling systems using narrow seeding points is a reduction in the non-limiting available water content. Letey (1985) and Cass et al. (1994) pointed out that at the wet end, soil water may be limiting because of aeration restriction (air-filled porosity < 0.1 m^3 m^{-3}). At the dry end, high penetration resistance may restrict root extension and hence available water.

The rate of soil strength increase on drying can be reduced by changing either the strength characteristic (P_r vs θ_v/θ_s) or rate of the drying or both. A number of different techniques exist for manipulating these parameters, one of which is tillage. However, because of the trend towards reduced tillage in Australia, mechanical disturbance of soil is now quite widely restricted to sowing operations only. Consequently manipulation of soil structural quality by tillage row centres on the effect of seeding points on soil structure. Differently shaped and sized sowing points may affect soil physical conditions differently. However, the effect of sowing implements on soil penetration characteristics are not well known. In particular, little information is available on the effects of narrow point shapes on soil structural quality. The hypothesis of this investigation is that narrow seeding points of different shapes alter the strength characteristics and rate of drying of soil.

The aim of the work reported here was to assess soil structural quality of a seedbed after sowing wheat with one of the five different seeding points. Soil structural quality was assessed in terms of plant available water and air-filled porosity at field capacity. The effect of strength development in soil on drying was assessed in terms of the limitations imposed on total plant available water and the consequent moderation to assessed structural quality.

6.2 Materials and Methods

The experiments reported here were conducted at Roseworthy Campus, University of Adelaide, at two sites, Clay loam (CL) and sandy loam (SL) in 1995. Wheat was sown into fallow uncultivated soil with a John Shearer seeder fitted with one of the four designated narrow points as described in Chapter 3, (45-0-0, 45-W-0, 45-W-S, 90-0-0) and also a conventional treatment (CT) which comprised two passes of a cultivator followed by sowing with the 45-0-0 points. Sowing depth was for all treatments 50 mm and sowing speed was 8 km/h.

6.2.1 Field capacity water content and soil bulk density

The method of *in situ field capacity* described by Cassel and Nielsen (1986) was used to measure field capacity of the soil on the field experiment where the penetration resistance measurements were done in 1995. "Field capacity" is the moisture content which freely draining soil will reach after thorough wetting. Veihmeyer and Hendrickson (1931) introduced the field capacity concept and defined it as "the amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased." *In situ field capacity* is defined in the *Glossary of Soil Science Terms* (1984) as the amount of water remaining in a soil 2 or 3 days after having been wetted and after free drainage has become negligible. The amount of water may be expressed on the basis of weight or volume of soil (kg kg^{-1} or m^3 m^{-3}).

Three undisturbed soil cores from each treatment were sampled from artificially moistened soil on the experimental sites (CL and SL) two days after sowing wheat with the experimental seeding points. Metal rings (diameter 750 mm, height 200 mm and wall thickness 2 mm) were gently pressed into the soil using a machine-mounted hydraulic ram. The soil outside the rings was backfilled around the outside of the rings and compacted. The soil surface within the rings was undisturbed and was covered with hessian bags to protect the soil surface from erosion by inflowing water. Tap water was then ponded inside the rings until water had penetrated to a depth of 0.5 m down the profile as judged by coring inside the ring of some sites. The rings were covered by plastic sheet and left for 48 hours. After this time the plastic was removed and undisturbed cores of soil were sampled (McIntyre, 1974) using thin walled (1 mm) metal sleeves (36 mm diameter × 25 mm high). Replicate (3) cores were taken at three depths 50, 100 and 150 mm from near the centre of the rings to avoid boundary effects. The cores were weighed and oven-dried at 105° C for twenty-four hours to constant weight.

Field capacity soil water content (θ_{fc}, $m^3\ m^{-3}$) was calculated as

$$\theta_{fc} = (m'_w / m_s)\times(\rho_b/\rho_w) \qquad [1]$$

where m'_w is mass of water retained in the soil after 48 hours of drainage and lost by oven drying (105° C) in the laboratory (kg), m_s is oven dry-mass of soil in the core (kg), ρ_b is soil bulk density ($Mg\ m^{-3}$), and ρ_w is water density ($0.998\ Mg\ m^{-3}$).

Dry bulk density ρ_b ($Mg\ m^{-3}$) of the soil cores was calculated as

$$\rho_b = m_s / v \qquad [2]$$

where m_s is oven dry-mass of soil in the core (Mg) and v is the volume of the core (m^3).

Saturated water content θ_s (or total porosity) was calculated as

$$\theta_s = 1 - (\rho_b / \rho_d) \qquad [3]$$

where ρ_b is bulk density ($Mg\ m^{-3}$), and ρ_d is particle density ($2.65\ Mg\ m^{-3}$).

The air filled porosity at field capacity θ_a and the total plant available water content θ_{paw} (Letey, 1985) were calculated as

$$\theta_a = \theta_s - \theta_{fc} \qquad [4]$$

$$\theta_{paw} = \theta_{fc} - \theta_{wp} \qquad [5]$$

where θ_{fc} is field capacity, θ_s is saturated water content, and θ_{wp} is wilting point.

6.2.2 Wilting point water content

Cassel and Nielsen (1986) defined permanent wilting point as the soil water content at which the plant remains permanently wilted and does not recover. The method of wilting point determination is described in Chapter 5, Section 5.2.3.2. These data were used for interpretation of penetration resistance (Fig. 6.3) and to evaluate soil structure quality (Table 6.2).

6.2.3 Penetration resistance characteristics

An automatic cone penetrometer with a stainless steel cone of 6.25 mm diameter and 30° internal angle (American Society of Agricultural Engineering, 1983) on a shaft of 4.5 mm in diameter was used to measure soil strength. The force on the cone was measured with a transducer of 450 N capacity. The cone was driven into the soil at 1.66 mm s^{-1} by means of two stepper motors, each of 0.6 Nm torque (at rotations of less than 300 revolutions min^{-1}), transferring the stepper motor rotation to the penetrometer shaft through two drive shafts. Transducer output was recorded at every 2 mm advance interval and stored in a laptop computer. Replicate penetration measurements were taken at three random positions along the middle of the sowing-line in each plot, and the mean penetrometer resistance to a depth of 150 mm was calculated for each treatment.

Water content of the soil was determined simultaneously with the penetration measurements at three replicated depth intervals of 0-50, 50-100, and 100-150 mm. These measurement were repeated at increasing intervals of 2, 3, 4, 5, 6, and 7 days over a total period of 27 days as the soil dried. At the end of this time the soil water contents were approaching wilting point. Mass soil water content (m_w) was determined by weighing the soil samples before and after oven drying at 105 °C. Volumetric water content (θ_v, m m^{-1}) was calculated using Equation 1, except that m'_w was replaced by m_w.

The relationship between penetration resistance (P_r) and degree of saturation (θ_v/θ_s), the *penetration resistance characteristic* was determined for each of the narrow point treatments. These relationships fitted a power function of the form

$$P_r = P_o\,(\theta_v/\theta_s)^b \qquad [6]$$

where θ_s is saturated water content and P_o and b are curve fitting coefficients.

Differences in the penetration resistance characteristics between treatments were evaluated by a statistical analysis of the magnitude of the b exponent of the penetration resistance characteristic (Cass et al., 1994). A pooled standard error (SE_p) was calculated from the standard error of a regression of P on (θ_v/θ_s) as

$$SE_p = [\,(SE_1^2 + SE_2^2 + \ldots + SE_n^2)/n]^{1/2} \qquad [7]$$

where n is the number of regression lines being tested and SE_1, SE_2 ... SE_n are standard errors of the b coefficients being tested. A t-test (Snedecor and Cochran, 1980) was used to evaluate the significance of the difference between coefficients using n-1 degrees of freedom. The t value was calculated for each comparison of the b exponents from any two of the regressions as follows

$$t = (b_i - b_j) / (\sqrt{2}\, SE_p) \quad [8]$$

where b_i and b_j are the slope exponents from any two of the regression lines which are being compared.

6.3 Statistical analysis

A randomised complete block design (RCBD) was used to analyse the data for both bulk density and field capacity. The statistical analysis was performed in Genstat 5 Release 3 (Genstat 5 Committee, 1993). Five treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT) were randomly allocated within each of the three replicates. The least significant difference (LSD) was calculated for pair wise comparisons of treatments at the 5 % level of significance. The Analysis of Variance table (ANOVA) is shown for bulk density and field capacity in Table 6.1.

Table 6.1 The ANOVA table for statistical analysis of bulk density and field capacity.

Source of variation	Degree of freedom
Replication	2
Tool type	4
Residual	8
Total	14

6.4 Results and discussion

6.4.1 Bulk density and field capacity

Figure 6.1 shows results of dry bulk density determinations for five narrow seeding point treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT) for three soil depth intervals of 50, 100 and 150 mm at the CL and the SL site.

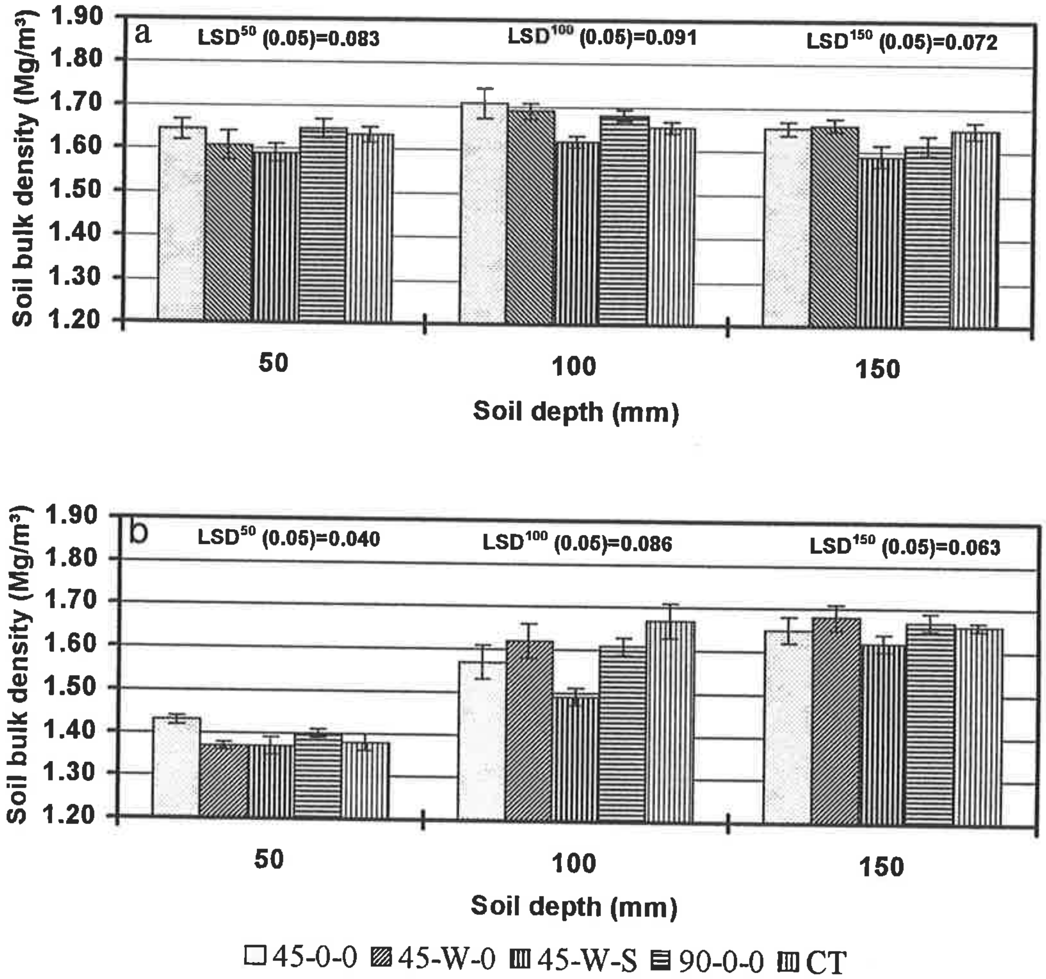


Figure 6.1 Dry bulk density (Mg m^{-3}) of the 50, 100, and 150 mm soil depths for five seeding point treatments at two sites (a Clay loam, b Sandy loam soil). Error bars are at 95% confidence interval.

Figure 6.1 shows that at 50 mm soil depth, the seeding point 45-W-S resulted in lower bulk density than other treatments at the CL soil while at the SL site, points 45-W-S, 45-W-0 and CT treatment produced lower bulk density than point 45-0-0. The point 45-W-S showed significantly lower bulk density than other treatments at both sites (CL and SL) whilst point 45-0-0 treatment had higher bulk density at the CL site and CT treatment at the SL site at 100 mm depth. There was no significant difference in dry bulk density between the treatments at a depth of 150 mm.

Field capacity water content is shown in Figure 6.2 for five seeding point treatments at three soil depth intervals 0-50, 50-100 and 100-150 mm at two sites (CL and SL).

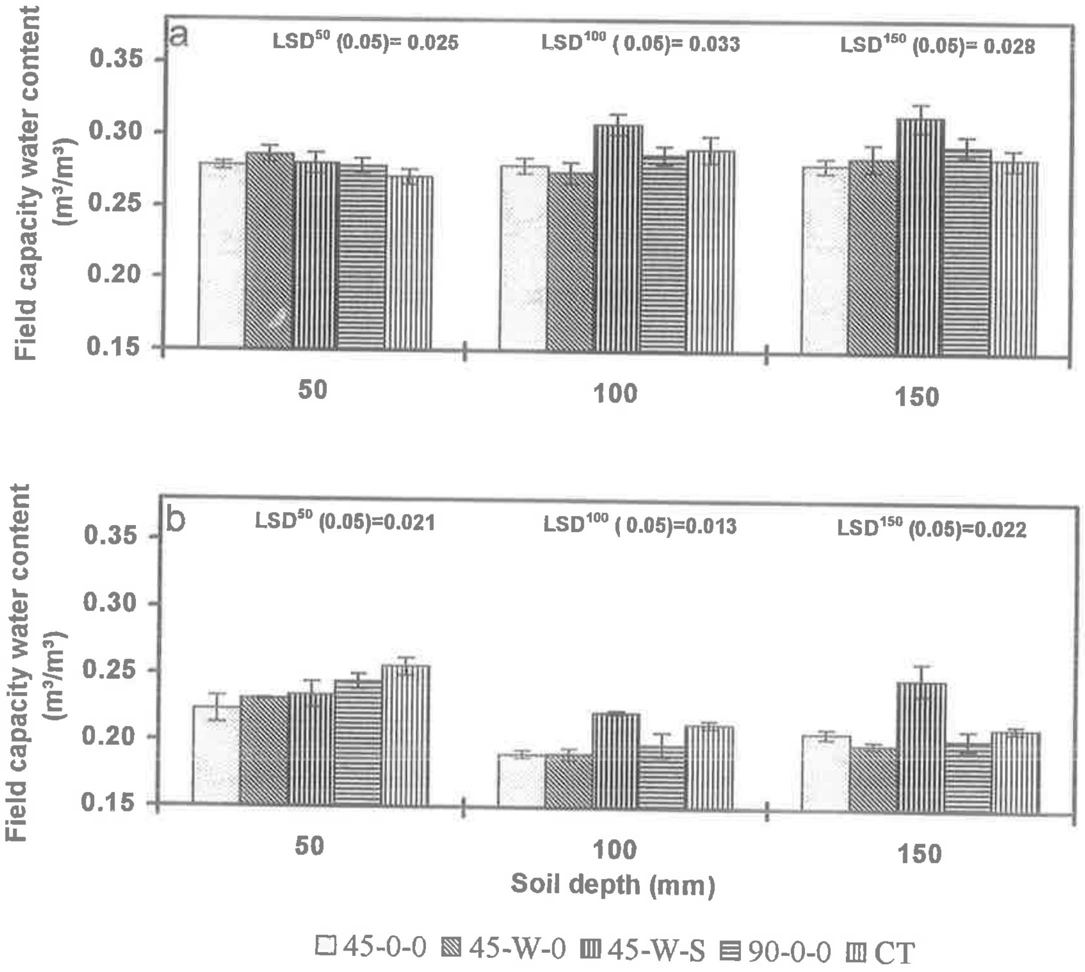


Figure 6.2 Field capacity water content (m^3 m^{-3}) of the 50, 100, and 150 mm soil depths for five seeding point treatments at two sites (a) Clay loam site, (b) Sandy loam site. Error bars are at 95% confidence interval.

Figure 6.2 shows that CT had a significantly higher field capacity water content than point 45-0-0 at the SL site but there was no significant difference at the CL site at 50 mm soil depth. The point 45-W-S and the CT treatment had significantly higher field capacity water contents at 100 mm soil depth than point 45-0-0 at both sites. There was no significant difference in field capacity water content between the treatments at a sowing depth of 150 mm, except point 45-W-S had significantly higher field capacity than other treatments at both sites.

6.4.2 Hydrological and soil structural parameters

Tables 6.2 and 6.3 show hydrological and structural parameters of soil tilled with five narrow seeding points (45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT) for three soil depth intervals of 50, 100 and 150 mm at the SL site.

Table 6.2 Soil structural and hydrological parameters ($m^3\ m^{-3}$) at the SL site for narrow point treatments: control point (45-0-0), with wings (45-W-0), with wings and blade (45-W-S), 90 degree rake angle (90-0-0) and cultivated treatment (CT).

Treatments	Depth interval mm	θ_s $m^3\ m^{-3}$	θ_a $m^3\ m^{-3}$	θ_{fc} $m^3\ m^{-3}$	θ_{wp} $m^3\ m^{-3}$	θ_{paw} $m^3\ m^{-3}$	θ_{fc}/θ_s —	θ_{wp}/θ_s —
45-0-0	50	0.498	0.274	0.223	0.056	0.166	0.449	0.112
	100	0.408	0.217	0.190	0.081	0.111	0.467	0.199
	150	0.376	0.168	0.207	0.091	0.120	0.552	0.242
45-W-0	50	0.484	0.253	0.232	0.056	0.175	0.478	0.116
	100	0.389	0.198	0.191	0.081	0.112	0.491	0.208
	150	0.366	0.167	0.199	0.091	0.112	0.544	0.249
45-W-S	50	0.483	0.249	0.235	0.056	0.178	0.485	0.116
	100	0.438	0.215	0.223	0.081	0.144	0.509	0.185
	150	0.390	0.123	0.248	0.091	0.180	0.636	0.233
90-0-0	50	0.471	0.226	0.245	0.056	0.188	0.520	0.119
	100	0.391	0.193	0.198	0.081	0.119	0.507	0.207
	150	0.371	0.168	0.203	0.091	0.116	0.546	0.247
CT	50	0.459	0.203	0.256	0.056	0.199	0.558	0.122
	100	0.369	0.155	0.214	0.081	0.135	0.579	0.220
	150	0.374	0.162	0.212	0.091	0.125	0.567	0.243

θ_s saturated water content (or total porosity); θ_a air-filled porosity at field capacity; θ_{fc} field capacity water content; θ_{wp} wilting point water content (mean of site samples); θ_{paw}, total plant available water.

Table 6.3 Standard error of mean of soil structural and hydrological parameters ($m^3\ m^{-3}$) at the SL site.

Treatments	Depth interval mm	θ_s $m^3\ m^{-3}$	θ_a $m^3\ m^{-3}$	θ_{fc} $m^3\ m^{-3}$	θ_{wp} $m^3\ m^{-3}$	θ_{paw} $m^3\ m^{-3}$
	50	0.002	0.012	0.010	0.007	0.010
45-0-0	100	0.017	0.020	0.003	0.010	0.003
	150	0.010	0.006	0.004	0.007	0.004
45-W-0	50	0.004	0.003	0.001	0.007	0.001
	100	0.015	0.019	0.005	0.010	0.005
	150	0.010	0.008	0.003	0.007	0.003
45-W-S	50	0.007	0.016	0.010	0.007	0.010
	100	0.009	0.010	0.002	0.010	0.001
	150	0.006	0.016	0.012	0.007	0.012
90-0-0	50	0.003	0.006	0.006	0.007	0.006
	100	0.006	0.014	0.010	0.010	0.009
	150	0.006	0.009	0.007	0.007	0.007
CT	50	0.007	0.013	0.006	0.007	0.006
	100	0.015	0.017	0.003	0.010	0.003
	150	0.003	0.004	0.003	0.007	0.003

Tables 6.4 and 6.5 show hydrological and structural parameters of soil tilled with five narrow seeding points (45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT) for three soil depth intervals of 50, 100 and 150 mm at the CL site.

Table 6.4 Soil structural and hydrological parameters ($m^3\ m^{-3}$) for narrow point treatments at the Clay loam site: control point (45-0-0), with wings (45-W-0), with wings and blade (45-W-S), 90 degree rake angle (90-0-0) and cultivated treatment (CT).

Treatments	Soil depth mm	θ_s $m^3\ m^{-3}$	θ_a $m^3\ m^{-3}$	θ_{afp} $m^3\ m^{-3}$	θ_{fc} $m^3\ m^{-3}$	θ_{wp} $m^3\ m^{-3}$	θ_{paw} $m^3\ m^{-3}$	θ_{fc}/θ_s —	θ_{wp}/θ_s —
45-0-0	50	0.365	0.089	0.265	0.279	0.112	0.167	0.762	0.306
	100	0.342	0.079	0.242	0.263	0.196	0.073	0.782	0.570
	150	0.385	0.078	0.285	0.307	0.203	0.104	0.798	0.527
45-W-0	50	0.385	0.118	0.285	0.267	0.112	0.155	0.694	0.291
	100	0.359	0.090	0.285	0.269	0.196	0.073	0.750	0.546
	150	0.373	0.080	0.273	0.293	0.203	0.085	0.776	0.547
45-W-S	50	0.412	0.131	0.312	0.280	0.112	0.168	0.682	0.272
	100	0.412	0.069	0.312	0.343	0.196	0.158	0.849	0.470
	150	0.419	0.081	0.319	0.338	0.203	0.143	0.819	0.481
90-0-0	50	0.377	0.108	0.277	0.269	0.112	0.157	0.714	0.297
	100	0.366	0.079	0.266	0.287	0.196	0.089	0.777	0.534
	150	0.371	0.078	0.271	0.294	0.203	0.091	0.791	0.547
CT	50	0.396	0.097	0.296	0.299	0.112	0.187	0.755	0.283
	100	0.366	0.081	0.266	0.285	0.196	0.097	0.805	0.539
	150	0.373	0.109	0.273	0.265	0.203	0.065	0.717	0.542

θ_s saturated water content (or total porosity); θ_a air-filled porosity at field capacity; θ_{afp} water content at θ_a = 0.1 m m^{-1}; θ_{fc} field capacity water content ; θ_{wp} wilting point water content (mean of site samples); θ_{paw}, total plant available water.

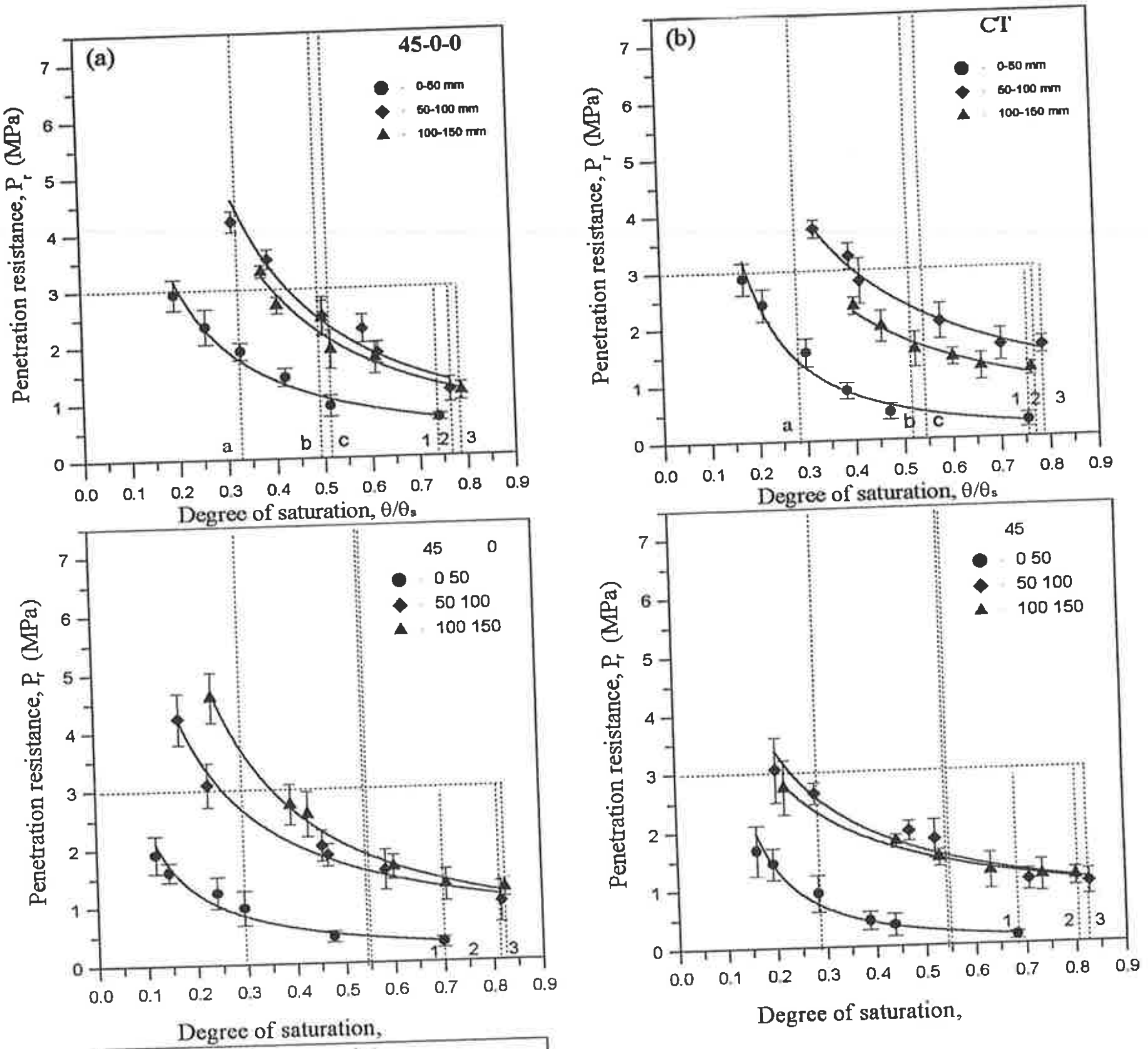
Table 6.5 Standard error of mean of soil structural and hydrological parameters ($m^3\ m^{-3}$) for narrow point treatments: control point (45-0-0), with wings (45-W-0), with wings and blade (45-W-S), 90 degree rake angle (90-0-0) and cultivated treatment (CT).

Treatments	Depth interval mm	θ_s $m^3\ m^{-3}$	θ_a $m^3\ m^{-3}$	θ_{fc} $m^3\ m^{-3}$	θ_{wp} $m^3\ m^{-3}$	θ_{paw} $m^3\ m^{-3}$
45-0-0	50	0.001	0.001	0.003	0.005	0.001
	100	0.006	0.007	0.006	0.025	0.002
	150	0.002	0.002	0.005	0.027	0.001
45-W-0	50	0.005	0.005	0.005	0.005	0.006
	100	0.003	0.010	0.008	0.025	0.007
	150	0.004	0.008	0.010	0.027	0.004
45-W-S	50	0.010	0.014	0.007	0.005	0.004
	100	0.002	0.004	0.007	0.025	0.004
	150	0.008	0.001	0.010	0.027	0.006
90-0-0	50	0.008	0.007	0.005	0.005	0.001
	100	0.006	0.004	0.006	0.025	0.005
	150	0.005	0.010	0.007	0.027	0.005
CT	50	0.007	0.009	0.005	0.005	0.005
	100	0.005	0.006	0.009	0.025	0.001
	150	0.003	0.005	0.007	0.027	0.004

6.4.3 Penetration resistance characteristics

Figures 6.3 and 6.4 show soil penetration resistance as a function of degree of saturation and the strength characteristic curves (Weaich et al., 1992) for the four narrow seeding points (45-0-0, 45-W-0, 45-W-S, 90-0-0) and CT treatment at 3 depth intervals of 0-50, 50-100 and 100-150 mm at two sites (CL and SL). The critical limit of penetration resistance (3 MPa) and both lower (θ_{wp}/θ_s) and upper limit of available water contents (θ_{fc}/θ_s), are shown. The intersection of penetration resistance curves with these limiting values provides criteria for assessing the quality of soil structure for shoot and root elongation (Letey, 1985; Cass et al., 1994).

If penetration resistance reaches the critical value for root or shoot growth between the upper and lower limits for water availability, then water uptake by the plant is likely to be limited at that level of water depletion, ie. before water content reaches the lower level of water availability (wilting point water content). Improvement in soil structural quality can be achieved by reducing the slope of the strength characteristics. Therefore that intersection of the curves with a critical penetration value occurs outside the limits of available water. A penetration value of 3 MPa has been chosen for root growth. No critical value of penetration is needed for shoot growth since seeding was at 50 mm and generally high strength did not impose limitation to emergence above this depth during the experimental period.



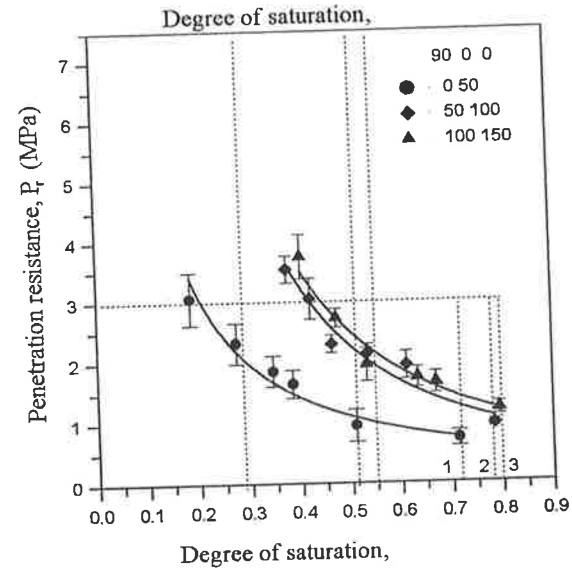
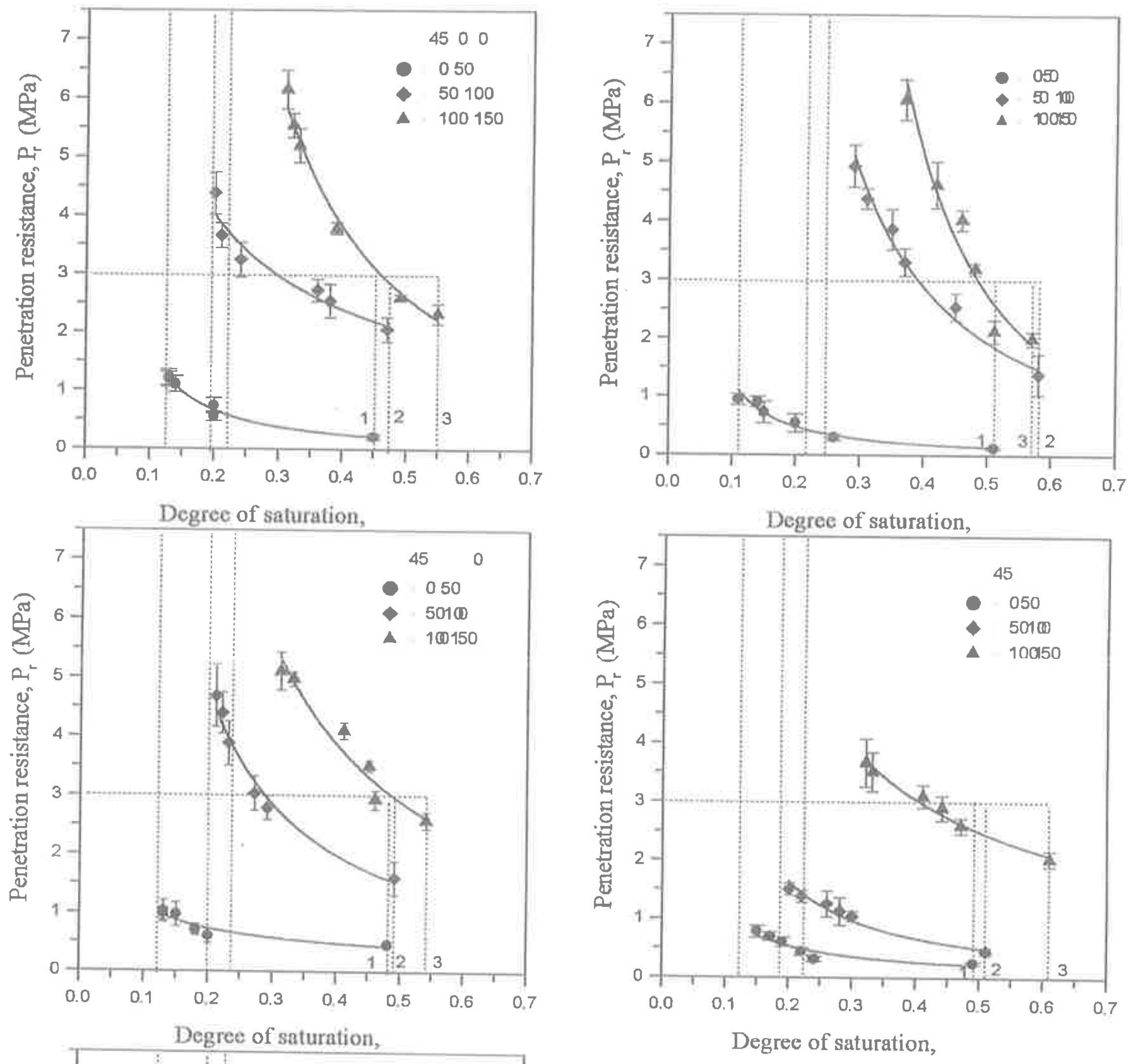


Figure 6.3 Penetration resistance as a function of degree of saturation for 5 seeding point treatments with 3 depth intervals, 0-50, 50-100 and 100-150 mm at the CL site. Treatments are: (a) 45-0-0, (b) 45-W-0, (c) 45-W-S, (d) 90-0-0 and (e) CT. Horizontal broken line shows the critical limit of P_r (3 MPa) and vertical broken lines are wilting point (a, b, c) θ_{wp}/θ_s and field capacity (1,2,3) θ_{fc}/θ_s values for the three depth intervals of 50, 100, and 150 mm respectively.



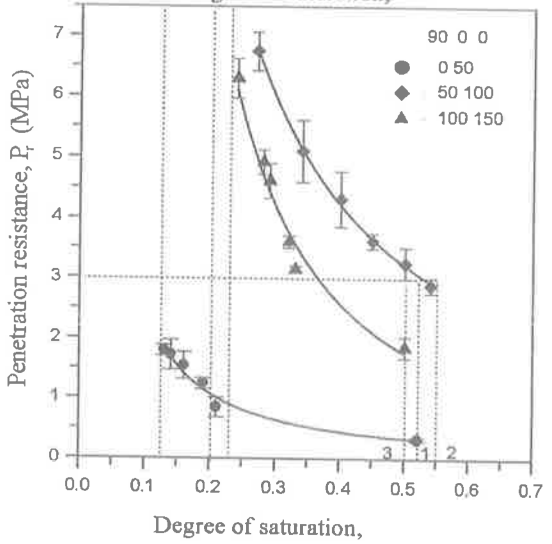


Figure 6.4 Penetration resistance as a function of degree of saturation for 5 seeding point treatments with 3 depth intervals, 0-50, 50-100 and 100-150 mm at the SL site. Treatments are: (a) 45-0-0, (b) 45-W-0, (c) 45-W-S, (d) 90-0-0 and (e) CT. Horizontal broken line shows the critical limit of P_r (3 MPa) and vertical broken lines are wilting point (a, b, c) θ_{wp}/θ_s and field capacity (1,2,3) θ_{fc}/θ_s values for the three depth intervals of 50, 100, and 150 mm respectively.

Figures 6.3 and 6.4 show that as the soil dried, it became stronger. The strength of the soil and the rate of strength increase was dependent on both treatment and depth in the soil.

Generally strength and the rate of strength increase was greatest for deeper layers and for layers not disturbed by the treatments. The only seeding point that penetrated deeper than 50 mm, 45-W-S, produced considerable weakening of soil as deep as 150 mm (Figs. 6.3 and 6.4d). Seeding points 90-0-0 and cultivated treatments CT (Figures 6.4e and b) appear to have caused compaction of soil at a depth of 50-100 mm. Generally the CL showed less development of soil strength on drying than SL and less critical coincidence of Pr = 3 MPa and $\theta = \theta_{wp}$. Figure 6.3 at the CL site shows that all treatments dried well beyond wilting point, even at the greatest depth (150 mm), so the main loss of water should be either evaporation or transpiration. In the SL soil, regardless of high strength in the seeding points 90-0-0 and 45-0-0, water-use evidently continued in soil at 150 mm soil depth.

The intersection of the strength characteristic curve with the critical limits for shoot and root growth (1 and 3 MPa respectively) within the available water content range (field capacity to wilting point) indicates when either emergence (Pr critical = 1 MPa) or root growth (Pr critical = 3 MPa) will be limited by soil strength. Seeds were sown at 50 mm and these conditions were not evident in the 0-50 mm layer. Consequently, with the conditions that existed at both sites, emergence was not threatened for any of the treatments because none substantially exceeded 1 MPa over the available water content range. Measured water content in the field did not drop below 50 % of total plant available water between sowing and emergence (Chapter 5).

The CL soil penetration characteristic shows that soil strength is not limiting to root extension and therefore water availability for all treatments and depths measured. This is because the penetration characteristics intersects the critical limit of 3 MPa below wilting point water content in all cases (Fig. 6.3).

However, all treatments on SL except 45-W-S, were potentially limiting to root growth if the soil became sufficiently dry. Only seeding point 45-W-S reduced the slope of the strength characteristic of the 50 to 100 and 100 to 150 mm depth intervals sufficiently to eliminate or minimise this risk. Because the other treatments did not disrupt the soil at these depths, previous compaction resulted in sufficient strength to exceed the critical limit (3 MPa) well before wilting point if the seedbed dried sufficiently. The data suggest that the 90-0-0 seeding point and conventional tillage treatment (CT) increased the slope of the strength characteristic between 50 and 100 mm depth (Figures 6.4b and e), possibly by compacting the soil beneath the seeding point or sweeps. Data shown in Figure 6.1 tend to confirm this.

Table 6.5 shows curve fitting parameters for the penetration resistance (P_r) as a function of degree of saturation using a power function

$$P_r + \sigma_{xy} = P_{o\pm}\ \sigma_{P^o}\ (\theta/\theta_s)^{(b\pm\sigma b)} \qquad [9]$$

where σ_{xy} is standard error of regression of (θ/θ_s) on P_r, σ_{P^o} is standard error of P_o, and σ_b standard error of exponent b.

Table 6.6 Curve fitting and statistical parameters for the penetration resistance characteristics of five seeding points and three soil depth intervals at two sites (CL and SL soil).

Site	Sowing point	Lower depth limit (mm)	P_o MPa	σ_{Po} MPa	b —	σ_b —	r^2 —	σ_{XY} —
Clay loam	**45-0-0**	50	0.0489	0.0432	-1.3563	0.0916	0.968	0.0431
		100	0.9209	0.0511	-1.3973	0.1590	0.938	0.0496
		150	0.9214	0.0239	-1.1147	0.0689	0.981	0.0226
	45-W-0	50	0.2411	0.0612	-1.0153	0.0976	0.955	0.0646
		100	0.9512	0.0309	-0.8432	0.0666	0.969	0.0382
		150	0.9535	0.0177	-1.1089	0.0495	0.990	0.0219
	45-W-S	50	0.0830	0.0693	-1.7350	0.1278	0.973	0.0667
		100	0.9428	0.0439	-0.8003	0.1077	0.916	0.0563
		150	0.9436	0.1336	-0.7182	0.0391	0.985	0.0179
	90-0-0	50	0.5055	0.0520	-1.1267	0.1095	0.954	0.0504
		100	0.7235	0.0633	-1.6418	0.2061	0.926	0.0537
		150	0.8355	0.0403	-1.5748	0.1528	0.955	0.0368
	CT	50	0.1759	0.0706	-1.6479	0.1364	0.966	0.0715
		100	1.2014	0.0207	-1.0074	0.0633	0.981	0.0218
		150	0.8309	0.0291	-0.0982	0.1068	0.954	0.0247
Sandy loam	**45-0-0**	50	1.2850	0.0715	-0.3674	0.0950	0.976	0.0438
		100	1.2235	0.0497	-0.7383	0.0904	0.929	0.0311
		150	0.8135	0.0359	-1.6861	0.1107	0.987	0.0199
	45-W-0	50	0.2807	0.0888	-0.5994	0.1182	0.832	0.0564
		100	0.5943	0.0951	-1.3231	0.1677	0.924	0.0478
		150	1.1942	0.0634	-1.2820	0.1599	0.926	0.0327
	45-W-S	50	0.1099	0.1427	-0.9894	0.2127	0.805	0.0867
		100	0.2070	0.0655	-1.2881	0.1159	0.960	0.0369
		150	1.5265	0.0174	-0.7629	0.0453	0.982	0.0123
	90-0-0	50	0.1384	0.0687	-1.2742	0.0940	0.973	0.0461
		100	1.8704	0.0354	-0.9718	0.0918	0.956	0.0256
		150	0.5006	0.0965	-1.7927	0.1927	0.944	0.0442
	CT	50	0.0519	0.0783	-1.3842	0.1065	0.971	0.0568
		100	0.5535	0.0510	-1.8004	0.1182	0.978	0.0294
		150	0.3963	0.1333	-2.8165	0.3936	0.909	0.0576

The rate of soil strength increase due to drying is most rapid when the penetration resistance characteristic has a steep slope (more negative *b* value). This means that the soil penetration resistance will reach the critical point more rapidly than if the slope is flat (less negative *b* value). When the slope is flat, soil structure for seedling growth and root elongation is more favourable. The flattest slopes were observed for winged seeding points especially 45-W-S and in the 0-50 mm depth interval. The CL soil had a flatter slope than the SL soil indicating less tendency to develop high strength on drying.

Table 6.6 shows results of the *t*-test applied to the estimates of regression coefficient (*b*) of the penetration resistance characteristics at the CL and the SL sites. There was no significant difference in the slope of the penetration resistance characteristics of point 45-0-0 and other points at 0-50 mm depth except point 45-W-S and CT treatment which had smaller slope. At a depth of 50-100 mm, the CT and points 45-W-0 and 45-W-S had a significantly smaller slope than 45-0-0 at the SL site but only points 45-W-0 and 45-W-S at the CL site. At a depth of 100-150 mm, 45-W-S had a significantly smaller slope than point 45-0-0 at both sites whilst the CT showed significantly greater slope than point 45-0-0 at the SL site.

Table 6.7 Significance of difference between the slope of the strength characteristics (Table 6.5) for narrow seeding points and CT, relative to the control point, 45-0-0.

Site	Soil depth	pooled SE	Seeding point comparison	Calculated t value
Sandy loam	50	0.1330	45-0-0 vs CT	0.09 NS
			45-W-0	2.58 NS
			45-W-S	2.01 NS
			90-0-0	0.50 NS
	100	0.1200	45-0-0 vs CT	6.26 **
			45-W-0	3.44 *
			45-W-S	3.24 *
			90-0-0	1.38 NS
	150	0.2131	45-0-0 vs CT	3.75 *
			45-W-0	1.34 NS
			45-W-S	3.59 *
			90-0-0	0.35 NS
Clay loam	50	0.1330	45-0-0 vs CT	3.18 *
			45-W-0	0.75 NS
			45-W-S	3.73 *
			90-0-0	0.06 NS
	100	0.1200	45-0-0 vs CT	2.11 NS
			45-W-0	2.99 *
			45-W-S	3.23 *
			90-0-0	1.32 NS
	150	0.2131	45-0-0 vs CT	1.76 NS
			45-W-0	0.56 NS
			45-W-S	4.96 **
			90-0-0	2.74 NS

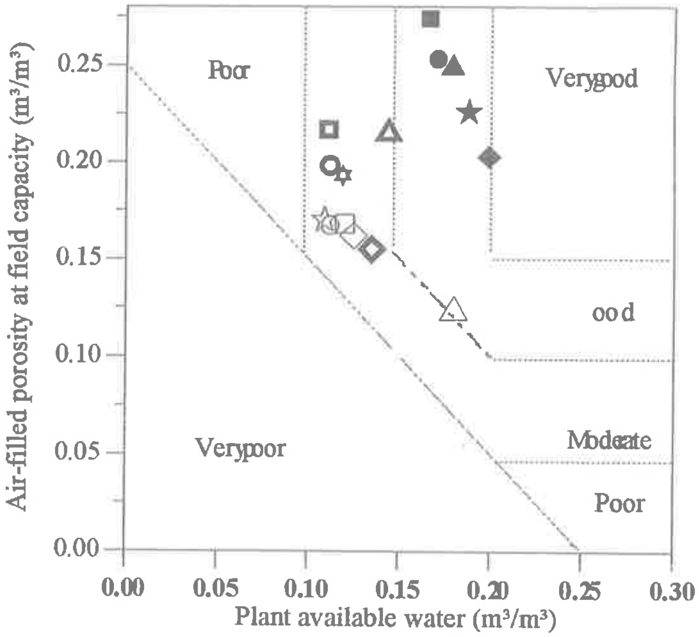
Asterisks indicate significance at: * $P < 0.05$, ** $p < 0.01$. NS, not significant.

6.4.4 Soil structural quality

Figure 6.5 shows soil structure quality produced by the five seeding points expressed in terms of the classification system of Hall et al. (1977) for three depth intervals, 0-50, 50-100 and 100-150 mm at two sites (SL and CL). The data for the SL site show that the seeding point 45-W-S produced good structure quality at all soil depths to 150 mm (Fig. 6.5a). The CT treatment had good soil structure at soil depth of 50 mm and moderate soil structure quality at both 100 and 150 mm soil depths. Soil structure was good for point 90-0-0 at soil depth of 50 mm but it was moderate at other depths. Points 45-0-0, 45-W-0 had good structural quality at 50 mm depth and moderate at 100 and 150 mm soil depth.

In contrast to the SL site, air filled porosity was low for all treatments at the CL site. The data for the CL site show that the soil structure quality was moderate to good for point 45-W-S at soil depth of 50 mm but it was moderate for other treatments (Fig. 6.5b). All treatments had very poor soil structure at both 100 and 150 mm soil depths.

(a) Sandy loam soil



(b) Clay loam soil

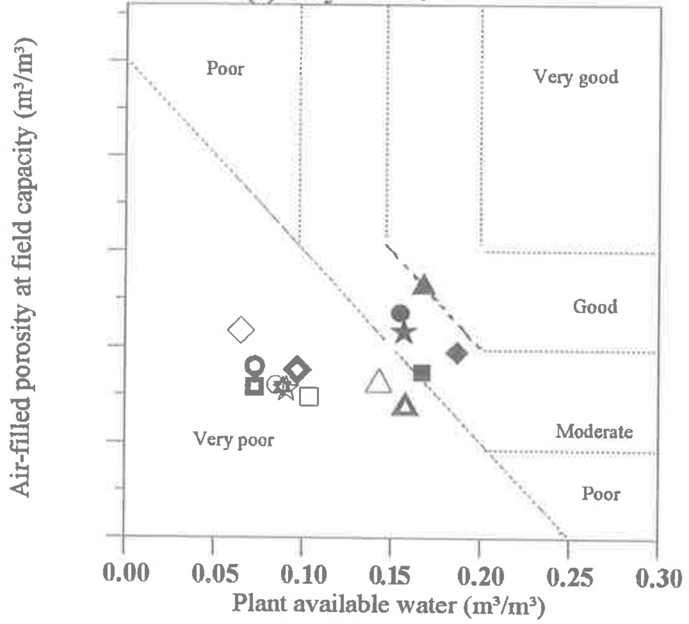


Figure 6.5 Classification of soil structure quality in terms of available water content and air-filled porosity at the field capacity (Hall et al., 1977) at (a) the SL and (b) the CL site for 0-50 mm (solid symbols) , 50-100 mm (semi solid symbols) and 100-150 mm (open symbols) for narrow seeding point treatments. Available water was determined for non-limiting conditions with CT (diamonds), seeding point 45-0-0 (squares), 45-W-0 (circles), 45-W-S (triangles) and point 90-0-0 (stars).

However, Letey (1985) and Cass et al. (1994) have shown that root growth may, under appropriate circumstances, be limited by either lack of aeration or high soil strength which may restrict water availability beyond the normally accepted limits of field capacity or wilting point. Using the relationships provided by Cass et al. (1994), the non limiting available water content of the sowing treatments were recalculated.

Inspection of Table 6.2 shows that aeration limitations did not exist at the SL site in any of the treatments ($\theta_a > 0.1$ m^3 m^{-3}). However, Figure 6.4 shows that most of the deeper layers (> 50 mm) had strengths that exceeded 3 MPa within the available water content range (field capacity to wilting point). Accordingly non limiting available water content (θ_{nlaw}) was calculated as

$$\theta_{nlaw} = \theta_{fc} - \theta_{wp} \qquad [10]$$

if $\theta_{wp} > \theta_{pr}$

or, as was the case for most seeding points, except 45-W-S as

$$\theta_{nlaw} = \theta_{fc} - \theta_{pr} \qquad [11]$$

if $\theta_{pr} > \theta_{wp}$

where θ_{fc} is field capacity water content, θ_{wp} is wilting point water content (Table 6.2) and θ_{pr} is water content at which $P_r > 3$ MPa. The values used in the calculation are shown in Table 6.7.

In the case of the CL site, strength was not a limitation to root exploration for water. Data in Figure 6.4 show that interception of the strength characteristic with wilting point always occurred at $\theta < \theta_{wp}$. However, Table 6.4 shows that several of the seeding points produced relatively poorly aerated conditions ($\theta_a < 0.1$ m^3 m^{-3}), notably 45-0-0 and CT treatment throughout the seedbed and all the other treatments at depths in excess of 150 mm, particularly 45-W-S in 100 mm soil depth. This means that, in term of the model of Letey (1985) and Cass (1994), lack of aeration may limit the uptake of water and the non-limiting available water content (θ_{nlaw}) is:

$$\theta_{nlaw} = \theta_{afp} - \theta_{wp} \qquad [12]$$

where θ_{afp} is the water content at $\theta_a = 0.1$ m m^{-1} (ie θ_s - 0.1). These data are shown in Table 6.8.

Table 6.8 Water content at $P_r > 3$ MPa, (θ_{pr}) and non-limiting available water, θ_{nlaw} calculated from Equation 11, for five seeding point treatments: control point (45-0-0), with wings (45-W-0), with wings and blade (45-W-S), 90 degree rake angle (90-0-0) and cultivated treatment (CT) at 100 and 150 mm soil depths at the SL sites.

Site	Soil depth (mm) →	100		150	
	Treatments	θ_{pr} (m^3 m^{-3})	θ_{nlaw} (m^3 m^{-3})	θ_{pr} (m^3 m^{-3})	θ_{nlaw} (m^3 m^{-3})
Sandy loam	**45-0-0**	0.122	0.068	0.176	0.031
	45-W-0	0.117	0.074	0.179	0.020
	45-W-S	0.081	0.142	0.156	0.092
	90-0-0	0.194	0.009	0.145	0.053
	CT	0.144	0.070	0.183	0.029

Table 6.9 Water content at $\theta_a = 0.1$ m m^{-1}, (θ_{afp}) and non-limiting available water, θ_{nlaw} calculated from Equation 12, for five seeding point treatments: control point (45-0-0), with wings (45-W-0), with wings and blade (45-W-S), 90 degree rake angle (90-0-0) and cultivated treatment (CT) at 50, 100 and 150 mm soil depths at the CL sites.

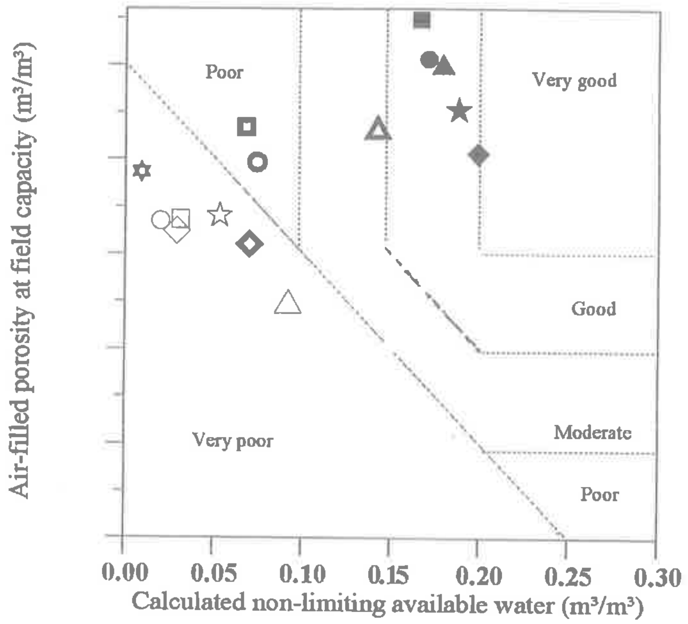
Site	Soil depth (mm)	50		100		150	
	Treatments	θ_{afp} (m^3 m^{-3})	θ_{nlaw} (m^3 m^{-3})	θ_{afp} (m^3 m^{-3})	θ_{nlaw} (m^3 m^{-3})	θ_{afp} (m^3 m^{-3})	θ_{nlaw} (m^3 m^{-3})
Clay loam	**45-0-0**	0.265	0.153	0.242	0.046	0.285	0.082
	45-W-0	*	0.155	0.289	0.063	0.273	0.070
	45-W-S	*	0.168	0.312	0.116	0.319	0.116
	90-0-0	*	0.157	0.266	0.070	0.271	0.068
	CT	0.296	0.184	0.266	0.070	*	0.065

* aeration did not limit available water.

Figure 6.6 shows classification of soil structural quality in term of non-limiting available water content using field capacity as the upper limit and the greater of either wilting point or water content at which penetration resistance reached 3 MPa (Cass et al. 1994) as the lower limit at the SL site (Fig. 6.6a) and air field porosity at $\theta_a = 0.1$ m m^{-1} at the CL site.

Use of non-limiting available water (θ_{nlaw}) rather than plant available water at the SL site causes the assessment of soil structural quality to decrease for soil layers below the disturbed layer from "moderate" to "poor" for seeding points 45-0-0 and 45-W-0 at 100 mm soil depth and to "very poor" for other narrow point treatments except for 45-W-S (100 mm soil depth) at the SL soil (Fig. 6.6a). The reason for this shift is of course the assumed restriction that high soil strength development places on shoot and root growth within the plant available water content range and the consequent possible restriction to water availability. Using non-limiting available water at CL site caused the assessment of soil structure quality to decrease from "moderate" to 'very poor' for 50 mm soil depth for seeding point 45-0-0. The soil structure quality remained at "very poor" at 100 and 150 mm soil depths for all treatments.

(a) Sandy loam soil



(a) Clay loam soil

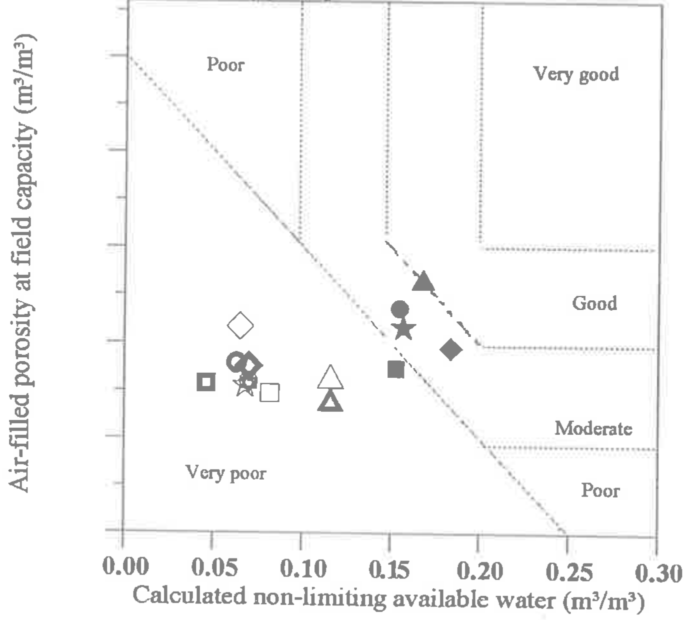


Figure 6.6 Classification of soil structural quality at (a) the SL and (b) the CL site in term of non-limiting available water content using field capacity as upper limit and the greater of either wilting point or water content at which penetration resistance reached 3 MPa (Cass et al. 1994) as the lower limit, and water content at $\theta_a = 0.1$ m m^{-1}: 0-50 mm (solid symbols) , 50-100 mm (semi solid symbols) and 100-150 mm (open symbols) for narrow seeding point treatments, CT (diamonds), seeding point 45-0-0 (squares), 45-W-0 (circles), 45-W-S (triangles) and point 90-0-0 (stars).

6.5 Conclusions

Point 45-0-0 without wings and blade, and 90-0-0 with a 90° rake angle, produced higher bulk densities at depths of 50 mm probably due to less soil disturbance than other points. A conventional sowing practice, CT, which comprised two passes of a sweep cultivator followed by sowing with the 45-0-0 points showed higher bulk density at soil depth of 100 mm, possibly caused by compaction of soil by the sweep cultivator used for tilling of soil before sowing. The point 45-W-S created lower bulk density by disturbing the soil under the seedbed and higher field capacity at all soil depths to 150 mm.

After sowing wheat with four different shaped seeding points and one conventional treatment, the soil strength and the rate of strength increase on drying was found to be dependent on both seeding point shape and depth of penetration to the soil. Generally, strength and the rate of strength increase were greatest for deeper layers and for layers not disturbed by the treatments. The only seeding point that penetrated deeper than 50 mm, 45-W-S, produced considerable weakening of soil as deep as 150 mm.

Soil structure quality after the sowing treatments was assessed using the relationship between plant available water and air-filled porosity. The seeding point with wings and blade which loosened the soil below the seedbed (45-W-S) produced good structure quality (high plant available water and aeration) at all soil depths to 150 mm at the SL soil and in 50 mm soil depth at the CL soil. The other points and the conventional cultivated treatment, created good soil structure at soil depth of 50 mm and moderate at both 100 and 150 mm soil depths at the SL soil. The point 45-W-S had good soil structure only at 50 mm and very poor at 100 and 150 mm soil depths at the CL soil. However, if soil strength limitations to water availability were considered, soil structural quality in soil below the seeding points was poor to very poor except for 45-W-S, which remained good to moderate.

CHAPTER 7

EFFECT OF NARROW SEEDING POINTS ON CROP ESTABLISHMENT AND CROP GROWTH

7.1 Introduction

Direct drilling or sowing without prior cultivation offers potential advantages for wheat production in south-eastern Australia, but it often leads to reduced seedling vigour, which in turn, can be associated with reduced yield (Cook et al., 1985; Cornish and Lymbery 1987; and Fischer et al., 1988). Tillage which alters transient soil physical properties influences field seedling emergence and seedling vigour significantly (Soane, 1975). However, yields of direct drilled crops have been shown to vary from superior (Van Doren and Triplett, 1969) to equal or less than (Phillips, 1969), compared to other conventional techniques. Schmidt and Belford (1994) pointed out that increasing the depth of soil disturbance increased grain yields of wheat, particularly for depths of disturbance of 100 mm or greater. Direct-drilling using 55 mm-wide narrow-winged points, without cultivating tines, achieved crop yields comparable to conventional points (Bligh, 1991).

Results presented in Chapters 5 and 6 have shown that the shape of the narrow seeding point can influence soil physical properties soil. The critical question which arises from these results is what effect the physical changes have had on plant establishment and growth.

The aim of the work reported here was to measure the seedling emergence, plant population, leaf area, root growth, yield and its components after wheat was sown, using four differently shaped seeding points.

In order to achieve these aims, an experiment was laid down on a Sandy loam (SL) soil at the Roseworthy Campus of the University of Adelaide in 1993. This soil was typical of a large proportion of the cereal growing areas of South East Australia. However in 1994, a Clay loam (CL) was included in the experiment program to test performance of the narrow points in a heavier textured soil. As 1994 was a drought year with 260 mm annual rainfall (compared to 415 mm in 1993), the experiments were repeated in 1995 on both the SL and CL soils to obtain crop yields in a more typical year.

7.2 Materials and Methods

7.2.1 Site characteristics

Two red-brown earth sites (SL and CL) were used for experiments. The two sites are less than 4 km apart. The physical and chemical characteristics of the sites were described in Chapter 5. In 1993 the soil (SL) water content at seeding time at the sowing depth was 11.8 % and in 1994 the soil water content at seeding time was 22 % and 20 % for the CL and the SL sites respectively. In 1995 the soil water content at seeding time was around 17 % for both the CL and SL sites. The crop rotation prior to 1993 for each site was: faba beans, wheat, peas, wheat, faba beans.

7.2.2 Experimental design

Wheat was sown into uncultivated soil with a John Shearer seeder fitted with one of the four designated narrow points (described in Chapter 3). There was also a cultivated treatment (CT) which comprised two passes of a cultivator followed by sowing with the 45-0-0 points. In 1993 seeding was carried out on 16 June, in 1994 both sites were sown on 3 July, and in 1995 on 26 June.

Treatments in each year were four narrow seeding points, 45-0-0, 45-W-0, 45-W-S, and 90-0-0, (see Fig. 3.2) and one cultivated treatment (CT). The sowing depths in 1993 for the narrow seeding point treatments were 25, 50 and 80 mm. The cultivated treatment (CT) was sown at a depth of 50 mm. In 1994 and 1995 the same treatments were applied using only one sowing depth, 50 mm on two sites (CL and SL). The experimental plots were 1.8 m wide (ten rows with 180 mm space between rows) and 20 m long. Sowing speed was 8 km/h for all experiments.

7.2.3 Laboratory experiment

In order to obtain the rate of emergence in controlled situations, wheat was sown into metal bins 1.5 m wide and 3 m long (described in Chapter 3) in the laboratory. A one metre length of sowing-line from each bin with four replicates were randomly selected. The number of emerged seedlings (coleoptile visible at the soil surface) was measured each day after the first seedling had emerged until most of the seeds emerged. In addition, total plant emergence was obtained by excavating the seed. All measurements were expressed as a percentage of the total number of seeds sowing (87 kg seed/ha was calculated to be equivalent to 216 seeds/m^2).

7.2.4 Field experiments

A week before sowing, the experimental sites were sprayed for weed control using Roundup© (1.5 litre/ha plus wetter). At sowing time, 100 kg/ha of diammonium phosphate (18 % Nitrogen and 20 % Phosphorus) fertiliser was applied with the seed. Machete, the most widely grown variety of wheat in South Australia was used in all the field experiments. It is a high yielding, early to mid season, semi-dwarf wheat with very strong straw.

7.2.4.1 1993 Experiment (SL93)

Seedling emergence and plant population

Crop emergence was counted in randomly selected one meter lengths of row (two replicates per plot). Seedling emergence was assessed from 26 June to 6 July in 1993 for all treatments. After most seeds had emerged, the total plant population was estimated using a 0.5 ×0.5 m quadrate on three randomly selected replicate positions in each plot. All measurements were expressed as a percentage of the total number of seeds sown.

Leaf area and dry matter

Sampling for leaf area and crop dry matter production, which started one month after sowing, was done at two week intervals on six occasions throughout the growing season. Each time one metre of row (two replicates per plot) was used. All samples were refrigerated to avoid shrinkage of the leaves and leaf area was measured by using a planimeter and expressed as area of leaf /area of soil (m^2 m^{-2}). After measuring leaf area, dry matter was determined after drying the samples for 48 hours at 60° C in a fan forced oven.

Nitrogen content

Herbage samples at anthesis, and harvested grain samples were analysed for N using a Kjeldahl digestion procedure (Nelson and Sommers, 1973). The dried samples were heated in sulphuric acid with a catalyst and digested until the protein/nitrogen was transformed into ammonium sulphate. Sodium hydroxide was added, the mixture heated, and the ammonia removed by distillation. The amount of ammonia was measured by titration, and the nitrogen content was calculated from the amount of ammonia liberated. Results were on expressed a dry matter basis. Nitrogen uptake was calculated from grain yield and N-concentration data. Grain protein content was derived by multiplying N concentration by 5.70, corrected to 120 (g kg^{-1}) moisture.

Root length and dry root mass density

In September 1993, at crop tillering, wheat roots from the surface soil layers (SL) were sampled randomly by pushing a 95 mm diameter thin-walled corer into the sowing lines with two replicates from each plot. The samples were sectioned into 100 mm lengths (0-100, 100-200, and 200-300 mm depth). To achieve a high recovery rate with minimal damage to root systems, soil samples were washed by hand with gentle agitation on a laboratory sieve. The samples were soaked in gently flowing water for 24 hours, the remaining soil was separated from the roots by a hand-held, fine, low pressure jet of water. The samples were then poured onto a 0.80 mm sieve and rinsed under a water spray until most of the soil was removed. Care was taken to minimise the loss of fine root material during washing. Roots were poured onto a

0.5 mm sieve for a final rinse under a gentle water spray, and decanted into a 0.1 % blue staining solution (formalin- ethanol-acetic acid, 10-50-5 % by volume, respectively) so the root samples were darkly stained. Root material was fixed to filter papers, while the root material was floated in the water, water was drained gently and the roots uniformly fixed on the paper. Organic debris was separated from the roots and discarded. A photocopy of the fixed roots was made and this image was scanned into a computer and analysed by an image analysis program (Kirchhof, 1992). Output from the program provided measurement of root length density (mm cm^{-3} soil) at three sowing depths (25, 50, and 80 mm) with three depth intervals (0-100, 100-200, and 200-300 mm) for all treatments with two replicates from each plot. After oven drying, the mass of root dry matter was obtained using a balance sensitive to 1 mg and expressed as dry root mass density (mg cm^{-3} soil).

Grain yield and yield components

Grain yield was determined by harvesting a 1 × 20 m swath from the inner 6 rows of each plot with a self-propelled combine harvester. Grain yield samples were weighed and expressed as kg ha^{-1} and 1000 seeds weight was measured with two replicates of each plot. Components of wheat grain yield (numbers of plants per square meter, numbers of heads per square meter) were determined before harvesting on two sections of one meter length from each plot.

7.2.4.2 1994 Experiments (CL94 and SL94)

In 1994 two field experiments were established: one on the SL94 and one on the CL94 sites, 4 km distant. Tillage treatments on these experiments were similar to those of SL93, except only one sowing depth (50 mm) was used.

Wheat emergence was counted from 8 July to 20 July for all treatments and plant populations were obtained after most seeds had emerged using the same procedure described for SL93. Leaf area and dry matter were measured at early tillering and at crop flowering stage. Root length density and mass were obtained by using 45 mm diameter soil cores from three soil depths (0-100, 100-200, and 200-300 mm) at early tillering and from 300-600 mm at anthesis. Plant disease (*Rhizoctonia solani*) was determined by the patches measuring method (MacNish and Lewis, 1985) at end of tillering. The grain yield and yield components were determined using the same procedure described for SL93.

7.2.4.3 1995 Experiments (CL95 and SL95)

The 1994 experiments were repeated in 1995 but only grain yield and 1000 seeds weight were obtained using the same procedures as in 1994.

7.3 Statistical analysis

The logistic function (Landsberg, 1977) was fitted to the seedling emergence data as

$$E = M / [1 + \exp(-K(t-m))] \qquad [1]$$

where E is the proportion of seeds sown (%) as a function of time (t, day) after sowing. This function gave estimated values for parameters M, K, m and corresponding standard errors, where M is total emergence, K is uniformity of emergence and m shows the emergence delay. A pooled standard error (SE_p) was calculated as

$$SE_p = [\,(SE_{45\text{-}0\text{-}0}^2 + SE_{45\text{-}W\text{-}0}^2 + SE_{45\text{-}W\text{-}S}^2 + SE_{90\text{-}0\text{-}0}^2 + SE_{CT}^2)\,/n]^{1/2} \qquad [2]$$

where $SE_{45\text{-}0\text{-}0}$, $SE_{45\text{-}W\text{-}0}$, $SE_{45\text{-}W\text{-}S}$, $SE_{90\text{-}0\text{-}0}$, and SE_{CT} are standard errors for seeding point treatments, 45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT respectively.

A t-test (Snedecor and Cochran, 1980) was used to evaluate the significance of the difference between coefficients M, K, and m using n-1 degrees of freedom where n is the number of treatments (5). The t value was calculated for each comparison of the M, K, and m exponents (t_M, t_K, t_m) from any two regressions as follows

$$t_M = (M_i - M_j) / (\sqrt{2}\ SE_p) \qquad [3a]$$

$$t_K = (K_i - K_j) / (\sqrt{2}\ SE_p) \qquad [3b]$$

$$t_m = (m_i - m_j) / (\sqrt{2}\ SE_p) \qquad [3c]$$

where M_i and M_j are the total emergence, K_i and K_j are the uniformity of emergence and m_i and m_j are the time of emergence delay from any two of regression lines which are being compared. The same statistical method was applied to the leaf area and crop dry matter data which were obtained on six occasions in SL93.

Data from measurements other than seedling emergence were analysed by using a factorial randomised block design for four treatments and three sowing depth intervals with four block replicates. For the comparison, the CT treatment was included (only with 50 mm sowing depth), the statistical design of the randomised block design was used as four narrow points for three sowing depth intervals (25, 50 and 80 mm) and CT treatment (50 mm) with four block replicates. In 1994 experiments which comprised five narrow point treatments (45-0-0, 45-W-

0, 45-W-S, 90-0-0 and CT) with only one sowing depth (50 mm), the randomised complete block design was used for analysis of variance. The LSD (least significant difference) multiple comparison method was used to compare each treatment mean to every other mean.

Table 7.1 shows the degrees of freedom available for statistical analysis of the data obtained with seeding points 45-0-0, 45-W-0, 45-W-S, 90-0-0 at three sowing depths (25, 50 and 80 mm) in 1993.

Table 7.1 The ANOVA table for statistical analysis of data in 1993.

Source of variation	Degree of freedom
Tool type	3
Depth	2
Tool type depth	6
Replicates	3
Residuals	33
Total	47

Table 7.2 shows the degrees of freedom available for statistical analysis of the data obtained with seeding points 45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT at one sowing depth (50 mm) in 1994 and 1995.

Table 7.2 The ANOVA table for statistical analysis of data in 1994 and 1995.

Source of variation	Degree of freedom
Tool type	4
Replicates	3
Residuals	12
Total	19

7.4 Results and discussion

7.4.1 Seedling emergence

7.4.1.1 Laboratory experiment

The effect of four seeding points on the placement and depth of soil cover of wheat seeds was described in Chapter 4. Table 7.3 shows the coefficients obtained from the fitted logistic function of Equation [1] to wheat emergence data as a function of time after sowing for four narrow seeding point treatments with three sowing depths (25, 50, 80 mm) at two sowing speeds (6 and 10 km h^{-1}).

Table 7.3 Coefficients obtained from fitting the logistic equation (Eq. 1) to wheat emergence data as a function of time after sowing (d) for four seeding point treatments in soil bin experiments in 1993.

Sowing speed of 6 km h^{-1}									
Sowing depth	25 mm			50 mm			80 mm		
Treatment	*M*	*K*	*m*	*M*	*K*	*m*	*M*	*K*	*m*
45-0-0	82.81	2.73	3.62	97.21	4.56	4.93	84.82	4.11	6.79
45-W-0	93.97	1.43	3.29	96.72	4.45	5.42	90.28	2.99	6.94
45-W-S	96.04	2.62	5.05	90.80	3.34	5.90	85.05	2.75	7.66
90-0-0	96.76	3.94	3.78	96.09	3.62	5.41	87.64	2.53	6.38
Sowing speed of 10 km h^{-1}									
45-0-0	95.80	2.12	4.80	95.17	2.29	5.26	98.01	1.06	7.66
45-W-0	87.42	2.69	4.83	94.16	2.88	5.43	95.13	1.30	7.71
45-W-S	85.22	2.77	4.89	88.17	3.64	6.41	85.76	1.36	7.46
90-0-0	94.90	2.35	4.41	94.41	2.24	5.61	87.69	1.77	6.69

Table 7.4 shown statistical data obtained from Equations 2 and 3 for evaluating the significance of coefficients of the logistic function (Eq.1) fitted to emergence data. Emergence coefficients for narrow seeding point treatments were evaluated relative to the control point (45-0-0).

Table 7.4 Significance of difference between the ultimate emergence (*M*), uniformity of emergence (*K*), and emergence delay (*m*) for narrow seeding points, relative to the control point, 45-0-0.

Emergence parameters →		*M*		*K*		*m*	
Sowing depth	Seeding point comparison	Pooled SE	Calculated t value	Pooled SE	Calculated t value	Pooled SE	Calculated t value
Sowing speed of 6 km h^{-1}							
25 mm	45-0-0 vs 45-W-0	0.3423	23.07 **	0.5633	1.62 NS	0.0446	5.32 *
	45-W-S		27.35 **		0.13 NS		22.68 **
	90-0-0		28.83 **		1.52 NS		2.52 NS
50 mm	45-0-0 vs 45-W-0	0.7352	0.48 NS	0.6390	0.12 NS	0.0231	14.79 **
	45-W-S		6.17 **		1.35 NS		29.49 **
	90-0-0		1.08 NS		1.04 NS		14.42 **
80 mm	45-0-0 vs 45-W-0	0.9400	4.19 NS	0.2171	3.62 NS	0.0233	4.57 NS
	45-W-S		0.18 NS		4.41 NS		26.49 **
	90-0-0		2.12 NS		5.16 *		12.31 **
Sowing speed of 10 km h^{-1}							
25 mm	45-0-0 vs 45-W-0	0.5507	10.75 **	0.0909	4.37 NS	0.0184	1.42 NS
	45-W-S		13.57 **		5.04 *		3.57 NS
	90-0-0		1.15 NS		1.77 NS		14.68 **
50 mm	45-0-0 vs 45-W-0	1.3090	0.54 NS	0.1889	2.21 NS	0.0404	2.89 NS
	45-W-S		3.78 *		5.06 *		20.09 **
	90-0-0		0.41 NS		0.17 NS		6.17 **
80 mm	45-0-0 vs 45-W-0	11.4640	0.24 NS	0.2207	0.77 NS	0.2793	0.13 NS
	45-W-S		0.82 NS		0.96 NS		0.49 NS
	90-0-0		0.70 NS		2.28 NS		2.44 NS

Asterisks indicate significance at: * $P < 0.05$, ** $P < 0.01$. NS, not significant.

Wheat sown at 25 mm depth showed significant differences in emergence, depending on the seeding point. Generally 45-W-0 and 45-W-S resulted in a significantly higher percentage (11 % and 14 % respectively) of seedling emergence at the lower sowing speed (6 km h^{-1}), but resulted in lower (8 % and 10 % respectively) seedling emergence at high speed (10 km h^{-1}) compared to 45-0-0 seeding point. Uniformity of emergence did not differ for seeding points at low speed, but the points 45-W-0 and 45-W-S resulted in less uniformity of emergence at high speed. The point 45-W-0 had a lower emergence delay but 45-W-S had a higher emergence delay when seeded at a speed of 6 km h^{-1}. This emergence delay response was reversed at the higher speed.

Wheat sown at 50 mm depth and 6 km h^{-1} speed showed 6 % higher emergence for point 45-W-0 compared to point 45-0-0. The other notable response was observed with points 45-W-0 and 45-W-S which showed less uniformity of emergence and higher emergence delay at low speed. Also the point 90-0-0 showed less emergence uniformity but less emergence delay.

When wheat was sown at 80 mm depth, all emergence parameters showed no significant difference between points except for 45-W-S which gave slower emergence at a speed of 6 km h^{-1}. The other notable response was observed with the 90-0-0 point which showed slower emergence and less uniformity of emergence at a 6 km h^{-1} sowing speed. The greater lateral seed spread (points 45-W-0 and 45-W-S) did not influence the uniformity of emergence whilst higher depth of seed cover (point 45-W-S) caused a delay in time of emergence, especially at the greater sowing depth.

7.4.1.2 Field experiment

SL93: Figure 7.1 shows emergence as a function of time after sowing and the fitted logistic function of Equation [1] for five narrow seeding point treatments and the 50 mm sowing depth. Only the 50 mm data are shown as examples.

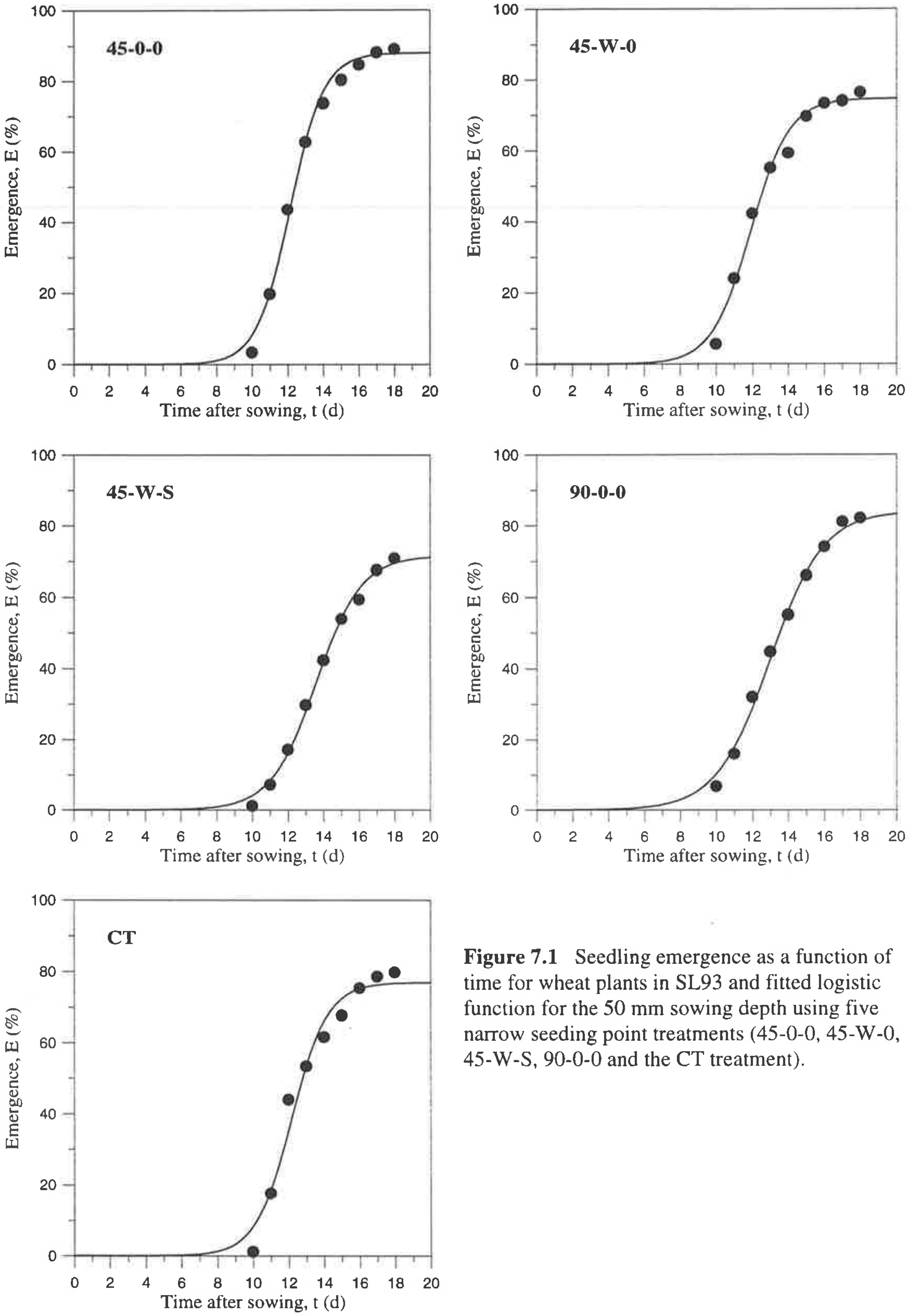


Figure 7.1 Seedling emergence as a function of time for wheat plants in SL93 and fitted logistic function for the 50 mm sowing depth using five narrow seeding point treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0 and the CT treatment).

The coefficients obtained from fitting the logistic function (Eq.1) to the emergence data are shown in Table 7.5. The significance of these results are shown in Table 7.6.

Table 7.5 Coefficients obtained from fitting the logistic equation (Eq. 1) to wheat emergence data as a function of time after sowing (d) for five seeding point treatments at the SL93.

Sowing depth	25 mm			50 mm			80 mm		
Treatment	M	K	m	M	K	m	M	K	m
45-0-0	47.43	1.54	11.48	87.56	1.06	12.14	67.36	1.09	15.66
45-W-0	82.34	1.85	10.95	74.06	0.93	11.91	81.78	0.86	14.37
45-W-S	89.06	0.81	12.82	71.61	0.78	13.56	84.41	0.78	13.32
90-0-0	42.70	0.84	12.51	84.64	0.60	12.95	70.58	0.99	13.71
CT	—	—	—	76.92	0.98	12.16	—	—	—

M is the total emergence, K is uniformity of emergence and m is emergence delay.

Table 7.6 shows significance of differences in magnitude between coefficients of the logistic equation (Eq.1) fitted to emergence data from the seeding point treatments and sowing depths.

Table 7.6 Significance of difference between the final number of wheat plants which emerged (M), uniformity of emergence (K), and emergence delay (m) for four narrow seeding point treatments, relative to the control point 45-0-0, in SL93.

Sowing depth (mm)	Emergence parameters	M		K		m	
	Seeding point comparison ↓	Pooled SE	Calculated t value	Pooled SE	Calculated t value	Pooled SE	Calculated t value
25	45-0-0 vs 45-W-0	1.759	14.0368 **	0.163	1.3485 NS	0.132	2.8806 *
	45-W-S		16.7365 **		3.1369 *		7.2149 **
	90-0-0		1.9013 NS		2.6968 NS		5.5612 **
50	45-0-0 vs 45-W-0	2.648	3.6050 *	0.122	0.7349 NS	0.167	0.9713 NS
	45-W-S		4.2595 *		1.5877 NS		6.0181 **
	90-0-0		0.7795 NS		2.2503 NS		3.4166 *
	CT		2.8426 *		0.4355 NS		0.0760 NS
80	45-0-0 vs 45-W-0	2.957	3.4488 *	0.095	1.6620 NS	0.155	5.9370 **
	45-W-S		4.0796 *		2.3004 NS		10.734 **
	90-0-0		0.7713 NS		0.7119 NS		8.9215 **

Asterisks indicate significance at: * $P < 0.05$, ** $P < 0.01$. NS, not significant.

SL93: When wheat was sown at 25 mm depth, the points 45-W-0 and 45-W-S showed significantly higher total emergence (M) compared to point 45-0-0 (Table 7.4). Points 45-W-0, 45-W-S and 90-0-0 had slower emergence than point 45-0-0. In 1993 there was a severe mouse plague resulting in pre-emergence destruction of seedlings. Seeds sown at 25 mm depth were particularly prone to damage by both mice and birds because of the shallow soil cover. Damage to plots sown with points 45-W-S and 45-W-0 was reduced, presumably because the greater vertical and horizontal scatter of seeds (Chapter 4) made them more difficult to detect or excavate.

When wheat was sown at 50 mm depth, total emergence (*M*) of wheat was significantly lower for points 45-W-0, 45-W-S and CT than 45-0-0. The other notable response was with point 45-W-S and 90-0-0 which produced significantly slower emergence (large *m* value, Table 7.6) than point 45-0-0. The deeper sowing depth reduced mice and bird damage but also decreased total emergence, in seeding point treatments that caused deepest and most severe soil disturbance (45-W-S and 45-W-0).

When wheat was sown at 80 mm depth, the points 45-W-0 and 45-W-S gave significantly slower emergence (large *m* value, Table 7.6), but higher total emergence than point 45-0-0. This occurred because of the greater depth of soil cover that the points 45-W-0 and 45-W-S produced. The point 90-0-0 and CT did not show any significant differences to point 45-0-0 for any of the emergence parameters (*K*, *M*, *m*) except point 90-0-0 which had slower emergence than point 45-0-0. This result suggests that degree of soil disturbance, depth of soil cover and quality of seedbed were similar for these points.

CL94 and SL94: Table 7.7 and Figures 7.2 and 7.3 show the results of a comparison of emergence for five seeding point treatments during 1994 on two sites (CL and SL).

Table 7.7 Coefficients obtained from fitting the logistic equation (Eq. 1) to wheat emergence data as a function of time after sowing (d) for five seeding point treatments at two sites (CL94 and SL94).

Site	CL94			SL94		
Treatment	*M*	*K*	*m*	*M*	*K*	*m*
45-0-0	85.99	0.99	13.73	81.15	1.54	13.84
45-W-0	79.53	1.06	14.46	81.11	1.26	14.42
45-W-S	78.33	0.82	15.21	68.92	0.90	15.18
90-0-0	83.98	0.98	14.18	78.12	1.16	14.19
CT	91.30	0.92	14.06	87.93	0.93	13.84

M is the total emergence, *K* is uniformity of emergence and *m* is emergence delay.

As in 1993 the seeding point 45-W-S had lower total emergence (*M*), lower uniformity (*K*) and higher emergence delay (*m*). The significance of these results were however, not clear cut (Table 7.8).

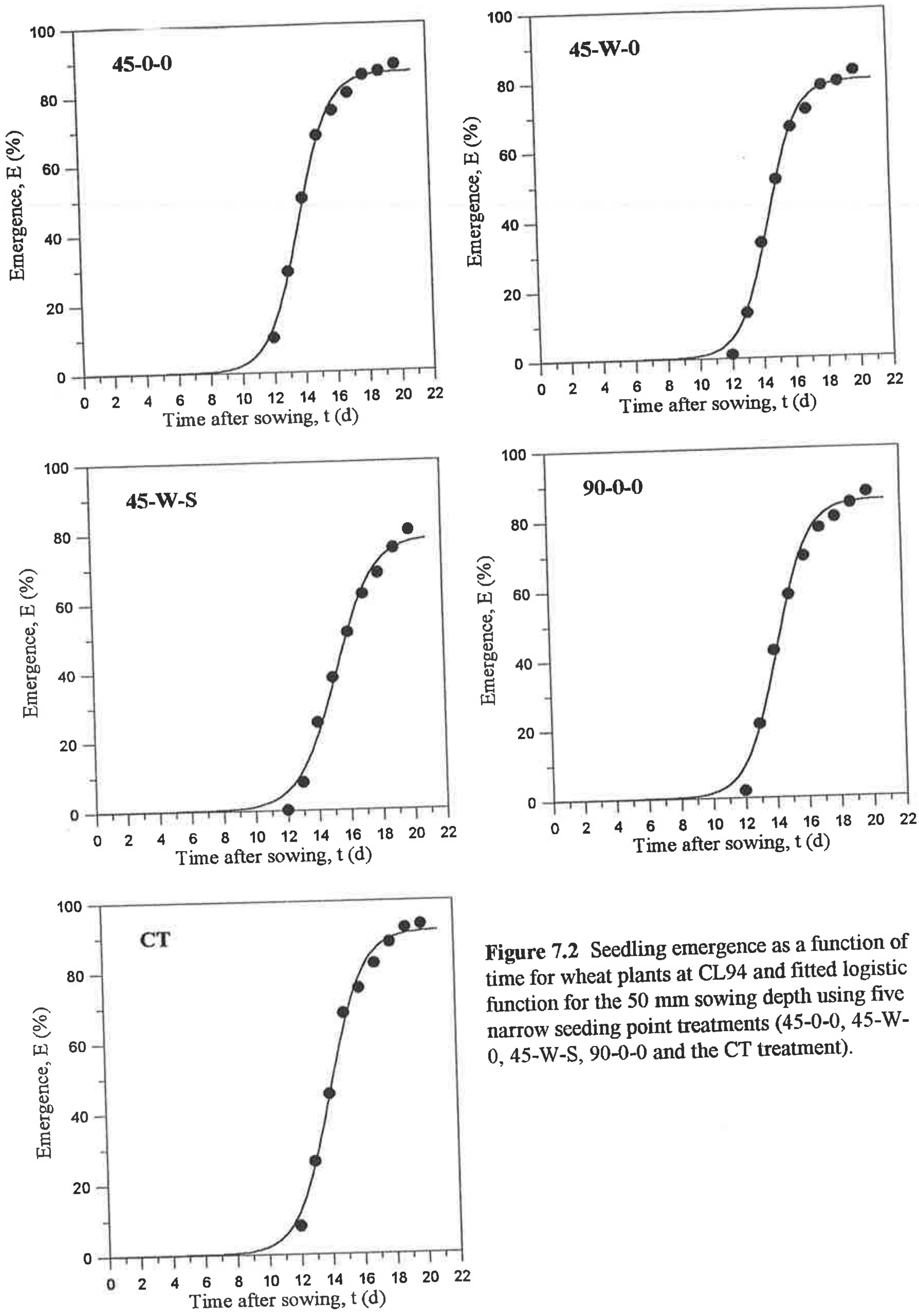


Figure 7.2 Seedling emergence as a function of time for wheat plants at CL94 and fitted logistic function for the 50 mm sowing depth using five narrow seeding point treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0 and the CT treatment).

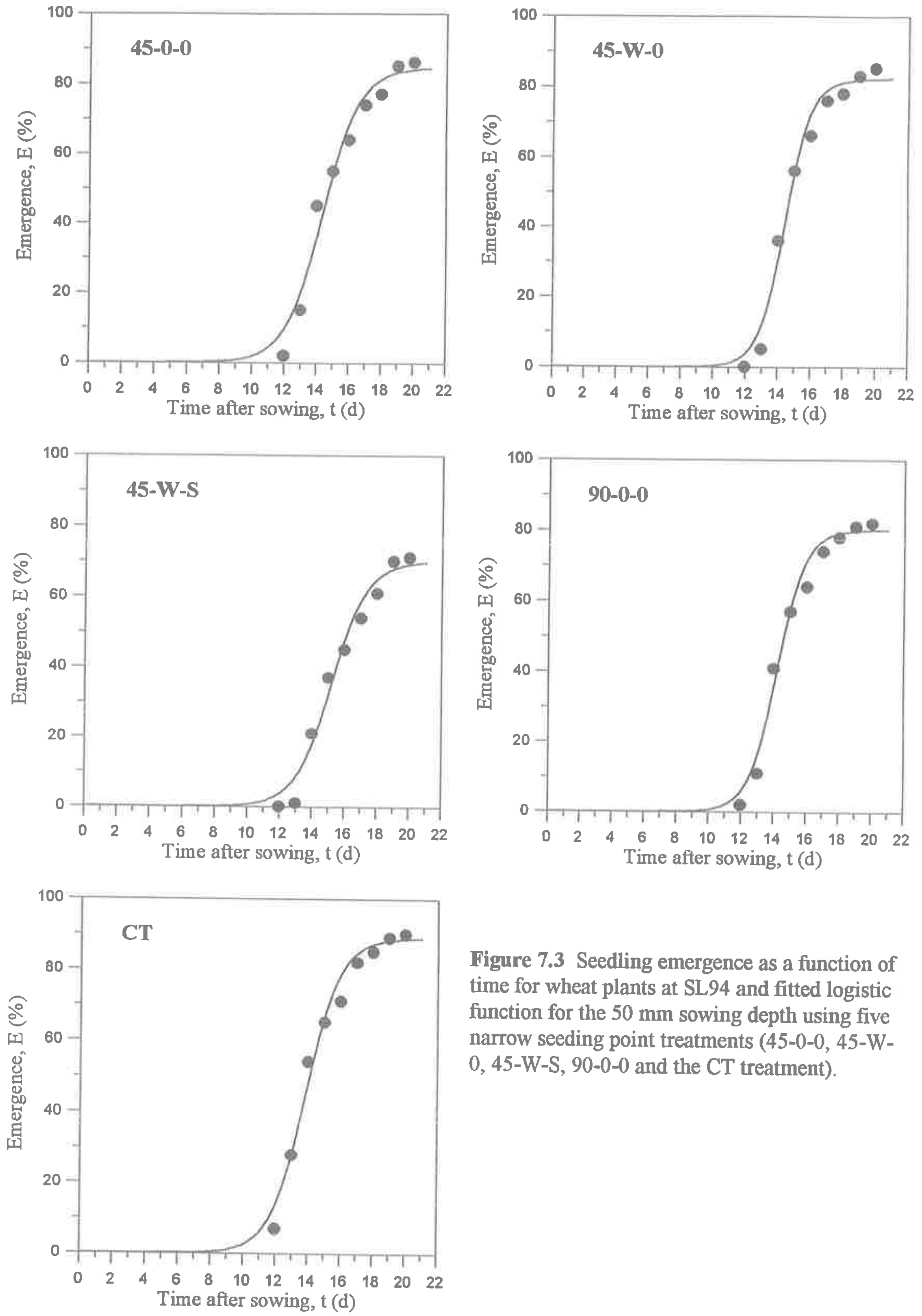


Figure 7.3 Seedling emergence as a function of time for wheat plants at SL94 and fitted logistic function for the 50 mm sowing depth using five narrow seeding point treatments (45-0-0, 45-W-0, 45-W-S, 90-0-0 and the CT treatment).

Table 7.6 shows the significance of differences in the magnitude of the coefficients of the logistic function (Eq.1) fitted to emergence data from wheat sown at two sites (CL94 and SL94) and with five seeding point treatments. At the CL94, no significant differences between the seeding points were observed for all parameters of Equation 1, except for 45-W-S and 45-W-0 which showed delayed emergence compared with point 45-0-0. At the SL94, the only notable response was for the point 45-W-S which was slower to emerge compared with seeding point 45-0-0. This is consistent with the results obtained in 1993 and in 1995 (data not shown here because they were similar to that obtained in 1994) for the 50 mm sowing depth. Mice and bird damage were not serious problem in 1994 or 1995.

During the period between sowing and emergence in all years studied, no significant amount of rain fell. The better soil physical condition associated with 45-W-S and 45-W-0 appear to have had no positive benefit for emergence, probably because soil physical quality did not limit germination and seedling growth. The only limitation was the depth of soil that covered the seed. However, these results may have been different if high rainfall had occurred between sowing and emergence, causing crusting and/or hardsetting. If moisture had been an important limitation, the points 45-W-S, 45-W-0 and CT may also shown better emergence results.

Table 7.8 Significance of difference between the final number of wheat plants which emerged (*M*), uniformity of emergence (*K*), and emergence delay (*m*) for five narrow seeding point treatments, relative to the control point 45-0-0, in CL94 and SL94 sites.

Site	Emergence parameters	*M*		*K*		*m*	
	Seeding point comparison ↓	Pooled SE	Calculated t value	Pooled SE	Calculated t value	Pooled SE	Calculated t value
CL94	45-0-0 vs 45-W-0	2.4252	1.8858 NS	0.1063	0.4516 NS	0.1393	3.6896 *
	45-W-S		2.2357 NS		1.1889 NS		7.4755 **
	90-0-0		0.5887 NS		0.0887 NS		2.2888 NS
	CT		1.5476 NS		0.4728 NS		1.6342 NS
SL94	45-0-0 vs 45-W-0	3.1627	0.0080 NS	0.2214	0.8921 NS	0.1926	2.1115 NS
	45-W-S		2.7225 NS		2.0274 NS		4.9097 **
	90-0-0		0.6774 NS		1.2169 NS		1.2669 NS
	CT		1.5167 NS		1.9496 NS		0.0257 NS

Asterisks indicate significance at: * $P < 0.05$, ** $P < 0.01$. NS, not significant.

7.4.2 Plant population

SL93: Figure 7.4 shows the number of wheat plants per square meter for four narrow seeding points at three sowing depth intervals and a cultivated treatment at 50 mm sowing depth at the SL site. The point 45-W-S gave a significantly ($P< 0.05$) higher plant population than other treatments at 25 and 50 mm sowing depths. This was because of less mice and bird damage that occurred with this seeding point at shallower sowing depths. A progressive increase in the sowing depth increased plant population for all seeding points except point 45-W-S which showed a non-significant decline with increased sowing depth. Because of higher vertical seed spread with this point (see Chapter 4), presumably some of the seed could not emerge when sown too deeply.

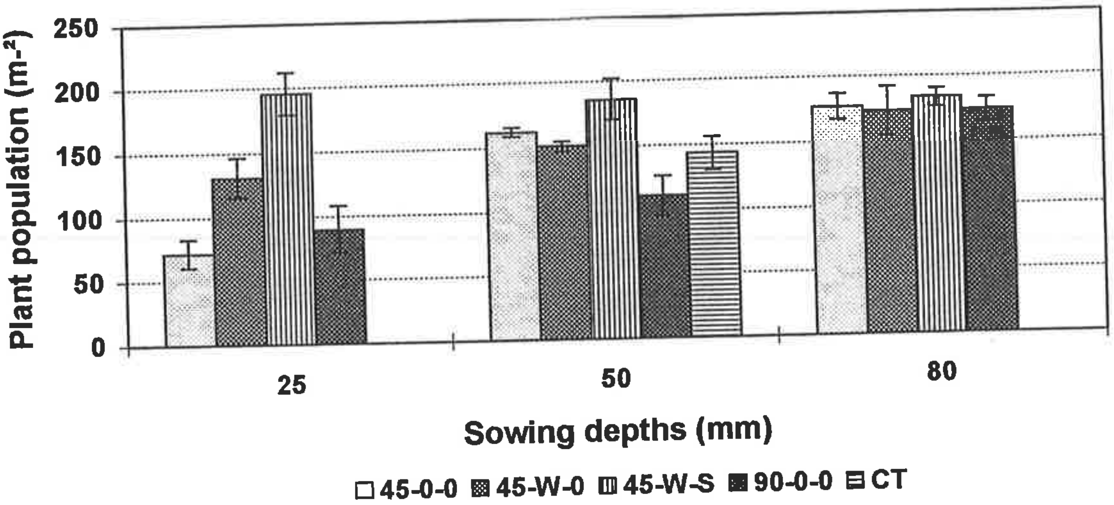


Figure 7.4 Plant population (number of plant per square meter) for three sowing depths (25, 50, 80 mm) using five narrow seeding point treatments at the SL93.

CL94 and SL94: Figure 7.5 shows the number of plants per square meter for four narrow seeding points and a cultivated treatment. The point 45-W-S produced significantly ($P < 0.05$) lower plant populations than other treatments. This occurred because of greater depth of soil cover and greater variation in vertical seed spread (Chapter 4). Similar results were obtained for the treatments at the two different sites (SL94 and CL94).

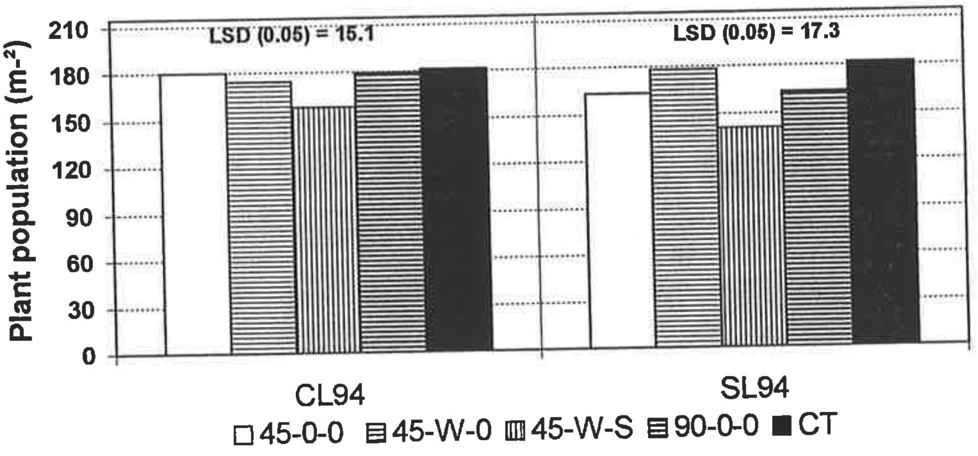
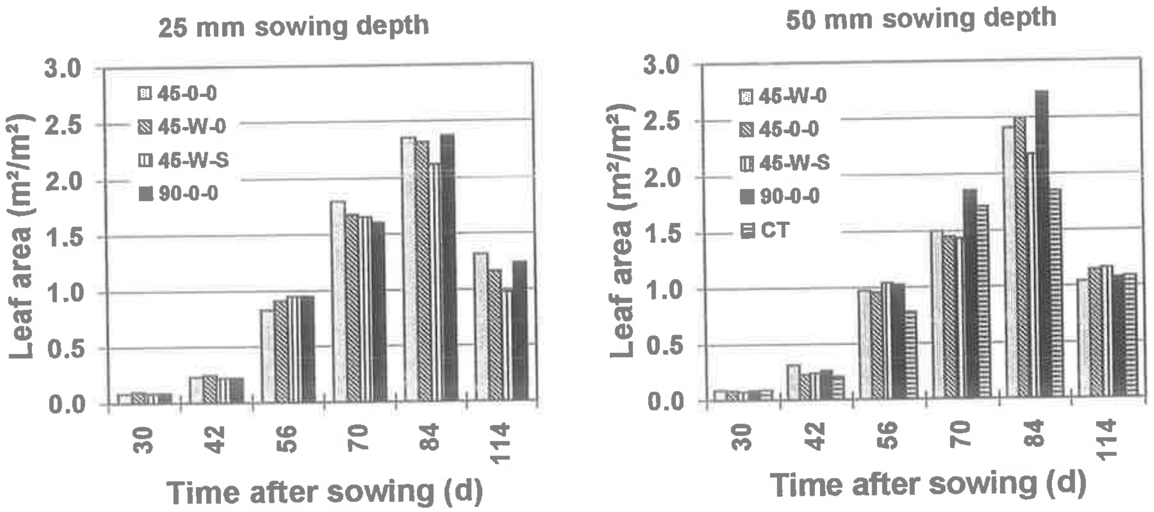


Figure 7.5 Plant population (number of plant per square meter), 25 days after sowing on two sties (CL94 and SL94) for five narrow seeding point treatments sown at 50 mm depth.

7.4.3 Leaf area and herbage dry matter

SL93: Leaf area and dry matter of the wheat plants were measured at six occasions from tillering to anthesis. Figure 7.6 shows the mean leaf area for four narrow seeding points at three sowing depths and the cultivated treatment (CT) at 50 mm sowing depth. Parameters derived from those data and significance of the results are shown in Tables 7.9 and 7.10 respectively.



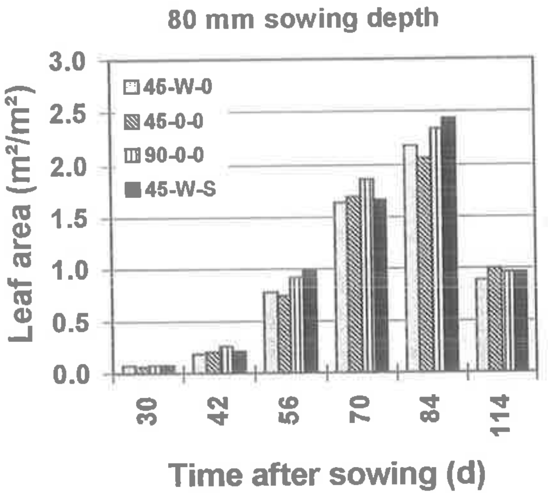


Figure 7.6 Development of leaf area as a function of time for wheat sown at 3 depths (25, 50, 80 mm) using different seeding point treatments at the SL93. The CT treatment was sown only to the 50 mm depth.

The logistic function (Eq.1) was fitted to development of leaf area as a function of time after sowing. The coefficients obtained in fitting this function are listed in Table 7.9.

Table 7.9 Coefficients obtained from fitting the logistic function (Eq. 1) to leaf area data as a function of time (d) after sowing for five seeding point treatments at the SL93.

Sowing depth →	25 mm			50 mm			80 mm		
Treatment ↓	*M*	*K*	*m*	*M*	*K*	*m*	*M*	*K*	*m*
45-0-0	2.49	0.12	68.84	2.82	0.09	65.85	2.94	0.08	74.88
45-W-0	2.85	0.09	67.45	2.92	0.08	67.83	2.44	0.10	65.91
45-W-S	2.33	0.12	61.58	2.23	0.13	59.42	3.77	0.07	77.74
90-0-0	2.32	0.10	62.96	3.57	0.09	69.58	3.00	0.08	70.64
CT	—	—	—	1.94	0.13	60.94	—	—	—

Table 7.10 shows results of the *t*-test applied to the coefficients of the leaf area (*M*, *K*, and *m*) for the narrow point treatments over the point 45-0-0 at three sowing depth intervals. The results showed that there was no significant difference in the coefficients of the leaf area between point 45-0-0 and other points in three sowing depths, except point 45-W-S which showed a significantly time delay on leaf growth at 25 mm sowing depth.

Table 7.10 Significance of the difference between the peak leaf area (*M*), uniformity of leaf area (*K*), and delay in development of leaf area (*m*) for narrow seeding points, relative to the control point 45-0-0, at SL93.

Sowing depth (mm)	Leaf area parameters		*M*		*K*		*m*	
	Seeding point comparison		Pooled SE	Calculated t value	Pooled SE	Calculated t value	Pooled SE	Calculated t value
25	45-0-0 vs	45-W-0	1459.9	1.7384 NS	0.011	1.5306 NS	1.738	0.5672 NS
		45-W-S		0.7372 NS		0.1786 NS		2.9535 *
		90-0-0		0.8287 NS		0.8044 NS		2.3948 NS
50	45-0-0 vs	45-W-0	2455.3	0.3148 NS	0.011	0.9768 NS	2.396	0.5847 NS
		45-W-S		1.6758 NS		1.8688 NS		1.8956 NS
		90-0-0		2.1982 NS		0.5749 NS		1.1021 NS
		CT		2.5314 NS		1.7663 NS		1.4493 NS
80	45-0-0 vs	45-W-0	4531.7	0.7852 NS	0.019	1.0863 NS	10.204	0.6219 NS
		45-W-S		1.3069 NS		0.2274 NS		0.1980 NS
		90-0-0		0.0963 NS		0.1472 NS		0.2938 NS

Asterisks indicate significance at: * $P < 0.05$, ** $P < 0.01$. NS, not significant.

Herbage dry matter weight showed similar trends to leaf area (data not shown). The results showed that there was no significant difference in the coefficients of the herbage dry matter between point 45-0-0 and other points in three sowing depths during 1993 at SL site.

CL94 and SL94: Table 7.11 shows wheat leaf area (m^2 m^{-2}) and herbage dry matter (g m^{-2}) on two occasions, once at early tillering and the other at flowering.

Table 7.11 Leaf area, L.A, (m^2 m^{-2}) and dry matter accumulation, D.M, (g m^{-2}) of wheat measured on two occasions (early tillering and flowering) at two sites (CL94 and SL94).

Seeding points	CL94				SL94			
	Early tillering		Flowering		Early tillering		Flowering	
	L.A	D.M	L.A	D.M	L.A	D.M	L.A	D.M
45-0-0	0.0131 a	0.65 a	0.868 a	252.5 a	0.0104 a	0.52 a	0.968 a	290.3 a
45-W-0	0.0151 a	0.76 a	0.914 ab	285.9 a	0.0125 a	0.62 a	1.002 a	312.5 a
45-W-S	0.0133 a	0.66 a	1.091 b	307.5 b	0.0121 a	0.60 a	1.255 b	362.5 b
90-0-0	0.0157 a	0.78 a	0.849 a	257.5 a	0.0111 a	0.55 a	0.952 a	294.5 a
CT	0.0158 a	0.80 a	0.850 a	265.3 a	0.0120 a	0.54 a	0.889 a	289.0 a
LSD	0.0032	0.162	0.141	43.56	0.0028	0.130	0.174	55.87

Mean followed by unlike letters in a column show significant differences at $P \leq 0.05$.

Table 7.11 shows that there was no significant difference in leaf area and dry matter accumulation between treatments at early tillering, but at flowering, the point 45-W-S produced significantly ($P < 0.05$) higher leaf area and dry matter than other treatments at the SL94. At the CL94 this point (45-W-S) produced a larger leaf area than points 45-0-0, 90-0-0 and CT treatment and more dry matter than other treatments. The reason for the higher leaf area and dry matter with this seeding point was as a result of higher soil moisture content (Chapter 5) at deeper depths (150-300 mm) which was observed at the flowering stage in the plots sown with 45-W-S. The other reason for this may be that this point had a lower plant population than others that produced greater leaf area and dry matter.

7.4.4 Nitrogen uptake in grain and herbage

Table 7.12 shows the mean herbage nitrogen and grain protein contents obtained from wheat sown with five narrow point treatments. At the SL93, there was no significant difference in herbage nitrogen content and grain protein between the narrow point treatments. Similar results were observed by McLeod, et al. (1992) who concluded that grain protein was not affected by the type of seed drill used for sowing. The result shows that the grain protein did not significantly differ by sowing depths.

Table 7.12 Herbage nitrogen and grain protein as mass proportions of total dry matter (DM) for five seeding point treatments at the SL93.

Treatments	Depth of sowing (mm)	N (% D. M.)	Grain protein (% D. M.)
45-0-0	25	2.38 a	12.35 a
	50	2.27 a	12.50 a
	80	2.21 a	12.35 a
45-W-0	25	2.19 a	12.25 a
	50	2.22 a	12.63 a
	80	2.18 a	12.35 a
45-W-S	25	2.20 a	12.27 a
	50	2.23 a	12.46 a
	80	2.18 a	12.35 a
90-0-0	25	2.44 a	12.45 a
	50	2.23 a	12.62 a
	80	2.22 a	12.35 a
CT	50	2.13 a	12.57 a

Mean followed by unlike letters in a column show significant difference at $P \leq 0.05$.

Although differences were not significant, the trends of grain protein as a function of depth of sowing were consistent across all treatments. Figure 7.7 shows the second order polynomial regression of grain protein vs sowing depth for four seeding point treatments. The data indicates that the sowing depth of 50 mm had higher grain protein compared to the 25 and 80 mm sowing depths, although not significant..

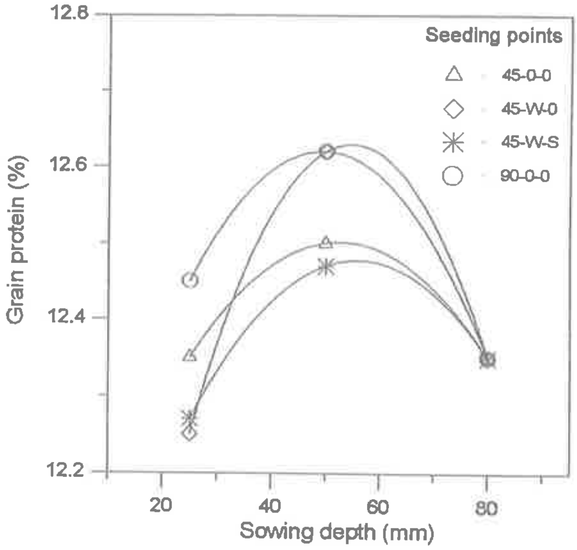


Figure 7.7 Fitted second order polynomial regression of grain protein content as a function of sowing depth for four seeding point treatments at the SL93.

7.4.5 Root growth

Root length density and root dry weights were measured at the end of tillering at SL93. Sampling of root length and root dry weight was included for the depth of 300-600 mm at flowering in CL94 and SL94. Figure 7.8 shows the root length and dry weight density at three sampling depth intervals (0-100, 100-200, 200-300 mm) for five seeding point treatments and three sowing depth intervals (25, 50, and 80 mm) at SL93. The results show that the 45-W-S seeding point produced significantly higher root length density than other treatment on both 25 and 50 mm sowing depth at 0-100 mm soil depth. Also the cultivated treatment (CT) had higher root length density than the points 45-0-0, 45-W-0, and 90-0-0 at 50 mm sowing depth in 0-100 mm soil depth. Root length increased with an increase in the sowing depth for all seeding point treatments except for point 45-W-S which showed a decline from the 50 mm to the 80 mm sowing depth. There was no significant difference in root length density between treatments at 100-200 and 200-300 mm soil depths.

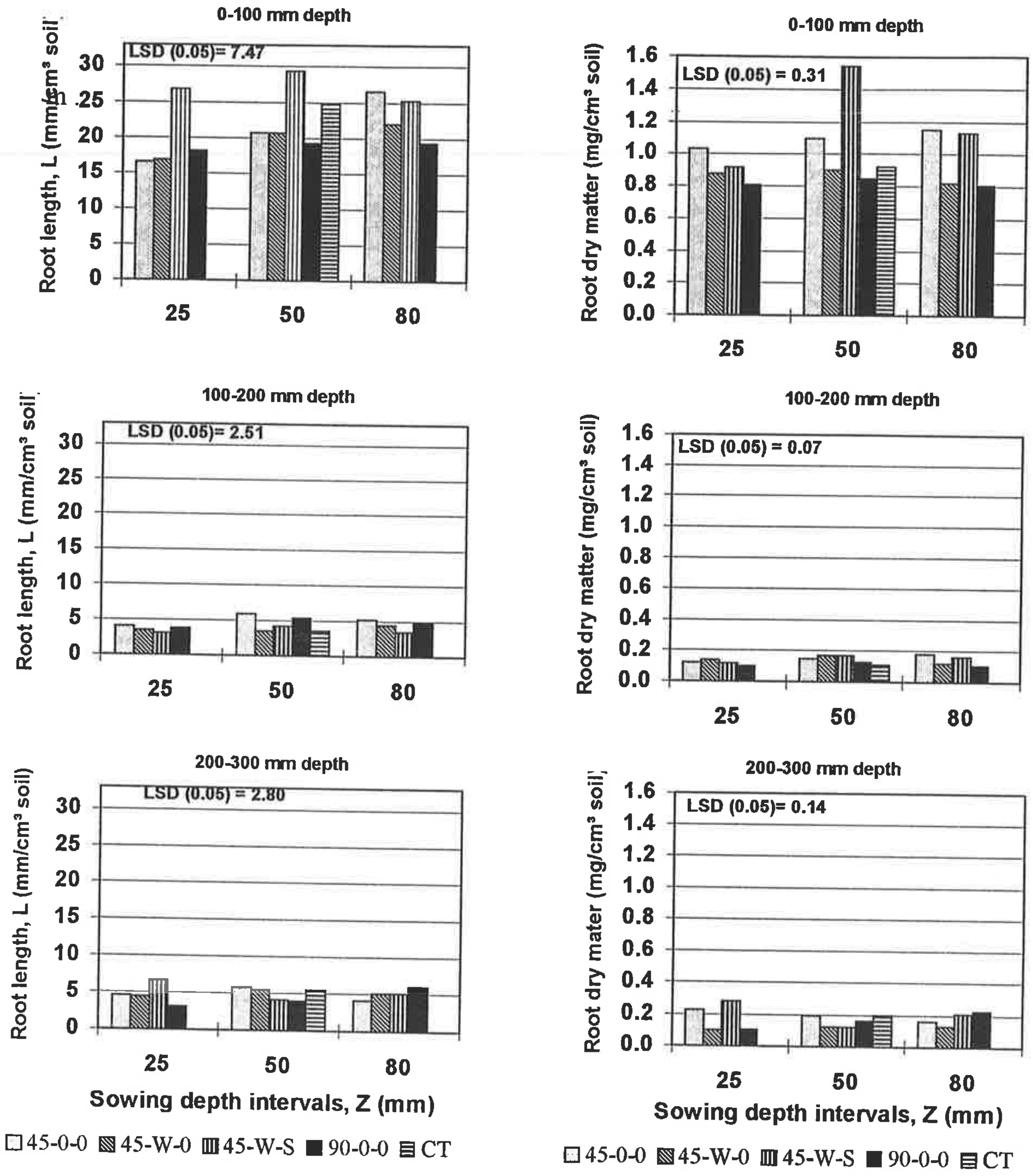


Figure 7.8 Mean root length density (mm cm^{-3} soil) and mean root dry weight density (mg cm^{-3} soil) at end of tillering, in 1993 sampled at 0-100, 100-200, and 200-300 mm soil depth intervals for five narrow seeding point treatments and three sowing depths.

Root dry matter weight showed similar trends to dry root mass density in the 0-100 mm sampling interval. However, dry root mass density for seeding point 45-W-S was not greater than the other treatments at the 25 mm sowing depth, nor did the weight of roots from the CT treatment exceed those of the 45-0-0, 45-W-0 and 90-0-0 treatment at 50 mm sowing depth. The result did not show any significant difference in dry root mass between treatments at 100-200 sampling interval. Dry root mass density for seeding point 45-W-S was higher than other treatments at 200-300 mm sampling interval in 25 mm sowing depth.

Table 7.13 shows the root length and dry weight density at three depth intervals for five seeding point treatments on two sites (CL94 and SL94) at early tillering. The results show that at the CL94 site the point 45-W-S had lower root length and root dry matter than other treatments at 0-100 depth. At the SL94 site similar results were observed at the same depth, although not significant. At the deeper soil depth (100-200 and 200-300 mm), this point had lower root length and root dry weight compared to others at the CL94 site. At the SL94 site this point and CT treatment had a greater root length than other treatments.

Table 7.14 shows the mean root length density and root dry weight at 300-600 mm soil depth for five narrow seeding point treatments at flowering stage in 1994. The results show that point 45-W-S had significantly higher root length density than other four treatments on both sites (CL94 and SL94). The root dry weight was significantly ($P< 0.05$) higher on the SL94 site. The data show that on CL94 site, the root dry weight for point 45-W-S was higher than other points but it was not significantly different to other treatments.

The reason for these higher values of root length density and root dry mass density with this seeding point at deeper layer of soil was as a result of higher soil moisture content (Chapter 5) at deeper layer (150-300 mm) which observed from the 45-W-S plots. This result supports that of higher leaf area for 45-W-S discussed in the previous section.

Table 7.13 Mean root length density (mm cm^{-3} soil) and mean root dry weight (mg cm^{-3} soil) during tillering at sampling depth intervals of 0-100, 100-200, and 200-300 mm soil depth for five narrow seeding point treatments on two sites (CL94 and SL94).

Seeding point Treatments	Depth mm	CL94		SL94	
		Root length mm cm^{-3} soil	Root dry weight mg cm^{-3} soil	Root length mm cm^{-3} soil	Root dry weight mg cm^{-3} soil
45-0-0	0-100	17.89 bc	0.425 d	18.51 a	0.241 a
45-W-0		12.36 ab	0.311 b	18.08 a	0.297 a
45-W-S		11.01 a	0.122 a	17.72 a	0.215 a
90-0-0		22.08 c	0.371 c	18.63 a	0.333 a
CT		17.57 bc	0.470 e	17.39 a	0.263 a
LSD		6.22	0.038	6.41	0.124
45-0-0	100-200	3.68 b	0.020 ab	2.43 ab	0.019 a
45-W-0		2.28 a	0.025 a	2.87 b	0.025 a
45-W-S		1.56 a	0.016 b	3.02 b	0.023 a
90-0-0		2.30 a	0.021 ab	1.15 a	0.020 a
CT		2.64 ab	0.026 a	4.56 c	0.035 a
LSD		1.21	0.006	1.41	0.017
45-0-0	200-300	3.32 b	0.032 b	2.71 b	0.027 ab
45-W-0		2.46 ab	0.035 b	1.98 b	0.038 b
45-W-S		1.28 a	0.014 a	2.36 b	0.023 a
90-0-0		1.95 a	0.016 a	0.74 a	0.012 a
CT		1.17 a	0.012 a	2.67 b	0.022 a
LSD		1.49	0.009	1.21	0.011

Mean followed by unlike letters in a column show significant difference at $P \leq 0.05$ (Duncans Multiple Range Test).

Table 7.14 Mean root length density and root mass density at 300-600 mm soil depth at flowering for five narrow seeding point treatments at both sites (CL94 and SL94).

Treatment	Clay loam		Sandy loam	
	Root length mg cm^{-3} soil	Root dry mass mg cm^{-3} soil	Root length mg cm^{-3} soil	Root dry mass mg cm^{-3} soil
45-0-0	7.03 a	0.068 a	6.85 a	0.049 a
45-W-0	7.80 a	0.064 a	8.06 a	0.068 a
45-W-S	10.46 b	0.086 a	11.21 b	0.093 b
90-0-0	6.76 a	0.054 a	7.13 a	0.057 a
CT	6.65 a	0.051 a	7.10 a	0.053 a
LSD	1.87	0.038	2.45	0.021

Mean followed by unlike letters in a column show significant difference at $P \leq 0.05$.

7.4.6 Root disease

In 1993 the experiment was tested for root disease (*Rhizoctonia spp.*) at 12 weeks after sowing and at heading stage. There was no severe root damage affected by *Rhizoctonia* in the

SL93. In 1994 both sites were tested at 12 weeks after sowing and at heading stage. Root damage caused by *Rhizoctonia* was found only in the SL94 site and at heading stage. Figure 7.9 shows the total area of *Rhizoctonia* root damage observed for five seeding point treatments at the SL94 site. The point 45-W-S had a significantly lower area of *Rhizoctonia* root damages at this site. This result supports the finding of Jarvis (1984) that soil disturbance and surrounding the seed with loose soil is important in reducing *Rhizoctonia* damage.

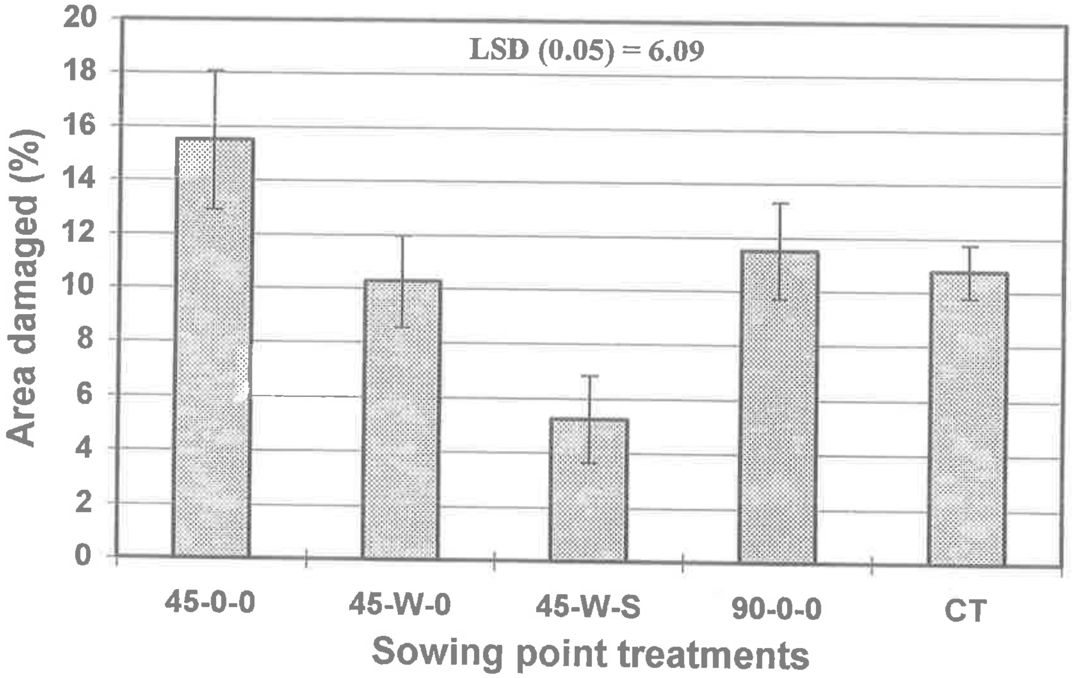


Figure 7.9 Area of *Rhizoctonia* damage to wheat plant at 12 weeks after sowing for five seeding point treatments at the SL94.

7.4.7 Grain yield and yield components

1993: Table 7.15 shows the mean grain yield and 1000 seed weight measured for five seeding point treatments with three sowing depths at the SL93.

Table 7.15 Mean grain yield and 1000 grain weight for five narrow seeding point treatments with three sowing depths (25, 50, and 80 mm) at the SL93.

Sowing depth (mm)	Treatments	1000 grain weight (g)	Grain yield (kg ha^{-1})
25	45-0-0	39.36 a	2436 a
	45-W-0	41.71 b	2725 b
	45-W-S	42.41 b	3010 c
	90-0-0	41.79 b	2705 b
50	45-0-0	42.23 b	2877 bc
	45-W-0	42.91 b	3254 c
	45-W-S	43.13 b	3214 c
	90-0-0	41.72 b	3023 c
	CT	42.01 b	2546 a
80	45-0-0	42.81 b	3023 c
	45-W-0	42.18 b	3142 c
	45-W-S	41.28 b	3016 c
	90-0-0	41.86 b	3148 c
LSD		1.97	259

The seeding point 45-W-S produced higher grain yield than other treatments for the 25 mm sowing depth. Point 45-W-0 and 45-W-S had higher grain yield whilst the CT treatment showed lower yield at 50 mm sowing depth. There was no significant difference between treatments at 80 mm sowing depth. The data shows that grain yield increased by increasing sowing depth except for point 45-W-S which showed a decline with increasing sowing depth.

1994 and 1995: Table 7.16 shows the mean of the grain yield and 1000 seeds weight for five narrow point treatments on two sites (CL and SL) in 1994 and 1995. During 1994 rainfall was lower than the average (260 mm compared with 440 mm). The lower rainfall caused reduction in grain yield at CL94 and SL94 compared to grain yields at CL95 and SL95 (382 mm rainfall).

On the CL94, point 45-W-S produced a significantly higher grain yield than other treatments except point 45-W-0. In CL95 this point (45-W-S) and CT treatment produced higher grain yield but it was not significantly different to other treatments (Table 7.16).

On the SL94, the seeding points 45-W-S produced significantly higher grain yield than other points except point 45-W-0 while in SL95, the point 45-W-S and CT produced significantly higher grain yield than other treatments. No significant difference was found between treatments for 1000 seed weight in CL94, SL94 and CL95, SL95 (Table 7.16).

Table 7.16 Grain yield and 1000 seeds weight for narrow seeding point treatments in 1994 and 1995 at the CL and the SL soil.

Seeding point	CL94		CL95		SL94		SL95	
	Grain yield kg ha^{-1}	1000 seeds weight g	Grain yield kg ha^{-1}	1000 seeds weight g	Grain yield kg ha^{-1}	1000 seeds weight g	Grain yield kg ha^{-1}	1000 seeds weight g
45-0-0	944 a	36.50 a	2831 a	42.90 a	1204 a	31.55 a	2069 a	45.72 a
45-W-0	1006ab	37.25 a	2786 a	42.43 a	1249ab	31.25 a	2289 a	45.09 a
45-W-S	1073 b	38.00 a	2903 a	42.57 a	1317 b	32.25 a	2610 b	45.00 a
90-0-0	910 a	36.25 a	2764 a	42.76 a	1189 a	32.25 a	2055 a	45.91 a
CT	920 a	36.00 a	2998 a	42.98 a	1098 a	32.25 a	2818 b	45.20 a
LSD	101	2.07	276	1.70	107	1.65	299	1.64

Mean followed by unlike letters in a column show significant difference at $P \leq 0.05$.

Table 7.17 shows the grain yield components in 1994 at two sites (CL94 and SL94). The result show that there is no significant difference between seeding point treatments for yield components. Table 7.17 shows that the seeding point 45-W-S produced a greater number of heads per square meter but it was not significantly different to other treatments at the CL94 and the SL94.

Table 7.17 Grain yield components for five narrow seeding point treatments at two sites, in 1994.

Treatment ↓	Number of plants per m²		Number of heads per m²	
Site →	CL94	SL94	CL94	SL94
45-0-0	183 a	185 a	299 a	255 a
45-W-0	195 a	222 a	321 a	263 a
45-W-S	218 a	217 a	322 a	313 a
90-0-0	192 a	203 a	296 a	282 a
CT	206 a	224 a	301 a	264 a
LSD (0.05)	50	65	66	66

Figure 7.10 shows the relationship between number of heads per meter and grain yield in 1994. The data show a significant linear relationship between grain yield as a function of the number of heads per meter at both sites in 1994.

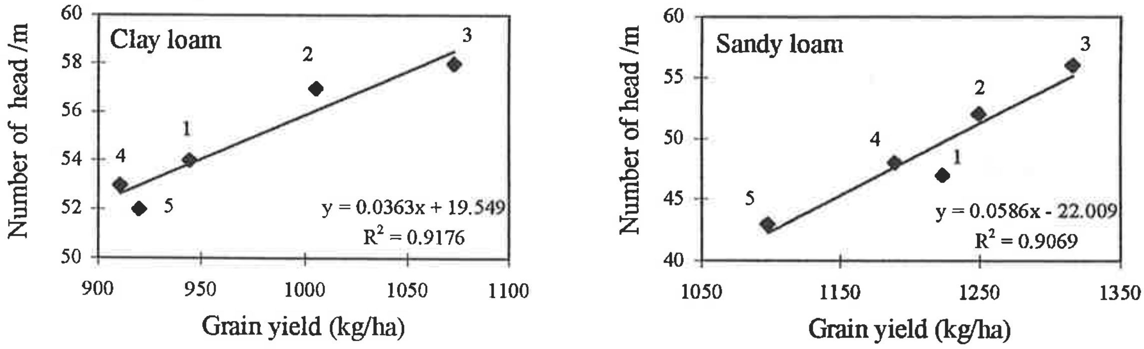


Figure 7.10 The relationship between number of heads per meter of row (independent variable) andgrain yield (dependent variable) at CL94 and SL94. Numbers (1, 2, 3, 4, 5) indicates the seeding point treatments 45-0-0, 45-W-0, 45-W-S, 90-0-0 and CT respectively.

7.5 Conclusions

SL93: the largest response to seeding point treatments occurred for total emergence of wheat sown at the shallowest depth (25 mm). Seeding points 45-0-0 and 90-0-0 produced about 40 % less total emergence than other treatments. This was largely the result of seed destruction by mice.

CL94 and SL94: soil moisture was high at sowing time which created a favourable condition for seedling emergence. In contrast to SL93, the seeding points 45-0-0 and 90-0-0 produced higher seedling emergence, compare to the 45-W-S and 45-W-0. However, it can be concluded that when soil moisture is high at sowing time, lower sowing depth or less soil cover treatments produce higher total emergence, but when the moisture is low, less seeds emerged.

Point 45-W-S showed a higher time delay on leaf growth at 25 mm sowing depth. This is largely the result of variation in sowing depths with this point.

There was no significant difference in herbage nitrogen content and grain protein between the narrow point treatments. Also the grain protein did not differ as a function of sowing depths but it was slightly higher on 50 mm sowing depth than 25 and 80 mm.

The 45-W-S seeding point produced higher root length density than other treatment on both 25 and 50 mm sowing depth at 0-100 mm soil depth interval. The cultivated treatment (CT) had higher root length density than the points 45-0-0, 45-W-0, and 90-0-0 at 50 mm sowing depth in the 0-100 mm soil depth intervals. Root length density increased by increasing the sowing depth for all seeding point treatments except for point 45-W-S which showed a decline from 50 mm to 80 mm sowing depth. The reduction of root length density at higher sowing depth (80 mm) was the result of placing some of the seeds in the slots that produced with this point (45-W-S).

In 1994, point 45-W-S produced a time delay of wheat emergence at the CL94 and SL94. Similarly for point 45-W-0 at the CL94 compared to control point 45-0-0. Also this point (45-W-S) produced lower plant populations than other treatments at 50 mm sowing depths.

Leaf area and herbage dry matter did not differ between treatments at early tillering, but at the time of flowering, the point 45-W-S showed higher leaf area than other treatments at both CL94 and SL94.

The point 45-W-S had higher root length density and root dry weight density than other treatments at 300-600 mm soil depth intervals at the flowering stage on both the CL94 and SL94. This point also showed less root disease (*Rhizoctonia spp.*) than other treatments.

In 1995, the point 45-W-S and CT produced higher grain yields than other points at the SL95. Also the point 45-W-S and CT produced higher grain yields than other points at the CL95. No difference was found between treatments for 1000 seed weight at any of sites (CL95 and SL95).

CL94: The result shows that point 45-W-S had a significantly higher grain yield than points 45-0-0, 90-0-0, and CT but in CL95 there was no significant difference in grain yield between treatments.

SL94: The seeding points 45-W-S and 45-W-0 produced significantly higher grain yield. In 1995, the point 45-W-S and CT produced significantly higher grain yield than other treatments.

Significant difference between treatments was not found for the weight of 1000 seeds in 1994 and 1995 at the CL and SL sites.

Overall, point 45-W-S was superior to other points in dry years (soil moisture was higher at sowing time) in terms of uniformity of emergence, leaf area, dry matter particularly in later crop growth and grain yield. In wet years, 45-W-S was superior in terms of total emergence, plant population and grain yield.

Little difference between soil texture (SL vs CL) was present in the response of wheat to point 45-W-S.

CHAPTER 8

GENERAL DISCUSSION AND CONCLUSIONS

8.1 Discussion

The performance of four narrow points (45-0-0, 45-W-0, 45-W-S, 90-0-0) and the conventionally cultivated treatment (CT) varied widely in force requirements, seed placement, soil physical properties and wheat establishment, growth and grain yield. In this general discussion of the research results, the performance of each point is evaluated independently with respect to the control point (45-0-0).

8.1.1 Seeding points 45-0-0 and 90-0-0

Points 45-0-0 and 90-0-0 performed similarly in most respects. Both points produced higher bulk density at a soil depth of 0-50 mm due to less soil disturbance than other points. This caused the soil to have a higher penetration energy (> 210 mJ/m^2) over the 0-150 mm depth intervals compared to other points 45-W-0, 45-W-S and CT treatments (>175, 108, 164 mJ/m^2 respectively).

Under controlled conditions in soil bins, these points gave better total and faster rate of emergence of wheat than other points (45-W-0 and 45-W-S). This was probably because both points tended to have a shallower sowing depth and less soil cover on the seed.

In 1993, under field conditions, the performance of seeding point 90-0-0 was essentially similar to the control point. However, the largest differences between these points and other points (45-W-0, and 45-W-S) occurred for total emergence at a shallow sowing depth (25 mm). Seeding points 45-0-0 and 90-0-0 had about 40 % less total emergence than other treatments. This was mostly because mice seemed able to detect the wheat seeds more readily when sown with seeding point 45-0-0 or 90-0-0. The displaced soil was thrown sideways by these points, which prevented the groove being filled, leaving some seeds exposed to emergence failure or damage by mice and birds.

The total emergence of wheat sown with these points was higher at 50 mm but lower at 80 mm sowing depth compared to other treatments. In terms of plant population, fewer plants emerged than for point 45-W-S. In 1994 these points performed better than other seeding points in terms of total emergence and plant population. When soil moisture was high at sowing time points 45-0-0 and 90-0-0 allowed more seedling emergence than others. In the case of seed placement, these narrow seeding points (45-0-0 and 90-0-0) resulted in lower lateral and vertical seed spread and also gave less soil cover than the other points. The lower vertical seed spread might be an advantage compared to the greater variability of seed placement of points 45-W-0 and 45-W-S.

Seeding points 45-0-0 and 90-0-0 did not create particularly favourable soil structure because bulk density and penetration energy were higher and mean pore size was lower than other points (45-W-0, 45-W-S and CT treatment). Soil water content was higher in the surface layers (0-150 mm) but lower in deeper layers (150-300 mm) with these points compared to 45-W-S.

Soil physical quality resulting from sowing with the various seeding points was evaluated in terms on non-limiting available water content and air filled porosity at field capacity or the highest water content at which air filled porosity was equal to 10% of the total porosity. This concept thus takes account of both aeration and soil strength limitation and soil strength limitations to water availability to plants.

Both points 45-0-0 and 90-0-0 showed that either soil strength or/and aeration had a considerable negative effect on plant available water. The effect of strength was most pronounced at the Sandy loam site where apparent soil physical quality for 45-0-0 and 90-0-0 was poor and very poor. The lack of aeration as a factor limiting water uptake was more obvious than development of strength at the Clay loam site. However, both seeding point 45-0-0 and 90-0-0 produced very poor soil quality at the Clay loam site which deteriorated when aeration limitations were considered

The striking differences between points 90-0-0 and 45-0-0 and the others was in draft force requirements. The 90° rake angle of the 90-0-0 seeding point resulted in higher draft force and vertical up force but lower wear rate than point 45-0-0 (45° rake angle). The critical depth was closer to the surface for seeding point 90-0-0 with a 90° rake angle compared to points with a 45° rake angle (45-0-0, 45-W-0 and 45-W-S).

Generally these seeding points (45-0-0 and 90-0-0) responded well under controlled situation (soil bins) in case of seedling emergence and vertical seed distribution but did not show any notable advantages in plant growth, grain yield and soil structural quality in the field when compared to other seeding points.

8.1.2 Seeding point 45-W-0

The point 45-W-0 showed a slight increase in draft force compared to 45-0-0 and vertical up force as expected due to its wing but a decrease in wear rate. The addition of wings (45-W-0) to the narrow point gave an increase in the effective width of the point hence increasing its critical depth and the volume of soil loosened. The presence of wings resulted a higher lateral spread of seed.

This point produced higher grain yields (3.25 t/ha) in 1993 (50 sowing depth) compared to other seeding point treatments 45-0-0, 90-0-0 and CT (2.93, 3.01, 2.55 t/ha respectively). Generally this point resulted in the best seedbed physical quality after point 45-W-S, particularly at a soil depth of 50-100 mm. Also this point gave better early plant growth and grain yield than other points except for point 45-W-S.

Soil physical quality of seeding point 45-W-0, in terms of non-limiting available water at the Sandy loam site deteriorated markedly because of development of high soil strength as the soil dried, going from moderate to poor to very poor. On the Clay loam site, similar soil quality responses for non-limiting available water were obtained for seeding point 45-W-0 as for 45-0-0, ie. aeration, not strength determined the possible limitation water.

8.1.3 Seeding point 45-W-S

The results showed that among the narrow seeding points, the point 45-W-S had a higher draft force and wear rate than 45-0-0, because it penetrated deeper than other points and disturbed more soil with the extended blade. The addition of wings and a blade (45-W-S) to the narrow point produced an increase in the effective width of the point hence increasing its critical depth and the volume of the loosened soil. This point caused greater seed spread in both the lateral and vertical positions and covered the seed with a deeper layer of soil than other points.

Point 45-W-S, was the only seeding point that penetrated deeper than 50 mm and it produced considerable weakening of soil as deep as 150 mm. Point 45-W-S created lower bulk density by disturbing the soil under the seedbed and higher field capacity water content at all soil depths to 150 mm compared to other treatments. This seeding point produced good soil structural quality at all soil depths to 150 mm at both the Clay loam and the Sandy loam sites.

Soil cultivated with point 45-W-S was generally more porous over the 0-150 mm depth interval and contained more water over the 150-300 mm, because of better moisture transmission, compared to other treatments during this growing season at both the Clay loam and Sandy loam sites. It had lower soil bulk density values than other treatments at 0-50 and 50-100 mm soil depth in both the Clay loam and the Sandy loam sites. This point 45-W-S operated deeply and was able to loosen soil up to 120 mm and ameliorate tillage pans or hard layers to this depth. This is an important advantage for Australian conditions where a compacted layer is very often present at 50 to 100 mm depth. Use of 45-W-S caused soil strength to decrease to less than 1 MPa at water contents below field capacity and even close to wilting point in the case of the Clay loam soil. Using this seeding point resulted in more soil disturbance than other treatments which gave lower penetration energy at 0-150 mm depth intervals for both the clay loam and the sandy loam soils (< 108 and 148 mJ/m^2 respectively).

This point 45-W-S produced a more favourable seedbed (greater porosity and pore surface area) than other treatments except point 45-W-0 whilst point 45-W-S improved pore attributes to a greater depth than 45-W-0 at the Sandy loam site.

When the non limiting available water soil quality was considered, very little change was detected at the Sandy loam site at depths greater than 100 mm. Below 100 mm, because the point produced minimal disturbance, the possible reduction of water availability because of high strength was large, soil physical quality deteriorating from good and moderate to very poor.

The 45-W-S seeding point caused a higher emergence delay at 25 mm sowing depth in 1993. Also this seeding point resulted in greater root length than other treatment for both 25 and 50 mm sowing depths at 0-100 mm soil depth interval. The seedbed was slightly warmer in the case of seeding point 45-W-S during germination to end of emergence compared to 45-0-0, 90-0-0 and 45-W-0.

In 1994, points 45-W-S caused slower emergence at the Clay loam and the Sandy loam sites, compared to points 45-0-0 and 90-0-0. Plant populations were lower for this point than other treatments at 50 mm sowing depths at both sites. Leaf area and herbage dry matter did not differ between treatments at early tillering, but at the time of flowering, the point 45-W-S showed greater leaf area than other treatments at both the Clay loam and the Sandy loam sites. The point 45-W-S had higher root length and root dry weight than other treatments at 300-600 mm soil depth intervals at the flowering stage on both sites. This point also reduced root disease incidence (*Rhizoctonia*) compared to other treatments. The reason for this was probably that it promoted faster vertical root development, removing the main root mass from the shallow active zone of the disease (D Roget, pers comm., 1995) Grain yield was higher than other seeding points except point for 45-W-0 at both sites.

In 1995, the point 45-W-S produced higher grain yield than other points except the CT treatment at both the Clay loam and the Sandy loam sites.

8.1.4 Cultivated treatment (CT)

The CT treatment gave higher soil bulk density at a depth of 50-100 mm, possibly because of compaction of the soil by the sweep cultivator used for tilling the soil before sowing. The CT treatment had lower penetration energy than points 45-0-0 and 90-0-0 at the Sandy loam site at soil depth of 0-150 mm. This treatment (CT), created very good soil structure at a depth of 0-50 mm but soil structure quality was moderate at both 50-100 and 100-150 mm soil depths at the Sandy loam site. In the Clay loam site, this treatment created moderate soil structure quality at a soil depth of 0-50 mm but soil structure quality was very poor at both 50-100 and 100-150 mm soil depths.

When non-limiting available water was used to judge physical quality of the seedbed, then, before a depth of 100 mm, strength development was the main factor limiting available water at the Sandy loam site, aeration was liiting, but only to a small extent.

The CT treatment produced a warmer seedbed during germination to end of emergence compared to other treatments. This treatment also produced more favourable pore attributes than 45-0-0 and 90-0-0. There was higher root length with this point than the points 45-0-0, 45-W-0, and 90-0-0 at 50 mm sowing depth in 0-100 mm soil depth intervals. Generally this treatment gave good results in most of the cases at shallower depth of soil but in the deeper layers of soil the result was poor. The reason for this was probably better loosening of soil top layer (0-60 mm) but compaction of the deeper layer by the sweep points during seedbed preparation. Generally the CT treatment did not perform better than the 45-W-S seeding point. In addition, it is worth noting that the 45-W-S generally produced a better seedbed and more favourable early growth with a single pass while the CT treatment required three passes to produce equivalent or inferior conditions and responses. On the other hand, draft forces and wear rates for the CT treatment will be higher than the 45-W-S because of two passes of the sweep point for seedbed preparation and additional pass for sowing purposes.

8.2 Future research direction

This discussion has shown that the seeding point with wings and extended blade (45-W-S) was superior to the other points. However there are a number of weaknesses associated with the research on this seeding point which have been outlined in the discussion. Further research is needed in four specific areas. Firstly, in fundamental engineering modification to reduce draft force. Secondly, in decreasing the sowing depth variation. Thirdly, there is need to use this point on other crops. Finally, a grater understanding is needed of how these points react in a wider range of soil types and climatic conditions such as:

1. summer dominated rainfall areas,
2. different soil type, eg. cracking clay soils,
3. different rainfall distribution patterns, eg. rain between sowing and emergence.

8.3 Conclusions

Seeding points did have different effects on soil physical properties and crop performance depending on their shape.

The points that produced the greatest benefits to soil physical quality and crop yield were those that caused the most soil disturbance around the seed, including below seeding depth.

Features of seeding points design that produced maximum soil disturbance were low rake angle (45 °), presence of wings and particularly the extended blade.

Repeated cultivation with conventional sweep cultivators and using the seeding point without wings and extended blade could not achieve the same level of soil disturbance as a seeding point with these two features.

The seeding point with wings and extended blade resulted in a seedbed with the best physical properties (high aeration, high non limiting available water content, low penetration resistance, good penetration of water to deep layers) which provided the highest grain yields and better wheat plant growth.

Progressive removal of the extended blade and wings caused less and less soil disturbance with less favourable physical properties in the seedbed and consequently gave poorer crop responses.

A seeding point with no wings, no blade and a higher rake angle (90°) gave poorer crop responses and caused less soil disturbance and may have compacted soil below its working depth.

Maximum disturbance to soil was not necessarily beneficial in all instances:

1. the seeding point with wings and extended blade had the highest draft force although still not as high as in conventional tillage with two or three passes of the sweep points,
2. the most variable vertical variation in seed placement, causing reduced emergence compared to other points.

However, these disadvantages did not outweigh the advantages in terms of final yield of grain.

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