

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

THE EFFECTS OF DRILL COULTER DESIGNS
ON SOIL PHYSICAL PROPERTIES AND PLANT
RESPONSES IN UNTILLED SEEDBEDS.

A Thesis presented in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy at
Massey University
Palmerston North
New Zealand

by

TRAN VAN MAI

July 1978

80-01340

2

TO *my parents*
in Vietnam

TABLE OF CONTENTS

ABSTRACT

<u>CHAPTER</u>		<u>PAGE</u>
1.	GENERAL INTRODUCTION	1
2.	THE INTERACTION OF SOIL AND DRILL COULTER PASSAGE	
2.1	Introduction and review of literature	3
2.1.1	Soil water and compaction	4
2.1.2	Soil air and compaction	6
2.1.3	Soil temperature and compaction	7
2.1.4	Soil bulk density, compaction and pore system	9
2.1.5	Soil strength and compaction	10
2.1.6	Soil stress and compaction	12
2.1.7	Draft	14
2.1.8	Visual assessments of macrostructural changes in soils	16
2.1.8.1	Thin sections	16
2.1.8.2	Scanning electron microscope techniques (S.E.M.)	18
2.1.9	Functional requirements of drill coulters	18
2.2	Experimental methods	23
2.2.1	Soil bin experiments	23
2.2.1.1	Site and soil type selection	23
	1. Field capacity and soil dry bulk density	24
	2. Permanent wilting point	24
	3. Available water capacity	25
	4. Soil porosity	25
2.2.1.2	Soil bin collection procedures - post collection preparation of turf blocks	29
2.2.1.3	Experimental designs	30

2.2.2	Drilling of turf blocks	35
2.2.2.1	Pre drilling	35
2.2.2.2.	Drilling operations	35
2.2.3	Field experiments	36
2.3	Measurements	39
2.3.1	Measurement of soil compaction by soil bulk density	39
2.3.1.1	Core sampling method	39
2.3.1.2	Small core sampler	40
2.3.1.3	Procedures	40
2.3.2.	Mechanical resistance of soil	41
2.3.2.1	Description of the measuring equipment	41
2.3.2.2.	Procedures	45
2.3.3	The instantaneous zone of influence (soil pressures)	48
2.3.3.1	Description of the measuring equipment	48
2.3.3.2.	Procedures	49
2.3.4	The assessment of macrostructural changes by visual methods	53
2.3.4.1	Materials and methods	53
	a. Thin sectioning - impregnating	53
	b. Electron microscopy	57
2.3.5	Draft Measurements	59
2.3.5.1	Description of the measuring apparatus	59
2.3 5.2	Procedures	62
2.3.6	Assessment of the zone of disturbance on the soil surface	62
3.	THE RESPONSE OF PLANTS AND ROOTS TO CHANGES IN SOIL PHYSICAL CONDITIONS WITHIN A SEED BED	66
3.1	Introduction and review	66
3.1.1	The effects of soil bulk density on root growth	69
3.1.2	The effect of mechanical soil strength on root growth	71

3.1.3	The effect of interactions amongst soil moisture, soil compaction, soil strength on root growth	76
3.1.4	The effect of direct drilling on crop yields	77
3.2	Experimental methods used in root studies	78
3.2.1	Laboratory tillage bin experiments	78
3.2.2	Box experiments	81
3.2.3	Field experiments	81
3.3	Seedling emergence	81a
4.	THE INFLUENCE OF SOIL FAUNA IN DIRECT DRILLED SOIL	82
4.1	Review	82
5.	OBJECTIVES AND RESULTS OF INDIVIDUAL EXPERIMENTS	83
5.1	General objectives	83
	a. Laboratory experiments	83
	b. Field experiments	83
5.2	Experiment 1.	85
5.2.1	Objectives	85
5.2.2	Results and discussion	
	a. Bulk density (permanent deformation)	86
	Results	
	Discussion	
	b. Soil strength (permanent deformation)	88
	Results	
	Discussion	
	c. Soil pressure (instantaneous deformation)	94
	Results	
	Discussion	
	d. Draft force	101
	Results	
	Discussion	
	e. Root studies	103
	Results	
	Discussion	
5.2.3	Brief summary of Experiment 1.	107
5.3	Experiment 2.	108
5.3.1	Objectives	108
5.3.2	Results and discussion	108
5.3.4	Macrostructural changes of soil under compression	117
5.3.4.1	Results and discussions	117

a.	Thin sectioning	117
b.	Electron microscopic technique	123
5.3.5	Root responses	130
	Results	
	Discussion	
5.4	Experiment 3.	135
5.4.1	Objectives	135
5.4.2	Results and discussions	136
a.	Bulk density and soil strength	136
	Results	
	Discussion	
b.	Soil surface disturbance	139
	Results	
	Discussion	
c.	Root responses	143
	Results	
	Discussion	
5.4.3	Brief summary	152
5.5	Experiment 4.	154
5.5.1	Objectives	154
	Results	
	Discussion	
5.5.2	Brief summary	162
5.6	Experiment 5. (field experiment)	163
5.6.1	Objectives	163
	Results	
	Discussion	
5.7	Experiment 6. (field experiment)	169
5.7.1	Objectives	169

5.7.1 (continued)	
Results	
Discussion	
a. Root and herbage dry weights	184
b. Seedling emergence	184
c. Earthworms	185
d. Yields	186
6. SUMMARY AND DISCUSSION	187
A. Equipment and measuring technique	187
B. Soil physical changes and plant and root response	192
a. Permanent deformation data	192
Bulk density	
Soil strength	
b. Coulter operational forces	195
c. Instantaneous dissipation of soil stress	197
d. Interactions	200
e. The effects of coulter shapes on root growth	200
7. CONCLUSIONS	206
8. REFERENCES	209

ACKNOWLEDGEMENTS

APPENDICES

LIST OF FIGURES

		PAGE
1.	Soil moisture content and suction curve of Tokomaru silt loam	28
1a.	The positioning of treatment bins on the testing rig	30e
1b.	The experiment layout	30f
1c.	The randomised block design	30g
2.	Turf block extraction procedure - Part 1.	31
3.	Turf block extraction procedure - Part 2.	32
4.	Turf block extraction procedure - Part 3.	33
5.	The experimental design of 12 bins	34
6.	The chisel coulter assembly	38
7.	The triple disc coulter assembly	38
8.	The multipoint penetrometer	44
9.	The measuring positions of the penetrometer	45
10.	The multipoint penetrometer at work	46
11.	Typical soil strength curves obtained with the multipoint penetrometer apparatus	47
12.	Holding magnets with adjustable clamp	50
13.	The soil pressure sensing tube assembly	50
14.	The positioning of the pressure tube in the turf block	52
15a, b & c.	Equipment used in thin sectioning	54
16.	The side view of draft measuring apparatus	61
17.	Rear view of moving gantry and tool testing apparatus	61
18.	Penetration of coulter assemblies by dead weights	64
19.	The instrumentation for monitoring the zone of influences around coulters	65
20.	The interrelationships of soil physical parameters and root growth under compaction	68
21.	Extraction of samples for root studies with perplex pin boards	79
22.	Soil resistance at eight side of the triple disc and	91

	disc coulter grooves	
23.	Variation of soil resistance at either side of the triple disc and chisel coulters	92
24.	Sidewall pressure detected at 30mm away from the groove	97
25.	Pressures detected at 50mm away from the base of the groove	98
26.	The effects of direct drilling coulter designs on lupin and dry weight (Expt 1.)	104
27.	The effects of direct drilling coulter designs on lupin root length (Expt 1.)	105
28.	The effects of direct drilling coulter designs on wheat root dry weight (Expt 1.)	106
29.	Soil resistance at either side of the triple disc and chisel coulters	112
30.	Variation of soil resistance at either side of the triple disc and chisel coulter	113
31.	Thin section sampling sites	118
32.	Sections of soil in their original condition	118
33.	Soil sections taken at 10mm from the soil/triple disc coulter interface	119
34.	Soil sections taken at 10mm from the soil/chisel coulter interface	119
35.	Soil sections taken at 20mm from the soil/triple disc coulter interface	120
36.	Soil sections taken at 20mm from the soil/chisel coulter interface	120
37.	Soil sections taken at 30mm from the soil/triple disc coulter interface	121
38.	Soil sections taken at 30mm from the soil/chisel coulter interface	121
39.	Subsampling positions for electron microscopic studies	125
40.	Micrograph (x170) of soil in "undisturbed" condition	125

41.	Micrograph of soil/triple disc coulter interface	126
42.	Micrograph of soil/chisel coulter interface	126
43.	Micrograph taken at 10-20mm away from the soil/ triple disc coulter interface	127
44.	Micrograph taken at 10-20mm away from the soil/ chisel coulter interface	127
45.	Micrograph taken at 20-30mm away from the soil/ triple disc coulter interface	128
46.	Micrograph taken at 20-30mm away from the soil/ chisel coulter interface	128
47.	Micrograph taken at the base of the triple disc coulter	129
48.	Micrograph taken at the base of the chisel coulter created groove	129
49.	The effects of direct drilling coulter designs on lupin root dry weight (Expt 2.)	132
50.	The effects of direct drilling coulter designs on lupin root length (Expt 2.)	133
51.	The effects of direct drilling coulter designs on wheat root dry weight	134
52.	The effects of direct drilling coulter designs on soil surface disturbance	140
53.	The triple disc coulter has a greated longitudinal soil/coulter contact	142
54.	The chisel coulter shatters soil abruptly on both sides of the coulter	142
55.	Distorted root growth of a lupin seedling in the triple disc groove	148
56.	A lupin root which has been deflected at the base of a triple disc groove	149
57.	Lupin root cross-section grown in uncompacted soil	150

58.	Cortex portion of lupin root cross-section flattened because of hard soil	151
59.	Poor seedling establishment in the triple disc coultter treatment	153
60.	Better seedling establishment in the chisel coultter treatment	153
61.	The characteristic shaped groove of the triple disc coultter	156
62.	The characteristic subsurface shattering of the chisel coultter	156
63.	Close-up seedling emergence with the smeared V-shaped groove	159
64.	Effects of smearing on seedling performance from various shapes of grooves	159
65.	The interrelationship between soil moisture content, soil bulk density and counter type in direct drilled silt loam	201

LIST OF TABLES

		PAGE
1.	The mechanical properties of soil	26
2.	Values of probe pressure at which root elongation ceased	75
3.	The sequence of root related measurements	80
4.	The effects of drill coulter designs on soil bulk density at groove base	86
5.	The effects of coulter designs on soil strength around the groove	88
6.	The effects of coulter designs on soil strength on either side of the groove	90
7.	The effects of coulter designs in maximum soil pressure at the base of the drilled groove	94
8.	The effects of coulter designs on maximum soil pressure at the sidewall of the drilled groove	95
9.	Draft forces required by two drill coulter designs in a silt loam at 23% w/w moisture content	101
10.	The effects of drill coulter designs on soil density around the groove (Expt 2.)	109
11.	The effects of drill coulter designs on soil strength	110
12.	The effects of drill coulter designs on soil strength on either side of the groove	111
13.	The effects of drill coulter designs on maximum soil pressure at the base of the drilled groove (Expt 2.)	114
14.	The effects of drill coulter designs on maximum soil pressure at the sidewalls of the groove	114
15.	The effects of drill coulter designs on draft force	116

16.	The effects on soil compaction of multiple runs with vibration rollers	135
17.	The effects of drill coulter designs on bulk density	137
18.	The effects of drill coulter designs on soil strength	138
19.	The effects of drill coulter designs on root properties of lupin seedlings sown in wet and dry soil	146
20.	The effects of drill coulter designs on wheat seedlings at day 4 in wet soil	147
21.	The effects of direct drilling groove formation techniques on seedling emergence	160
22.	The effects of shape, smear, compaction and cover of direct drilled grooves on wheat and lupin plants	161
23.	The effects of soil and drill coulter designs on lupin and wheat root dry weights in field conditions	167
24.	The interaction of soil and coulter on lupin and wheat root dry weight in field conditions	168
25.	The effects of drill coulter designs and soil on root and shoot growth of wheat and lupin crops at 3 weeks (main treatment effects)	171
26.	The interaction of direct drilling coulter designs and soil compaction on root and shoot growth of wheat and lupin crop at 3 weeks (interactions)	172
27.	The effects of drill coulter designs and compaction on root and shoot growth of wheat and lupin crops at 5 weeks (main treatment effects)	173
28.	The effects of direct drilling coulter designs and soil compaction on root and shoot growth of wheat and lupin crops at 5 weeks (interactions)	174
29.	The effects of drill coulter designs and soil compaction on	

	root and shoot growth of wheat and lupin crops at 7 weeks (main treatment effects)	175
30.	The effects of drill coulter designs and soil compaction on root and shoot growth of wheat and lupin crops at 7 weeks (interactions)	176
31.	The effects of drill coulter designs and soil compaction on seedling emergence of wheat and lupin (main treatment effects)	177
32.	The effects of drill coulter designs and soil compaction of wheat and lupin (interactions)	178
33.	The effects of drilling coulter designs and soil compaction on Earthworm population (main treatment effects)	179
34.	The effects of drill coulter designs and soil compaction on Earthworm population (interaction effects)	180
35.	The effects of drill coulter designs and soil compaction on Wheat yield	181
36.	The effects of drill coulter designs and soil compaction on lupin yield (main treatment effects)	182
37.	The effects of drill coulter designs and soil compaction on lupin yield (interactions)	183
38.	Summary of the effects of drill coulter designs on bulk density, porosity and soil strength	19
39.	Summary of forces required for coulter penetration of two direct drilling coulters	19
40.	Summarized effects of direct drilling coulter designs on soil pressure	19

LIST OF APPENDICES

1. a. Results of soil bulk density measurement Expt.1.
- b. Results of soil bulk density measurement Expt.2.
- c. Results of soil bulk density measurement Expt.3.
2. Soil strength data.
3. Draft force data.
4. Root dry weight per plant basis.
5. Estimation of evaporation from turf blocks under rain canopies.
6. Calibrations.
7. Determination of root percentage in soil cores.
8. Meteorological data.
9. Brief descriptions of soil bins, testing apparatus and coulter
 designs.
10. Equipment.
11. Computer listings.

ABSTRACT

During the process of direct drilling different shaped drill coulters have been observed to create different micro-environments at the seed zone. This study has been to examine possible changes in soil structure and the state of soil compaction around the groove, which in turn might affect root penetration.

Several methods and pieces of equipment were developed to investigate the influence on the soil of two contrasting coulters shapes. These were the commercially-available triple disc coulters and an experimental chisel coulters. To measure soil bulk density in the drilled groove zone, a small core sampler was designed and tested. Soil strength was assessed using a modified multi-point penetrometer which could be inserted vertically into the soil or normal to the groove walls.

The instantaneous and permanent soil pressure zone of influence around the groove, which was created by the passing of the coulters, was monitored using a liquid-filled tube with a terminal diaphragm and a minipressure transducer.

Macroscopic visual assessment of the compaction of soil at the seed level was undertaken using a freezing sampling technique which facilitated thin section subsamples to be studied by photographic techniques. In addition, 3 mm^3 subsamples were taken directly from the grooves for electron microscopy study.

Supplementary measurements included draft force and the coulters-passage-disturbance-zone at the soil surface using a load cell and a displacement transducer respectively.

Wheat and lupin seeds were sown to study the effects of soil changes on root growth of a fibrous and tap root system.

The data suggested that the triple disc coulter tended to compact well-defined zones around the groove while the chisel coulter produced no apparent compaction.

Such soil compaction in a moist silt loam of initial bulk density less than 1.1g/cc did not result in any apparent differences in plant root responses between the two coulter types. In a drier, harder soil however (greater than 1.32g/cc) there appeared to be a clear disadvantage from use of the triple disc coulter in this respect. With lupin, root growth was restricted and deformed from use of the latter coulter, while in the case of wheat, seedling emergence was restricted in comparison with the chisel coulter.

Smearing was found on the groove wall in moist soil with the triple disc coulter but the experiments were not able to show any mechanical restriction to root and plant development arising from the smear.

In the field conditions, in contrast to the laboratory conditions (where seedling performance and root growth were better with the chisel coulter in almost all of the tested conditions except with moist and loose soil where it was equivalent to the triple disc) any localised compaction of soil by the triple disc coulter (particularly at and near the base of the groove) appeared to be compensated by other factors (weather, earthworms etc.) during the plant's full growth cycle.

Compaction and mechanical impedance in isolation did not appear to be solely responsible for the root and plant growth responses.

A physiological study of soil moisture transport process and soil water vapour availability in the seed zone should therefore be the subject of further studies.

1.

GENERAL INTRODUCTION

Direct drilling or no-tillage is generally defined as a practice where seeds are introduced by mechanical devices into untilled soil with or without chemical treatment of the vegetation.

There has been a considerable amount of work involving comparative studies of crop yields resulting from direct drilled and conventionally tilled seedbeds. (55,57,78,127,154) However little knowledge has apparently been gained of the physical micro-environment in untilled seedbeds which is created by the passage of drill coulters. This micro-environment in turn can be expected to affect root growth and other essential plant functions. Better information is therefore necessary to provide realistic specifications for designing drill coulters or furrow openers to fulfil the requirements of plants.

The dynamic action of the passage of drill coulters, affects the state of compactness and strength of the soil environment, thus altering its void ratio and shifting the balance of liquids and solids in the matrix. If the porosity of a given soil is adequate, then roots will grow through the interstices between particles. Otherwise the roots will be required to either displace the soil grains or deform the rooting medium, if their growth is not impeded. (20,45,165)

It has been reported that shallow or branched rooting was obtained in direct drilled treatments, and that this pattern of root development reflected the increased mechanical impedance of the soil to root penetration. (10,134) Dixon (68) and Baker (103) suggested that localised compaction in the seed grooves may have been undesirable. They further reported that one of their tested coulters assemblies

(the triple disc coulter) appeared to have compacted the soil at the base of the grooves.

The study reported herein has been an attempt to investigate by what means and to what extent different designs of drill coulters affect the physical state of compaction of a given soil as a result of their passage through that soil. Further to this, the study also sought to measure plant root responses to variations of in-groove compaction.

In order to achieve these objectives the study was required to fulfil the following specific aims.

(a) To develop techniques and instruments which would permit study of the effects of various coulter designs on changes in soil physical conditions within and adjacent to direct drilled grooves.

(b) To make quantitative and qualitative comparisons of selected coulter designs in terms of their abilities to create changes in selected soil properties such as bulk density, penetrometer resistance, soil stress, and pore space distribution.

(c) To study the effects on root growth of these soil changes when sowing a tap rooted and a fibrous rooted species.

2. THE INTERACTION OF SOIL AND DRILL COULTER PASSAGE

2.1 INTRODUCTION AND REVIEW OF LITERATURE

Over the last two decades, the environmental requirements for cultivated seedbeds and rootbeds have been the subject of much study. Reports in the literature have dealt in whole or in part with the physical factors affecting germination of seed and development of root growth. (3-8) Work has also been undertaken in order to understand specifically how mechanical impedance of soil, whether cultivated or not, affected the exploration of roots. (19-24)

Little work, however appeared to be related to the direct drilling situation where the micro seedbed in the drilled groove is affected by coulter shape. (19,103) Reports indicated that the most critical period in a direct drilled crop was during germination and establishment which could be influenced by physical conditions of the micro-environment in which the seeds were drilled. (25,26) Other reports further suggested that direct drilled seeds required either some firming of loose disturbed soil around the seed to establish moisture contact with soil (4,9,11,12,27) or some pressure exerted on the soil at seed level and then some loose soil left above the seed. (10)

Wilkinson (27) felt that in a direct drilling situation, where seeds were sown into undisturbed soil, the soil at seed level should provide (a) an adequate depth of friable and well developed aggregates; (b) a surface soil which was sufficiently mechanically weak to allow the drill to work satisfactorily, and for the free flow of gases and water; and (c) a soil surface on which crop residues were kept in such a way as not to complicate drilling or to harbour pests.

2.1.1 Soil Water and Compaction

Water movement in the soil is generally acknowledged as being governed by the distribution of air filled pore space where pore diameter is more than 30μ . In clay soils, small voids and/or small grains of clay allow packing to smaller voids before intergranular stress resists further decrease in void size. Therefore clay is more susceptible to compaction in moist conditions. The total soil water and soil grain surface contact is greater, which in turn, increases the capillary water force. Under compaction, it is generally recognised that the pore system tends towards a smaller proportion of larger pores.

Direct drilling or no tillage soil was found to have a smaller number of larger pores compared to those of tilled soil. (28,29) It is therefore reasonable to conclude that soil under direct drilling or no tillage conditions is subject to more natural compaction than that under tillage conditions. The soil moisture content had also been found higher in the absence of cultivation, particularly near the surface (30,31), and further work in the United States attributed this to the mulching action of crop residues and the generally higher levels of organic matter in the surface soil. (32)

Baeumer and Bakermans (33) reported that Ehlers had suggested that the difference in soil water content between tilled and untilled soil was relatively small and inconsistent compared to the difference in the soil water tension and hydraulic potential. Direct drilled soil, with a similar water content had a lower soil water tension which indicated a smaller resistance to water uptake by plant roots and higher conductivity of soil water. It was reportedly unlikely however, that soil water per se was a limiting factor to root growth, but root growth

was reduced as soil water potential was decreased. (34) Taylor and Ratcliff (35) went further in their experiments to show that soil strength was also affected by soil moisture. They grew cotton in root observation boxes filled with a sandy loam soil at several water contents and several soil strengths, which were estimated by penetrometer resistances. They reported that root length of cotton grown at 32°C and 0.05 bars penetrometer resistance was not affected by water potential between -0.17 and -7 bars.

Attempts were also made to take moisture tension measurements independent of other soil variables by growing pea seedlings without soil and allowing their roots to grow against the surfaces of a vertical porous ceramic plate which remained saturated as the moisture tension was adjusted with a manometer. Root length was reported slightly affected at the 10 to 300 mm tension level but there were no differences at higher tension levels. (23)

The compaction process can be interpreted as a change in volume for a given mass of soil, and one of its most widely used measures is bulk density. Bulk density is found by weight of dry soil that occupies a known volume. It provides a measure of how close the soil particles are packed but does not yield any information about their geometric arrangements. Compaction of a soil therefore reduces the total pore spaces and consequently reduces the conductivity of the soil when saturated with water. The readiness of a soil to transmit water under saturated and unsaturated conditions is referred to as hydraulic conductivity. Increases of dry bulk density have resulted in a marked reduction in hydraulic conductivity. For example, in one experiment, an increase of

bulk density from 1.2g/cm^3 to 1.4g/cm^3 caused a ten-fold decrease in hydraulic conductivity. (36)

Other researchers using a modified Proctor compaction test, have reported that after the point of maximum compaction was reached, the reduced compactability of soil reflected the effect of saturation. In other words, as all voids in the soil were filled with water at saturation to achieve more soil compaction, water had to be squeezed out of soil. As moisture content increased, compaction increased to an optimum point. Above the optimum moisture content compaction decreased as pores were partly filled and therefore less able to reduce in volume. (37,38)

2.1.2 Soil air and Compaction

Soil compaction results in the collapse of large pores which are responsible for effective drainage and aeration. Gases flow through air filled pores and the quantity of flow is directly proportional to the air porosity of a given soil. (16) However, diffusion rather than mass flow was also believed to be the major process for aerating soils. (39,40,41) Work has also indicated that wind turbulence caused greater mass flux in shallow layers than at greater depths. (42,43)

The calculations of Wooley (44), based on a diffusion theory, indicated that 4% by volume of interconnected gas filled pores would supply adequate oxygen for respiration of roots at a soil depth up to 1 meter or more. He felt that transfer of gases through water films surrounding root and micro organism was a critical part of soil aeration. Mass flow of gases through waterfilm was unlikely. Rather, he felt that by consuming O_2 and producing CO_2 wherever soils were warm

enough to need ventilation, roots and soil micro organism continuously created concentration gradients for diffusion.

A number of studies of pore space distribution have been related to the direct drilling situation. It was generally found that any decrease of large and mostly air filled pores reduced aeration. Air capacity of pF_2 was found to be below 10% (V/V_v) on medium to heavy textured undisturbed soil. (28)

Anaerobic soil conditions were expected when soil was compacted in direct drilling because of the restricted entry of oxygen especially in wet soil. However no large decreases in concentration of oxygen in soil had appeared to have been caused by direct drilling. (46,47)

It is evident therefore from the literature that while some measurements have been made of these factors in the general soil matrix, little or no attempts have been recorded which sought to highlight the result of the passage of specified coulter designs through untilled soil. Much less has been the apparent interest in separating the physical soil properties in the groove from these of the undisturbed matrix between the grooves, nor of the interface between the two.

2.1.3 Soil temperature and Compaction

Soil heat flow appears to be influenced by bulk density, porosity, moisture content and surface mulch cover. Willies and Raney (48) reported fully on the effects of compaction on the content and transmission of heat in soil and concluded that compaction caused increases in density with a resultant increase in thermal conductivity and a probable increase in thermal diffusivity. Kohnke and Barber (49), experimenting on

a dry and unmulched soil, found that untilled soil showed wider temperature fluctuations at 10cm depth than cultivated soil, even though the latter in their experiments had a lower bulk density.

Temperature was also reported to have varied more than 25°C throughout the year in the surface few centimeters of soil. (50) Steep temperature and moisture depth gradients might be also expected at the undisturbed soil surface and this was believed to be due to the dynamic nature of the soil water flux in the surface zone of a field soil subjected to diurnally varying environmental conditions. (51)

These generalised conditions were found to be also consistent with the situation under direct drilling. Soil under direct drilling appeared to be denser (higher bulk density), and usually had been at a higher moisture content, thus increasing the thermal capacity of the soil. (33) A marginally narrower range of temperature fluctuation at 10cm depth in uncultivated denser soil (which was often of higher moisture content) than comparable cultivated soil was also found. (52)

Heat transfer in soil was also influenced by such things as season of the year, soil colour, soil cover, surface roughness, thermal conductivity and air movement. Temperature has been reported to vary with soil profiles. Richard et al.(53) quoted Hagan as reporting diurnal variations which amounted to about 10°C in the surface centimeter of soil and less than 1°C at about 500cm. Experiments in Virginia and Kentucky separately indicated that trash cover on uncultivated soil acted as an insulating layer which reduced the temperature fluctuation near the surface. (54,55)

While not denying the above findings, Blevens and Cook (55) reported that the effects of temperature fluctuations were probably not important although they did not elaborate on why they formed this conclusion. Baker (56) claimed that Larsen had found that crop residues of 6,270Kg/ha left on the surface were capable of reducing temperature by 1° - 2° C in the top 10cm of soil, a conclusion which was confirmed by Lal (52).

2.1.4 Soil Compaction, soil bulk density and pore system

Bulk density is a measure of soil compaction. An increase in bulk density reduced macroporosity, resulting in decreased water intake and restricted gas movement (58). The resulting compaction from a given pressure (from biophysiological or mechanical sources) depended also on the mineral and mechanical compaction and internal consolidation of the soil. The void ratio was used to illustrate how the packing relationship of soil grains related to soil bulk density. (59) For a given type of soil and amount of compactive effort, the compaction achieved was strongly dependent on the moisture content. These findings were confirmed by Lambe (38) who further stated that dry bulk density obtained at a given optimum moisture content was related to the size distribution and the shape of soil particles.

The consequences of compaction are of more concern than compaction per se. Considerable work has been undertaken in studying the relationship between soil compaction and machine operations. (2,39) However, similar work relating to direct drilled soil has been undertaken only recently. Cannell and Finney (62) found that soil after direct drilling was usually more compacted than after ploughing and conventional cultivation. Although this had also been observed in the upper zones of

the profile in soil varying from loamy sand to silty clay loam.

(31,45,63,64,66) Hughes (67) and Baker (68) claimed that a "Tokomaru" silt loam, which had been sprayed with herbicides and direct drilled was significantly more resistant to soil structural damage than the same soil ploughed and conventionally cultivated which itself was better than rotary cultivation. These differences apparently increased with time out of pasture and involved both dry and wet sieving assessments.

Other reports had related compaction to pore spaces. Beaumer et al. (69) found that the pore system in a direct drilled soil was more continuous and finer than that of a cultivated soil. Although others found a greater continuity of pores after direct drilling (31) the increase was not very much. (70) Another aspect of the soil/drill interaction appeared to be the tendency of some coulters to smear the sides of the groove in damp conditions. Although Soane et al. (66) had observed some problems associated with smearing, incomplete slit closure, and seed/soil contact with specific drill coulters, most studies of soil parameters have been restricted to the general soil matrix.

2.1.5 Soil Strength and Compaction

The mechanical strength of soil is the ability or capacity of a particular soil in a certain condition to resist or endure an applied force. It is therefore a force itself, a physical quantity. However, it is difficult to measure and describe. A wide range of soil strengths can be observed for different soils and the strength changes when force is applied and movement occurs. Therefore, test results may only be quantitatively compared with those undertaken under the same testing conditions.

One of the most widely accepted measures of evaluating soil strength is the penetration test. Depending on the shape and type of penetrometers used, cutting, separation, shear failure, compression, tension, friction, plastic failure or any combination of these may occur as the penetrometer is forced into the soil. (71) The resistance to penetration of the soil was considered to be some combination of these possible failures and was therefore a composite property.

The concept of penetration involves a measure of resistance as it changes with depth. Consequently, a penetrometer attempts to measure resistance near its tip. There are other methods of evaluating soil strength such as the measurement of bearing strength (72) and crushing strength. (73,74)

Chancellor (75), in studying the effects of compaction on soil strength, suggested that soil strength was closely associated with stress density factors. Various strength parameters such as tensile strength modulus of rupture, compressive strength, modulus of compression, shear strength and pulverisation energy were discussed. Velocity of stress wave propagation as it is related to soil strength was also studied. (76,77) The findings indicated little or no increases of the velocity of stress wave propagation with an increase in bulk density when soil was moist and penetrometer resistance was also increased with propagation velocity.

Compared to tilled soil, untilled soil was smoother, even, firmer, denser (33) and structurally more stable. (67) Therefore more energy would be needed to mechanically manipulate the soil. Thus untilled soil could be expected to have a higher soil strength than tilled soils. Higher impedance was found in the top 0-5cm layer of soil which had been

subjected to direct drilling. (52) Soane et al. (66) found an approximately five fold increase in mechanical resistance to a cone penetrometer. Soil shear strength of generally about double the values for "normally" ploughed treatments were obtained from the 0-5cm horizon of soil subjected to direct drilling.

2.1.6 Soil stress and Compaction

Soils comprise discrete solid particles and spaces between them. These spaces or voids may be filled with gas and/or liquid. Therefore, soils are multiphase in nature consisting of a mineral phase and a pore phase. These phases interact chemically in a manner described by Young and Warkentin. (119)

Firstly, liquid and air or both, could flow through the soil and alter the forces at the points of contact between the individual particles. These forces were those of repulsion and attractive forces. Repulsion forces resulted from the interaction between overlapping diffusion layers of adjacent particles and from absorption of water on the surfaces of adjacent particles. Attractive forces were of two kinds: London-van der Waals and Coulombic. The Van der-Waals' forces occurred between unchanged molecules and coulombic forces were electrical forces between particles.

Secondly, when a load was applied to a soil mass a part of it was transmitted through soil at the points of contact between adjacent particles, and was carried by the pore fluid.

Because liquid could be considered almost incompressible, all the applied force was resisted by an increase in the pore fluid ^{pressure} for a fully saturated soil. However, water could slowly flow through the

pores in the soil mass and with time the applied load was slowly transferred to soil grains, the rate depending on the pore size. This process has become known as consolidation. As water escapes from soil pores, the soil compresses, the amount of compression depending upon the difference between applied stress and the stress in the water in the pores.

The concept of force per unit area (i.e. surface pressure) appears to be of restricted value in a three dimensional semi-infinite medium such as soil where neither the direction of the applied force nor a finite area is fixed. The concept of stress at a point can be visualised as force per unit area acting across an infinitesimal area. Vandenberg (79) was the first to apply continuum mechanics to the study of soil compaction. According to Soëhn (80) Boussinesq was the first to obtain a solution of stress distribution in a semi finite medium. His work was apparently modified by Froëlich with the introduction of a concentration factor.

The ultimate interest in the force distribution is the resulting soil compaction; lower forces result in lower compaction. Consequently if forces can be lowered by some design changes, less compaction should result.

The basic concept of stress measurements was to place in the soil a device that would experience the same pressure as an equivalent volume of soil and would signal the magnitude of those pressures (81,82). Such devices had one or more pressure sensitive faces that could be oriented to obtain measurements in the direction of interest.

Using electrical resistance gauges, several efforts have been made to measure the distribution of force under vehicular loads. (84,85) One of the effects of pressure has been to cause a reduction of size and number of larger pores, thus slowing water movement. (85) A brief summary on the subject of stress induced by compaction was given by Cohron in 1971 (86), but few of his conclusions were considered relevant to the specific work reported herein.

2.3.7 Draft

Draft force was affected by three categories of variables according to Telischi et al. (13). These variables were listed as follows:

Soil variables

- Particle size distribution, including the type of colloidal material
- Chemical composition, including the effect of organic matter
- Moisture percentage
- State of compaction or bulk density
- Soil structure, including soil cementation effects
- Effect of vegetation and crop residues
- Effect of slope of soil

Implement variables

- Kind of implement
- Kind of metal
- Surface condition and sharpness of the implement
- Bearing area against the soil
- Curvature and the shape of surface applying force

Other variables

- Speed
- Width and depth of the furrow

Draft is therefore clearly governed by a combination of interactive variables. According to recent attempts at formulating analytical methods to predict draft had not been proved successful. Prior to that a small number of authors had successfully developed partial mechanics to predict draft force. (120,105) Zelenin (loc.cit) suggested that draft and working depth were parabolically related to the relation $p = kh^n$ (where p was the draft of a horizontal blade, k the coefficient of soil resistance, h the depth of operation and n a coefficient = 1.35).

Payne (120) noted that draft increased with working depth and the angle of approach, he also indicated that soil cohesion which was influenced by soil moisture, soil texture, soil organic matter, was linearly proportional to the draft of a cultivation force.

Payne and Tanner (121) also studied the soil reaction as it was governed by the direction of the applied force. A tool operating with an angle approach of less than 48° usually resulted in an upheaval of soil. If the angle of approach was increased above 130° , the main reaction of the soil was directed downwards, so that an undisturbed appearance resulted. Data obtained from their experiments indicated a linearly proportional relationship between rake or lift angle and draft force.

Bowditch (122) found that the energy required by tillage operations increased rapidly as the size of the clods produced was decreased and as prior compaction of the soil was increased.

Tillage requires a large total energy input compared to direct drilling which also incurred less in investment and operating costs. Little work has been reported, however, which compares draft measurements of different direct drilling machines. Koronka (100) experimented with a specific direct drilling coulter (triple disc) and found that it required less draft force than disc and knife coulter.

2.1.8 Visual assessments of macrostructural changes

2.1.8.1 Thin Sections.

Thin sectioning techniques have been widely used in petrographical studies and in studies of the geometrical arrangement of soil particles in a friable organic soil. This technique was also found useful in the study of particle orientation. (87) Lund (88) used thin sections to study particle orientation at the root/soil surface. He found that a limited number of sections failed to show how much orientation had taken place but did show a packing effect. The choice of a suitable filler material with desirable physical and chemical properties (e.g. viscosity, refraction and hardness) and techniques of impregnating moist soil samples have been the dominant problems.

"Kollolith" was used but it was found that this resin would not penetrate readily into compacted soil (89). "Bakelite" was also tried but its refractive index was reportedly too high.

Buol and Fadness (90) claimed that epoxy "Castolite" was satisfactory and suggested that soil samples to be impregnated should be predried at 105° - 110° C for twenty four hours and evacuated prior to flooding with the epoxy resin. This was to minimise the effect of surface tension which was encountered when evacuation followed flooding

of the soil samples with epoxy resin. Innes and Pluth (91) claimed that they had achieved complete impregnation of high bulk density soil clods using epoxy "Scotch Cast No. 3".

Moist samples of organic soil impregnated with "Carbowax" (a polyethylene glycol compound) apparently resulted in less shrinkage than oven dried and lyophilised samples impregnated with thermal polyester resin. (92) Others also claimed success in the use of "Carbowax 6000" mounted with "Castoglas" to prepare impregnated samples with little shrinkage. (93)

Sampling of friable, organic undisturbed soil was claimed to have been made easier with a technique of freezing "in situ". (87) This technique involved applications of liquid nitrogen on the soil until the soil block was frozen hard. The frozen samples were then air dried and impregnated with epoxy resin. The technique was found to be successful in the study of the influence of tree roots on physical properties and spatial arrangement of adjacent soil material.

Whatever method of extraction and impregnation has been used, thin sections cut from a larger block of impregnated soil have usually been examined using optical methods. Polarised light was used to evaluate soil fractions and the fabric of compacted clay (82) with samples prepared with thin sectioning.

The only apparent adoption of these techniques to the study of direct drilling and its effects on soil has been by Boone et al. (70). They used a thin sectioning technique in their macromorphological analysis of the difference in soil structure between cultivated and no-tillage soil. They reported that no-tillage soil was more dense

and more homogeneous in which aggregate stability increased. However, as with studies of other aspects, their work failed to note any relevant effects from the passage of drill coulter in either situation, or of the interface area between the drilled grooves and the inter-groove soil.

2.1.8.2 Scanning electron microscope technique.

Scanning electron microscope techniques (S.E.M.) have permitted examination of the surfaces of soil materials and the microstructure of the soil matrix. The technique has been widely found to be a useful adjunct to the field observations of soil morphology and has also been useful in the study of soil fabric. (96)

Other researchers used the technique at various magnification levels to successfully study the micro pore structure of ferromanganiferous soil concretions (97) and the root soil interface. (98) However, little or no work has been reported in the literature using this technique in a direct drilling situation.

2.1.9 Functional requirements of drill coulters

The difficulties which are involved in the determination of the limiting physical factors that govern the satisfactory performance of a given design of drill coulter, have so far provided farm machinery designers with little or no alternatives to an approach of trial and error when designing direct drilling coulters.

Baker (68) reported that there had been little work directed to answer the questions "What physical conditions best suit seeds sown into undisturbed seedbeds" and thus "What mechanical designs of seed

drill coulters and ancillary equipment best fulfil these demands?" Completely satisfactory answers may still be some way off but the collective observations of researchers might contribute to the solution of the problem, the nature of which is very inter disciplinary, involving aspects of agronomy, soils and engineering. On the other hand, many of the observations recorded in the literature to date have been of limited value only, as little effort had been made to monitor the climatic and biological factors prevailing at the time; nor to compare performance of any one device against a repeatable base line. Nevertheless Lillard et al. (12), in a study of planter requirements for uniform performance and optimum seed germination in killed sod and no-tillage seed beds, drew the following conclusions:

- (A) An assisting tool in front of a corn planter opener was necessary to:
 - ensure penetration
 - provide limited subsurface tillage in the immediate seedling environment zone, and
 - remove enough dead sod from the row surface to minimise impedance to plant emergence.
- (B) A seed press wheel was necessary to firm grains into the soil, and a coverer was needed to completely close the slit opened by the opener so as to eliminate air pockets in the vicinity of the seed.
- (C) A press wheel of appropriate shape was needed to firm soil over the seed row.

Baker (68) reported that Koronka (100) had reviewed the design specifications underlying the development of a specific coulter (triple disc) but questioned the insufficiency of the criteria in providing an adequate foundation on which to formulate a mechanical design.

Phillips and Young Jr (101) contended that a no-tillage planter must fulfil several basic requirements. It must:

- (A) - Be heavy and strong enough to plant under adverse soil conditions and cut through various crop residues.
- (B) - Provide a narrow band of tillage for receiving the seed. A 50 to 75mm wide and 75mm to 150mm deep zone of soil manipulation would be sufficient.
- (C) - Plant seed at different depths. Seed size, soil temperature and depth of adequate moisture should dictate the depth of seed placement. Accurate control of planting depth from 25mm to 75mm would be required.
- (D) - Cover and firm soil around seed. Coverage was important to assure germination and protection from bird and rodent damage. Firming of the soil in the row was needed to reduce air pockets and to maintain desirable moisture conditions around the seeds.

Russell (102) saw the definite need for the development of a suitable light and multi purpose drill. The basic requirements of such a drill were that it should:

- (A) - Place the seed at an even depth below the soil surface.
- (B) - Create little smearing of the wall and bottom of the slit in which seeds were dropped, so that water did not pond in the slit.

- (C) - Place some loose soil over the seed so that the slit was not left open.
- (D) - Be able to cope as effectively as possible with any crop or weed residues left on the surface and possible should allow for "combine drilling" of fertiliser and the seed. In addition, they felt that in much of the direct drilled land, a drill that created a narrow band of loosened soil in which the seed could be placed was to be preferred.

Although it is difficult to trace any of the fundamental data on which the above listed design criteria have been based, the numerous suggestions, observations and comments have led to a number of commercially available direct drilling machines. Phillips and Young Jr (101) grouped these machines into three general types - Chisel type, angle coulter, and fluted no-tillage planter. These authors also listed the advantages and disadvantages of each of these types although again, no data was quoted to indicate the reasons for these opinions.

Dixon (103) and Baker (56) both believed that it was important to understand the effects of changes in soil physical conditions at the seed zone when designing a suitable drill coulter for any given situation. They both suggested smearing and compaction in the groove might have some effects on seed emergence and root growth but that such factors should be studied in detail before conclusive statements were made and action taken which might influence coulter shapes. Dixon (103) conducted early experiments in this respect using a modified experimental technique developed by Baker (loc.cit). Although the work itself

was not conclusive it pointed to the need for a more detailed and expansive study.

A wholly successful direct drilling technique is still to be found but it appears that this is not the only factor which has so far limited the technique. At least in the U.K., Allen (104) listed the contributing factors as follows:

- Failure to achieve consistently similar yields to those of traditionally sown crops
- Development of "Couch" and other perennial grass weeds where direct drilling was practised.
- Soil type and structure
- Lack of a "farmer" direct drill
- Regeneration of paraquat sprayed swards and annual grass weeds
- Slugs
- Lack of convincing "farm management" evidence in favour of direct drilling
- Inconsistency of results obtained when direct drilling grass into grass
- Reluctance of farmers to buy an expensive direct drill which they felt would commit them to far more direct drilling than they could contemplate with confidence
- Insufficient confidence in the "idea" of direct drilling both outside and within the I.C.I. Limited group.

2.2 EXPERIMENTAL METHODS.

Two categories of experiments were employed in this study. Bin experiments involved the removal from the field of bins of undisturbed soil for treatment in a laboratory. Field experiments involved the siting of field plots on appropriate soil types.

2.2.1 Soil Bin experiments

2.2.1.1 Site and soil type selection.

The soil type used in all bin and field experiments was "Tokomaru" silt loam. The mechanical properties of this soil are given in table 1. Two sites were used from which trial blocks were extracted. The use of different extraction sites may have been expected to introduce some lack of uniformity in physical properties of the soil, but such heterogeneity of this soil type was apparently not typical according to Pollock (pers-comm)(106). In the specific soil properties that might be expected to be important for thin sectioning of small sub samples, Gradwell (107) had reported that the groups of soil known as "Manawatu silt loam" of which "Tokomaru" silt loam is a part, had not displayed marked signs of swelling when wetted. He also found that the mean porosity in the wetted areas exceeded that in the dry by only 1.4%.

The parent vegetation of the extraction sites was predominantly established rye grass (*Lolium perenne*) and white clover (*Trifolium repens* L) with some flat weed species.

The specific soil management history was not recorded but the pasture had been grazed by sheep for the past four to five years. There was no attempt made to conduct a botanical analysis of the parent cover because it was to be chemically killed later.

As a check of the consistency of root material in the top soil of individual turf blocks, predrilling checks were carried out in the following manner. Oven-dried soil cores were soaked in water, then broken up by hand and gently rubbed through an .125mm aperture sieve until all soil was removed from the roots. These were then oven-dried and weighed.

Other soil characteristics were determined as listed below:

1. Field capacity and soil dry bulk density. Field capacity is the moisture content to which soil in the field drains under gravity after thorough wetting. In the laboratory an approximation of field capacity was obtained by measuring the water content (g.water/100g of oven-dried soil) of undisturbed soil cores (52mm diameter and 33mm long) in equilibrium with a tension of 200cm of water in a tension table apparatus and/or a pressure plate apparatus. Soil dry bulk density was determined by direct measurements of volume weight after the test cores had been oven-dried at 105° - 110° C for twenty four hours.
2. Permanent wilting point.

Permanent wilting point is reached when plants cannot extract water from soil quickly enough to replace that lost by transpiration. This was measured using test soil cores enclosed and drained in a pressure membrane apparatus at 15 atmospheres for forty eight hours. The water content at this point was taken as an expression of wilting point and expressed as g. water/100g of solid soil.

3. Available water capacity.

The available water capacity of a soil is the maximum amount of water the sample can store that is available to the plant. This was determined by difference between the field capacity and wilting point. Figure 1 is a graphical representation of the available moisture calibration of the soil used in the bin experiments.

4. Soil porosity.

The porosity was determined using the following equation:

$$n = 100 - \frac{D}{d}$$

where n = porosity %

D = soil bulk density (g/cm^3)

d = particle density = $2.67\text{g}/\text{cc}$

Gradwell (108)

TABLE 1: Mechanical properties of "Tokomaru" silt loam soil.

Horizon	Depth (cm)	Clay	Silt	Sand	B _D g/cm ³	Porosity %	Field capacity g/water 100g of solid soil	Wilting point g/water 100g of solid soil	Available water g (water) 100g of solid soil	Root g/100g of solid soil
Ah,	0-8	23%	68.5%	8-9%	1.07	60	43.2	15.3	27.9	
Ah ₁ *	0-5 cm				1.04 *	61 *	40 *	14. *	26. *	1.4 *
refer- ence										
Ah ₂	8-20	22%	69 %	8.7%						

* = Experimental data. Otherwise, all data is from Gradwell (loc.cit)

Soil Type

Tokomaru silt loam (Tuapaka farm
Massey University).

Soil Growth: Central yellow grey earth.

Parent: loess.

Altitude of site: 70m

Rainfall: 1050mm

Location of site:

Grid reference NZMS 1 = N/149/114300

Slope at = 0° (degrees)

point of sampling

Soil layer of interest: top 5cm (sprayed pasture soil).

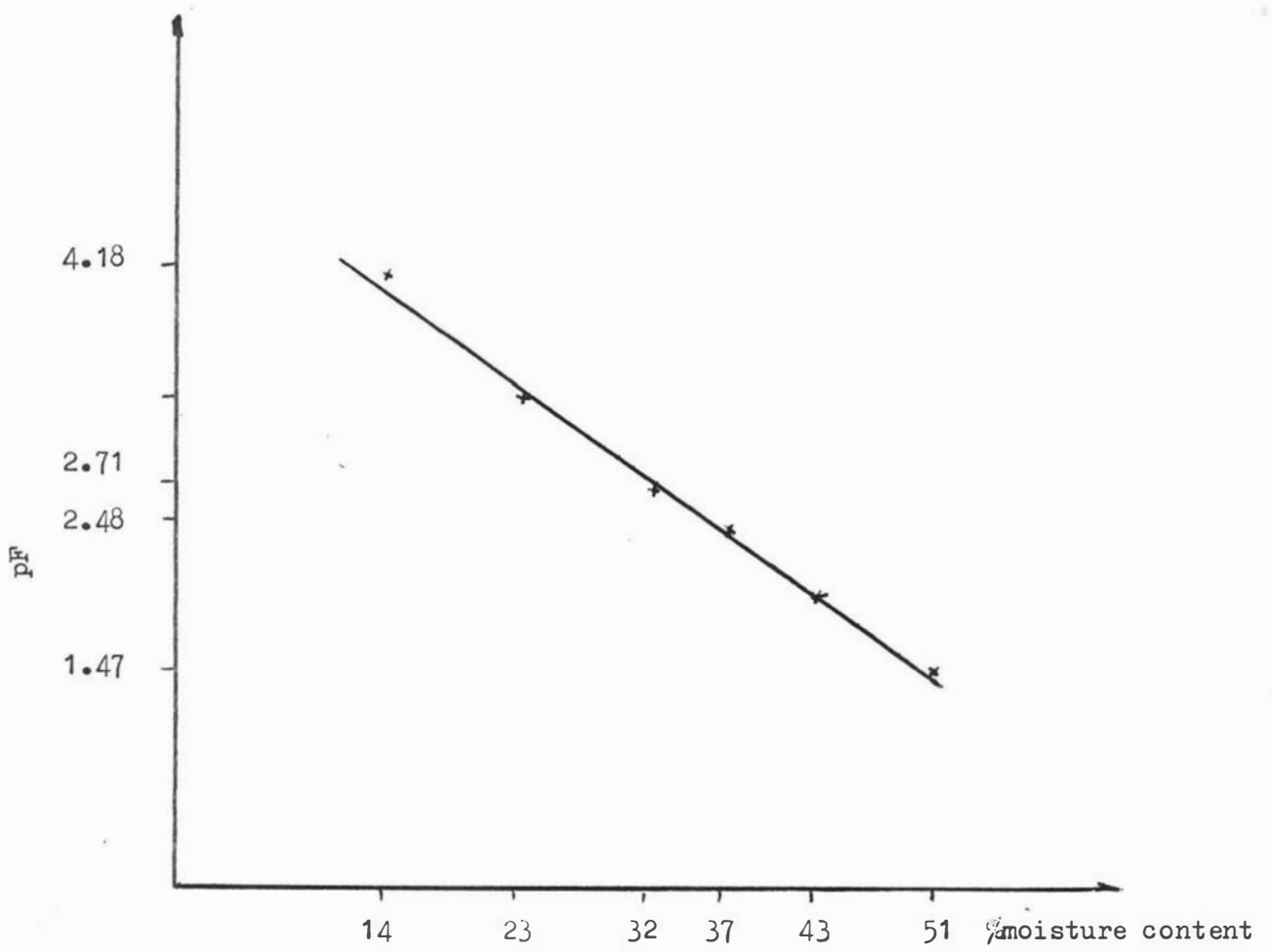


Fig.1. Soil moisture content and suction curve of
"Tokomaru silt loam"(0-50mm).

2.2.1.2 Soil bin collection procedures.

Turf blocks were extracted from the field using twelve steel bins measuring 1.80m long x .66m wide x 0.20m deep. The turf extraction method and equipment were both developed by Baker (68) and are illustrated in figures 2, 3 and 4.

An effort was made to choose extraction sites at random. However, some selection of sites was undertaken as it was considered desirable to maintain a fairly even soil surface and also to seek homogeneous soil, in so far as this was reflected by an even vegetative cover.

Undue machinery traffic was avoided during collection of turf blocks as wheel compaction could have affected the initial soil condition.

(a) Post collection preparation of turf blocks.

After collecting, the turf blocks were numbered and trimmed at both ends. Loose material was then removed from the ends and molten paraffin wax was applied to prevent moisture loss from these otherwise exposed vertical soil faces. The turf blocks were then placed in steel trays (measuring 2.40m x .91m x .15m) which were housed under four removable transparent rain canopies. A pilot study of soil moisture loss under these rain canopies compared with field conditions was reported by Baker (68). He concluded guardingly from the data obtained in his limited investigation that although the rain canopies appeared to have been effective in intercepting rainfall they had not materially affected evapo-transpiration. The result was that soil moisture under the canopies had been reduced, suggesting that the soil in bins should behave in most respects as if they were in rainless conditions in the field, at least where moisture supply

was not greatly affected by ground water from beneath. In this manner, during the predrilling period, each of the rain canopies was considered to be a replicate within which three tillage bins were randomly positioned.

Prior to drilling, water was introduced to each of the trays to a predetermined depth for 12-24 hours to saturate the soil, after which the water was drained from the trays. Daily evaporation loss from the soil bin surface under the rain canopies was estimated using the "bucket" method described in appendix 5.

Two days before drilling, the turf blocks were sprayed at the rate of 5.6 litres paraquat/ha.

2.2.1.3 Experimental design.

I. Experiments 1, 2 and 3:

The comparison of interest was between the two coulter types. Supplementary comparisons which were considered to be important were between wet and dry post drilling soil regimes; lupin and wheat as examples of tap rooted and fibrous rooted varieties; and the mechanical response of the soil in the vicinity of the grooves.

Using the tillage bin technique described in section 2.2.1.2, certain limitations were imposed in the experimental designs. These were that:

1. It was not possible to drill each plot (or bin) in total isolation as might be expected in a field experiment. This was because of the need to provide lead-in and run-out bins at either end of each treatment bin. Clearly it would have been impractical to provide sufficient lead-in and run-out bins to drill each treatment bin separately. Instead a line of 3 treatment bins (figure 1a) were positioned end to end on the support bed. Preceding the first of these

bins was a lead-in bin and a run-out bin was placed after the last one. In effect, treatment bin No.2 became also the lead-in bin for treatment bin No.3 and this, in turn, became the run-out bin for treatment bin No.2. This physical limitation was not felt to have seriously affected the validity of the experimental design, except that it dictated to some extent the order of drilling.

2. It was considered important to conduct the physical soil measurements immediately after the bins were drilled, in order to minimize any possible soil biological activity around the created grooves which might have arisen as a function of time and altered the physical characteristics of the soil.

3. It was impractical and uneconomic to use a full bin as a single plot for each treatment because of the number of bins thus required, and the difficulties in physical handling of a large number of bins in a reasonable time.

With these limitations in mind, the following experimental designs were used. Five separate experiments were laid out and conducted simultaneously, with 12 bins. This arrangement was felt to have utilized the expensive bin facility to its maximum potential.

The arrangement of each of the first three experiments (Experiments 1, 2 and 3), conducted in partly controlled climatic conditions was similar. Within each experiment, the general layout of the five separate sub-experiments is illustrated in figure 1b

The main comparisons were between the two rows drilled with each coulter in each bin with each species ("Chisel" and "Triple Disc", Fig. 1b. A third drilled row in each bin is labelled in figure 1b as c or t. This row did not have seed sown in it and became a separate

sub-experiment for destructive measurements of soil physical parameters.

Immediately after drilling, each bin was partitioned using a steel plate which was driven vertically into the soil. Each half of the bin was maintained at one of two moisture regimes which were also considered to be separate sub-experiments. These were "low" (no further moisture added) and "adequate" (water added as precipitation from above to maintain the level close to the pre-drilling initial moisture content). These bins are labelled as "WET" and "DRY" in figure 1b.

In this manner, five sub-experiments were conducted in the 12 bins as follows:

- A. A comparison of the physical response of soil to two coulter types (one row in each of two bins).
- B. A comparison of wheat root responses in a low soil moisture regime as a function of the two coulter types (two rows in each plot or half bin).
- C. A comparison of wheat root responses in an "adequate" moisture regime as a function of the two coulter types (two rows in each plot or half bin).
- D. A comparison of lupin root responses in a "low" moisture regime as a function of the two coulter types (two rows in each half bin).
- E. A comparison of lupin root responses in an "adequate" moisture regime as a function of the two coulter types (two rows in each half bin).

In this manner, with sub-experiment A, each bin was considered to be a plot of one full row length. A full row length was used because the destructive physical soil measurements were conducted prior to the division of the bin into two smaller plots with the steel plate. Thus experiment A involved two treatments with six replicates. Each bin was

a plot and each pair of bins was a block. The blocking of two plots (and therefore two bins) in the design of experiment A was felt to be desirable for the following reasons:

1. The order of randomization used in this particular sub-experiment necessitated a change of coulter types for each 2-bin run.
2. The two bins which were to be blocked had been placed under the same rain canopy prior to positioning them on the testing rig.

In experiment B, each bin contained two plots (viz. two coulter type treatments) of half row length. Thus each bin became a block of which there were six containing wheat in the "low" moisture regime (dry).

Similarly, experiment C consisted of six blocks each of two bins, each of which contained half row plots of wheat in the "adequate" moisture regime (wet). Experiment D consisted of six blocks of bins each of which as in C contained half row plots of lupin in the low moisture regime (dry).

Experiment E consisted of six blocks of bins as for D and C but in this case each contained half row plots of lupin in the "adequate" moisture content (wet).

Baker (.68), in his experiments involving plant emergence counts of direct drilled barley and wheat, felt that his experiments had failed to account for the apparently large variability amongst plots treated alike because of the small number of replicates (S) used in his experimental design. As most of his experiments compared three main treatments and the experiments described herein were to compare in many cases only two treatments, a larger number of replicates than had been used by Baker seemed justified in the present study to increase the sensitivity of treatment differences. This was all the more so because the treatment comparisons to be made were of unknown magnitude and variability, due

to the dearth of published data on the subject.

The standard error of the difference between two means decreases as S decreases and n increases ($S_d = \sqrt{\frac{2s^2}{n}}$).

It was therefore felt that, even though no valid correlation could be made between the two studies of different subjectives, any experimental designs which utilized more than three replicates was likely to be statistically more satisfactory than that of Baker (*loc.cit.*).

The data obtained from the experiments described herein were interpreted using a two-way analysis of variance (randomized complete block design). A computer programme was developed (which was similar to the "Teddybear Burrough" software packages for statistical purposes) and used to analyse the results. Listings of the computer programme are given in appendix 11.

II. Experiment 4:

In experiment 4, 24 boxes of "Tokomaru Silt Loam" (see section 5.5.1) were randomly sampled and collected from a Massey University farm site. The boxes were grouped in four blocks of six boxes each. One box in each block was assigned to a drilling treatment (one of the six groove shapes) and two crops (wheat and lupin). Thus, two separate sub-experiments were conducted in each box (fig.1c).

Results obtained were interpreted using a two-way analysis of variance (for completely randomized block experiments). Treatment means were then compared using Duncan's range test. The computer programme developed for the analysis of the results is given in appendix 11.

III. The designs of field experiments 5 and 6:

The experimental designs for experiments 1, 2, 3 and 4 can be regarded as factorial experiments in which two factors were involved (the treatments: triple disc and chisel coulters form one factor and the blocks form another factor).

The experimental designs for the field experiments 5 and 6,

Direction of travel of the testing apparatus

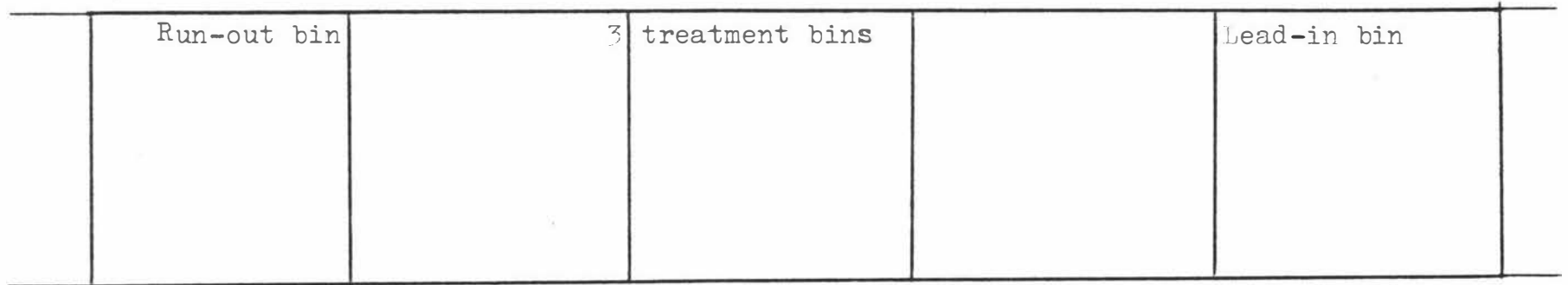


Fig. 1a The positioning of treatment bins on the support bed of the testing rig.

The design of Experiment 1 (Similar arrangements were used for experiments 2 and 3)

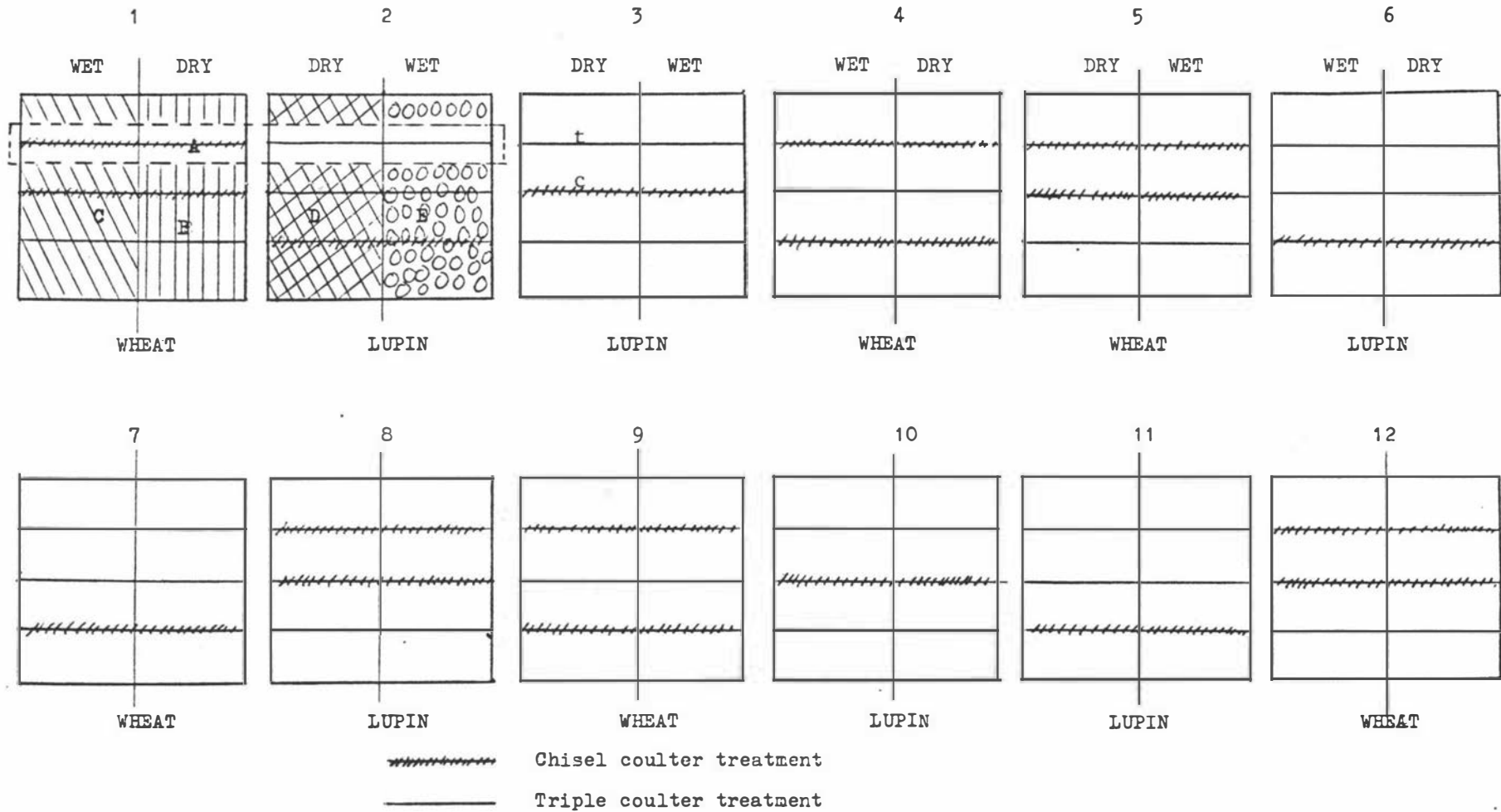


Fig. 1 b Five separate sub experiments conducted simultaneously with 12 bins.

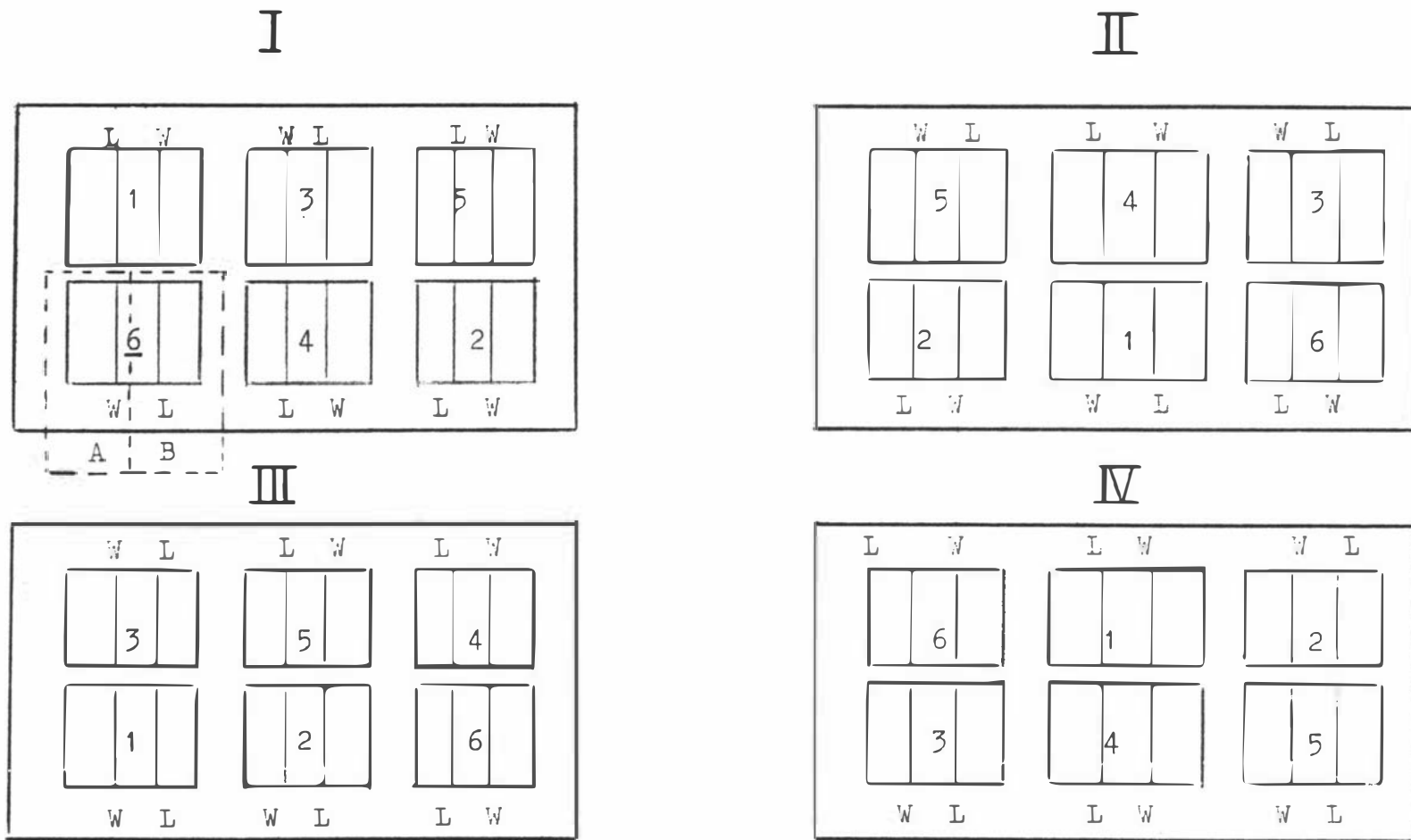


Fig.1c Randomised block design experiment (4 blocks of 6 treatments each)
L: Lupin W:Wheat

however, were conventional factorial experiments involving two different treatments, each with two different levels (coulters types: triple disc and chisel coulters; and soil conditions: rolled and unrolled).

The reasons for this design were to investigate the longer term interactions that soil conditions and coulters types may have had on crops in field conditions.

Four treatment combinations (or four treatments) were assigned to a block. There were four blocks for each crop (lupin and wheat). In this manner, two separate sub-experiments were conducted simultaneously. One involved wheat and the other involved lupin as the response variables. Another response variable included in the experiments was earthworm population. The data was interpreted using a three-way analysis of variance, the computer programme for which is given in appendix 11.



Fig.2.(from Baker(68))Turf block extraction procedures.

Upper:The turf cutter and tillage bin attached.

Centre:Water(used as a lubricant)discharging from the
turf cutter blade.

Lower:Connection of a tillage bin to the turf cutter
blade.

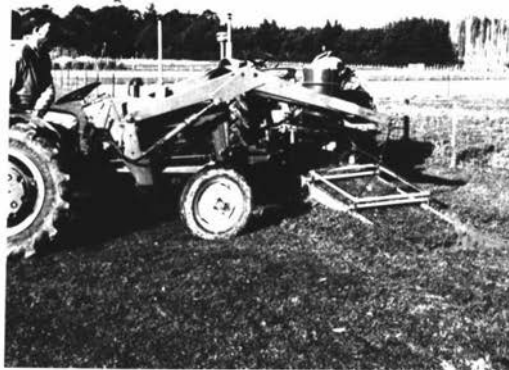


Fig.3.Turf block extraction procedures(contd).

Upper:The turf block slides in as extraction begins

Centre:A tillage bin at full depth(note the 4 lifting rings)-to be isolated at block ends.

Lower:Uplifting a turf block.

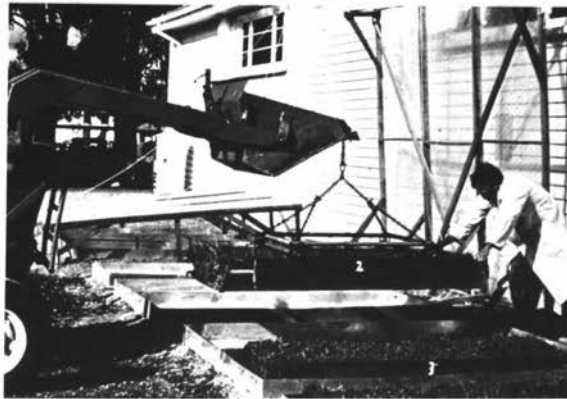
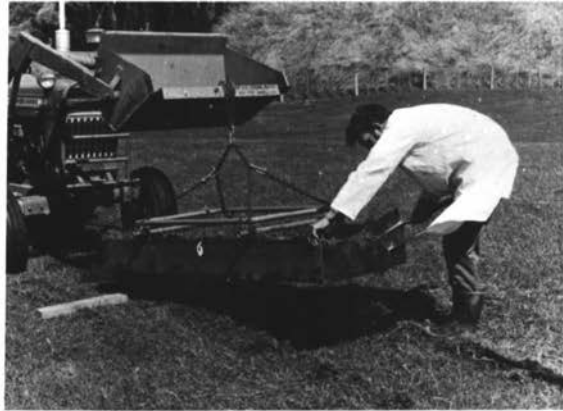


Fig.4.Turf block extraction procedures(contd).

Upper:Trimming of block ends.

Centre:Waxing after the removal of loose soil from the turf block ends with a wire brush.

Lower:Placement of a prepared tillage bin into its tray,with the rain canopy in the raised position.

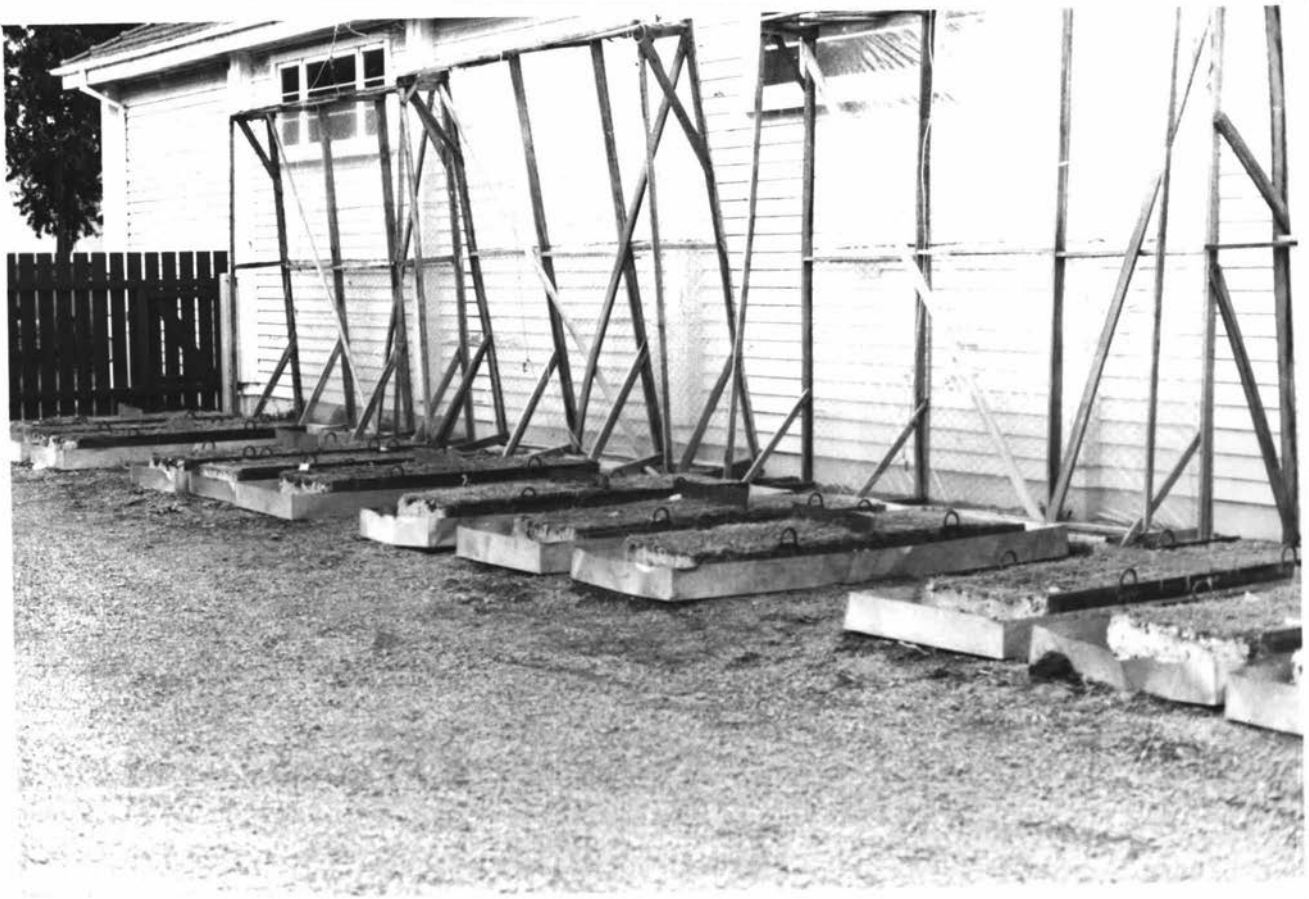


Fig.5. The experimental design of 12 bins grouped into 4 replicates of 3 bins each, placed under 4 rain canopies.

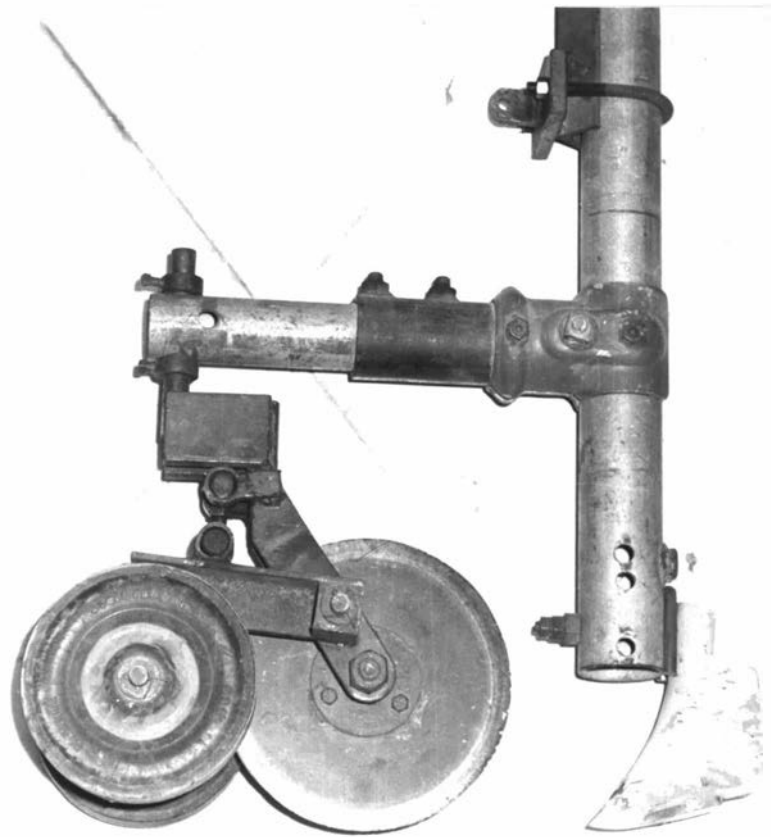


Fig.6.The chisel coulter assembly.

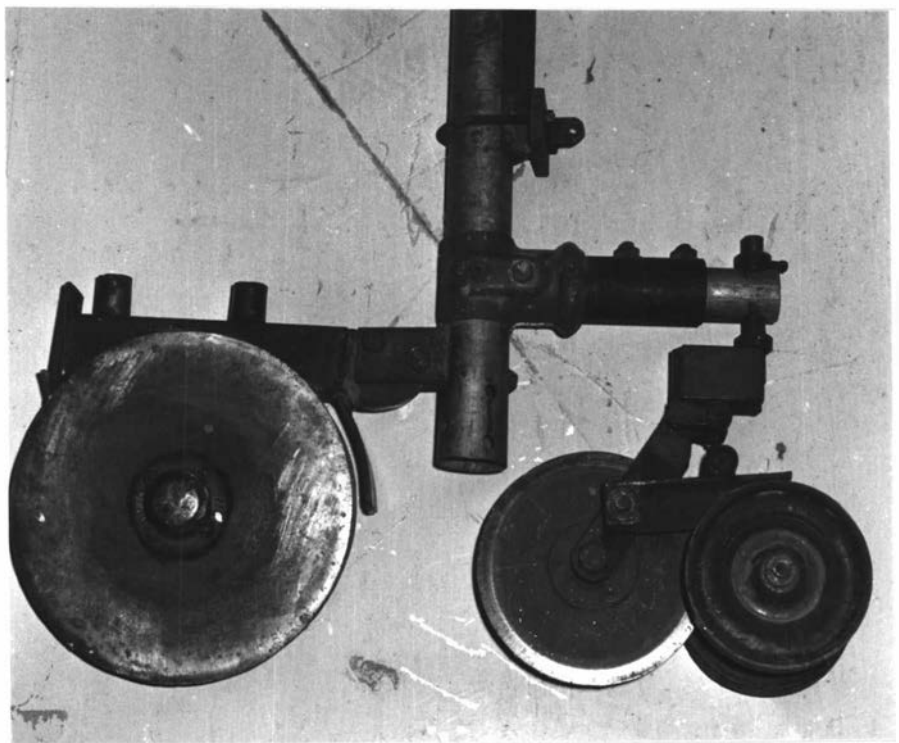


Fig.7.The triple disc coulter assembly.

2.2.2 Drilling of turf blocks

2.2.2.1 Pre-drilling.

In preparation for drilling, three bins taken from beneath the rain canopies were placed end to end on an elevated support bed described by Baker (loc.cit). Preceding the first of these bins was a lead-in bin. A "run-out" bin was also placed after the last treatment bin. Thus, in this manner, all five bins fitted snugly together forming a shallow continuous tillage bin. Care was taken to ensure the continuity of the soil surface.

A tool carrier straddled the bins and was supported on tracks running parallel to the bins. Three pairs of trailing arms were pivotally attached to the shaft of the moving rectangular gantry, on which the coulter assemblies were mounted. The two coulters used in the study were a commercially available triple disc coulter and an experimental chisel coulter (figure 6 and 7). Brief descriptions of these coulters are given in appendix 9.

Each coulter was used with a preceding single 200mm diameter vertical flat disc to cut turf. Prior to drilling, the coulter assemblies were adjusted so that the base of this leading disc was level with the lowermost portions of the following coulter bodies. All tests involved positive control of depth using a pair of 100mm diameter wheels which rested on the undisturbed soil alongside the leading disc.

2.2.2.2 Drilling operations.

At the start of a drilling run, the moving gantry was positioned above the "lead in" bin where all final adjustments (i.e. penetration, operation depth, pitch, seeder operation, pre-disc alignment) were made

before the coulter entered the first treatment bin at a predetermined but adjustable operating speed.

In this study, an operating speed of 1m/min was chosen to allow observation of seed placement and to facilitate other measuring operations which took place while the coulters were passing through the soil.

At the end of run one, the coulters were left resting on a wooden track provided to gradually take the load as the coulter left the final experimental bin. The coulter and the seeder wheel were raised and the moving gantry was returned to the "lead-in" bin.

To drill another row, the coulter assembly was disconnected from its pair of trailing arms and reconnected to an identical adjacent pair 150mm across the bin, and the process was repeated.

The inter row spacing of 150mm was chosen to leave the outer rows (of the three rows per bin) 190mm distant from the bin walls. This was felt to be desirable to avoid any possible influence from the narrow zone of disturbed soil alongside the edge of the bin Baker (loc.cit).

Three rows per bin were drilled in this manner. No interruption or adjustments were made to an operating coulter during a run unless for emergency purposes. After drilling, the covering operation was undertaken using a section of bar harrow which had a scuffing action (68). Each bin was then returned to its predetermined position under its respective rain canopy for sampling and harvest.

2.3.3 Field experiments

Two field experiments were laid out during Autumn-Winter 1977 and Spring/Summer 1978 seasons on the "Tokomaru" silt loam located on the

University No. 4 Dairy Unit. Each was a factorial experiment with four randomised complete blocks involving two soil bulk densities, two crops (lupin and wheat) and the two coulters. Detailed descriptions of each experiment are given in sections 3.7 and 3.8.

2.3 MEASUREMENTS

All physical measurements were made either at the time of, or immediately after the passage of the drill coulters through the soil.

2.3.1 Soil Bulk density

Soil bulk density is the most widely accepted measure of compaction. Within a given soil, the bulk density provides a measure of the packing condition of solids but does not yield any information about the arrangement of soil particles. However, if the specific gravity of the soil grains is known, then the bulk density value can also be used to derive a measure of porosity or void ratio ($n\% = 100 - \frac{D}{d}$).

2.3.1.1 Core sampling method.

The principal difficulty in determining soil bulk density is the measurement of volume occupied by the solids. Various methods have been suggested and used. (109,110,111) However, each method appeared to be applicable to a specific situation and/or a certain objective.

A piston-type drive core sampler with the following dimensions was used to determine soil bulk density and soil moisture content in these experiments prior to drilling. The same device was used for sampling from undisturbed soil between the rows after drilling.

Core dimensions.

Diameter	=	52mm
Length of core	=	33mm
Wall thickness	=	4mm
Total volume of core	=	70cm ³

2.3.1.2 Small core sampler.

Willardson and Taylor (112) reported that small diameter samples were as good as, or better than large diameter samples and that the variance associated with the smaller cores was low enough for most uses. Thus, a small piston-type drive core sampler was designed to enable core samples to be taken from the actual grooves left after the passing of drill coulters. A pilot trial testing the reliability of this instrument compared with the larger instrument described previously showed good results. Comparing bulk density and soil moisture content obtained using both samplers there were no significant differences ($p = 0.05$) between twenty pairs of samples tested.

Core dimensions:

Diameter	=	11mm
Length of core	=	13mm
Wall thickness	=	1mm
Volume of core	=	1.235cm ³

2.3.1.3 Procedures.

Core samples were taken randomly from the undisturbed soil between the rows in each bin after the passing of the drill coulters. Soil moisture content and soil bulk density were determined gravimetrically from each sample. Five small core samples were taken from the base of the grooves in each bin to determine post-drilling soil bulk density in that region. Extreme care was taken to minimize any compaction that could have arisen as the *sampler was* being driven steadily and gently down into the soil.

2.3.2 Mechanical resistance of soil

2.3.2.1 Description of the measuring equipment.

Soil strength is usually expressed as a parameter of soil resistance which must be overcome to cause physical deformation of a body of soil, and is normally assessed by penetrometer tests.

The penetrating elements are generally either circular or rectangular flat plates or cone shaped tips. The methods of advancing the penetrometer into the soil are either static (113-116) or impact methods. (117)

The lack of standardisation of penetrometers has caused difficulties in the interpretation of data obtained from different penetrometer models. This has resulted in the development of various types of penetrometers, needle (113,118), cylindrical tips (114-115) and vane (116) each suited to the experimenter's needs and experimental conditions.

The multipoint penetrometer used in these experiments was first developed by Baker (loc.cit) and reported by Dixon (loc.cit). It was modified by the author for this study.

Twenty square ended steel cylindrical probes of 90mm length and 1mm diameter are mounted 10mm apart on a crossbar attached to an adjustable frame in such a way that each probe can be clamped individually. In this manner, individual probes can be adjusted in height to conform to the irregularities of a soil surface before being clamped and pushed into the soil profile. The probes can be inserted into the soil in one of three positions; horizontally, vertically and perpendicular to the groove wall.

Once in the desired position, two symmetrically spaced pairs of probes are locked by thumbscrews. In this way, five separate readings are able to be obtained for one position of the instrument. Each reading becomes the average of four probes. By positioning symmetrically paired probes, it is assumed that a uniform distribution of force on the mounting bar will result. Even if complete symmetry of force is not always achieved variations are usually only minor and have not greatly affected the function of the instrument. Should an occasional stone be encountered by a solitary probe, the resultant imbalance is easily detected and that reading discontinued.

Penetration of the probes is facilitated by a threaded telescopic shaft of 12.7mm diameter driven by a hand held, electric motor at 20mm per minute. A nominal depth of penetration of 10mm was arbitrarily chosen and an inductive displacement transducer, attached across the diameter of a proving ring, recorded the deflection of the ring as a function of soil resistance to the probes.

The feed-in mechanism is rigidly attached to a circular plate which can be angled in relation to a similar backing plate (fig. 8). The latter plate is itself adjustable for both height and lateral position on a frame which straddles the tillage bin and is clamped onto the runners on either side, for rigidity. In this manner, the resistance to penetration of the probes with depth was recorded in any or all of three positions. For example, the base and side wall positions in the grooves could be probed either vertically or normal to their surface. Vertical insertions recording resistance across the profile of a formed direct drilled groove were also made. (fig. 9) Indications of zones of

compaction and of smearing interfaces were therefore determined by comparison with penetrometer readings of the undisturbed soil between the grooves.

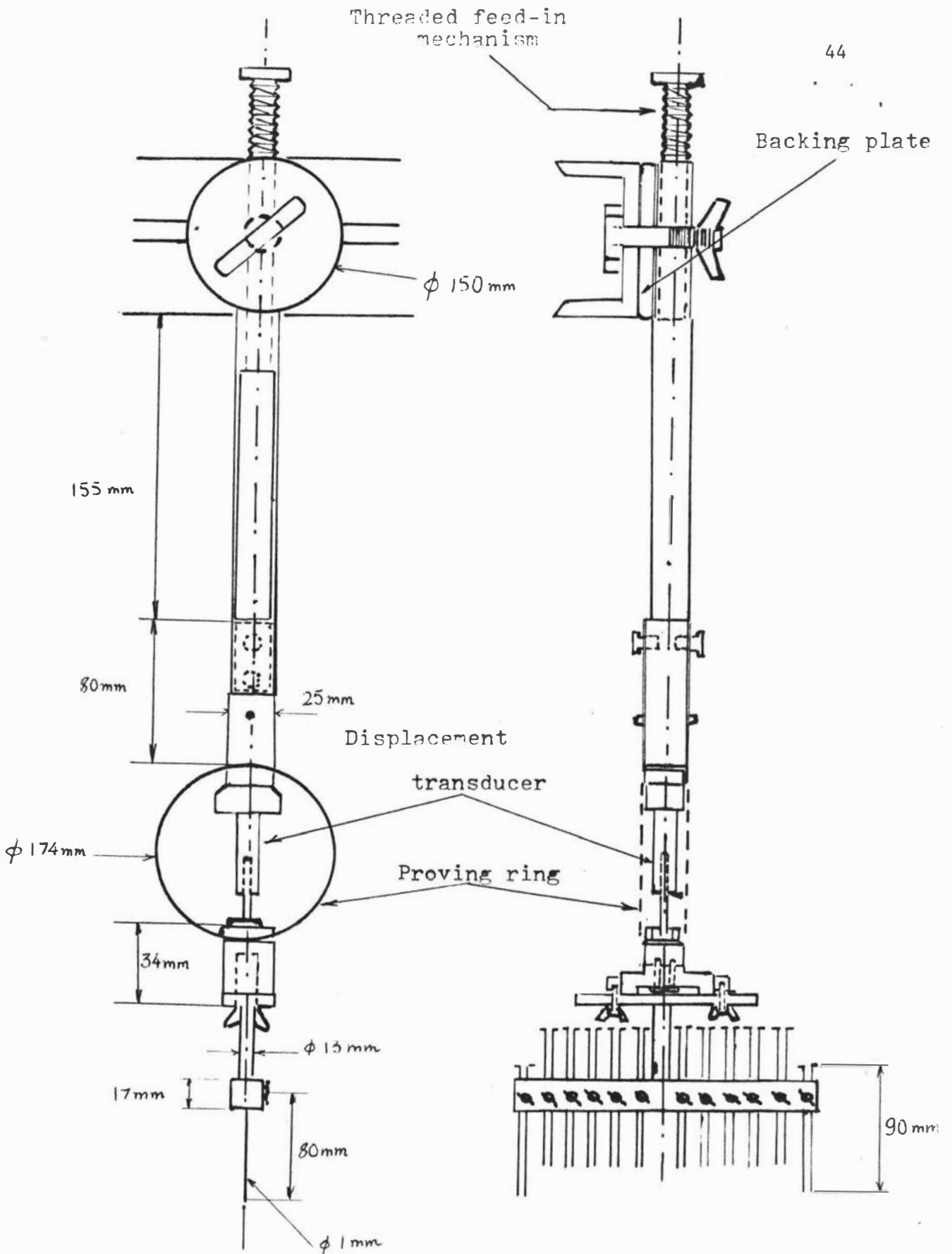


Fig.8. The multipoint penetrometer.

2.3.2.2 Procedures.

Measurements were taken at a randomly positioned site in a drilled but unseeded groove. Because the sampling is destructive a special area was reserved for these physical measurements. For comparative purposes one set of five measurements of the original soil strength was also taken for each bin. At all stages, care was taken to avoid excessive disturbance to the soil surrounding the grooves. Once the probe was placed in position, the displacement transducer was connected through a converter to a chart recorder. Force being recorded as a function of depth. Typical curves drawn on the chart recorder are given in fig. 11. The curves are presented here because they are not presented in this form in the Results section. Rather the area under each curve was measured as an indicator of mean force. Calibration was achieved using a dead load test. Interpretation of data was achieved by the use of the calibration curve given in appendix 6.

Five readings were taken for each position except the measurements of penetration across the groove, this latter test was designed to detect the extent of localised compacted soil layers on either side of the grooves. In this measurement probes were positioned symmetrically 50mm, 40mm, 30mm, 20mm, and 10mm from the centre of the groove.

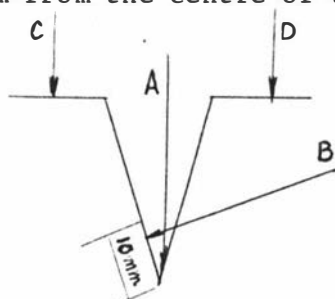


Figure 9: Sampling positions of the multipoint penetrometer.

A: at the base of the groove

B: normal to the groove wall

C, D: across the groove at positions equidistant from the centreline.

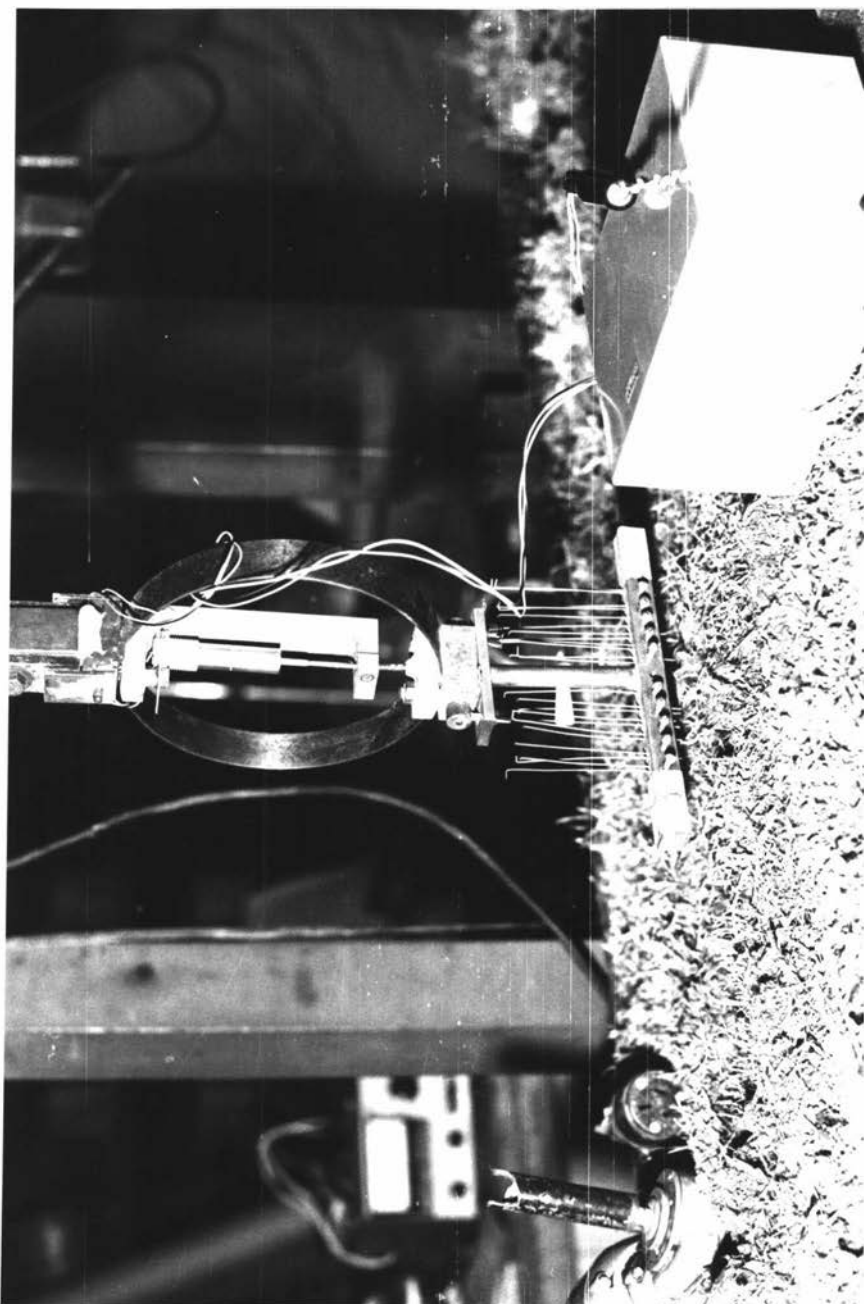


Fig. 10. The multipoint penetrometer at work.

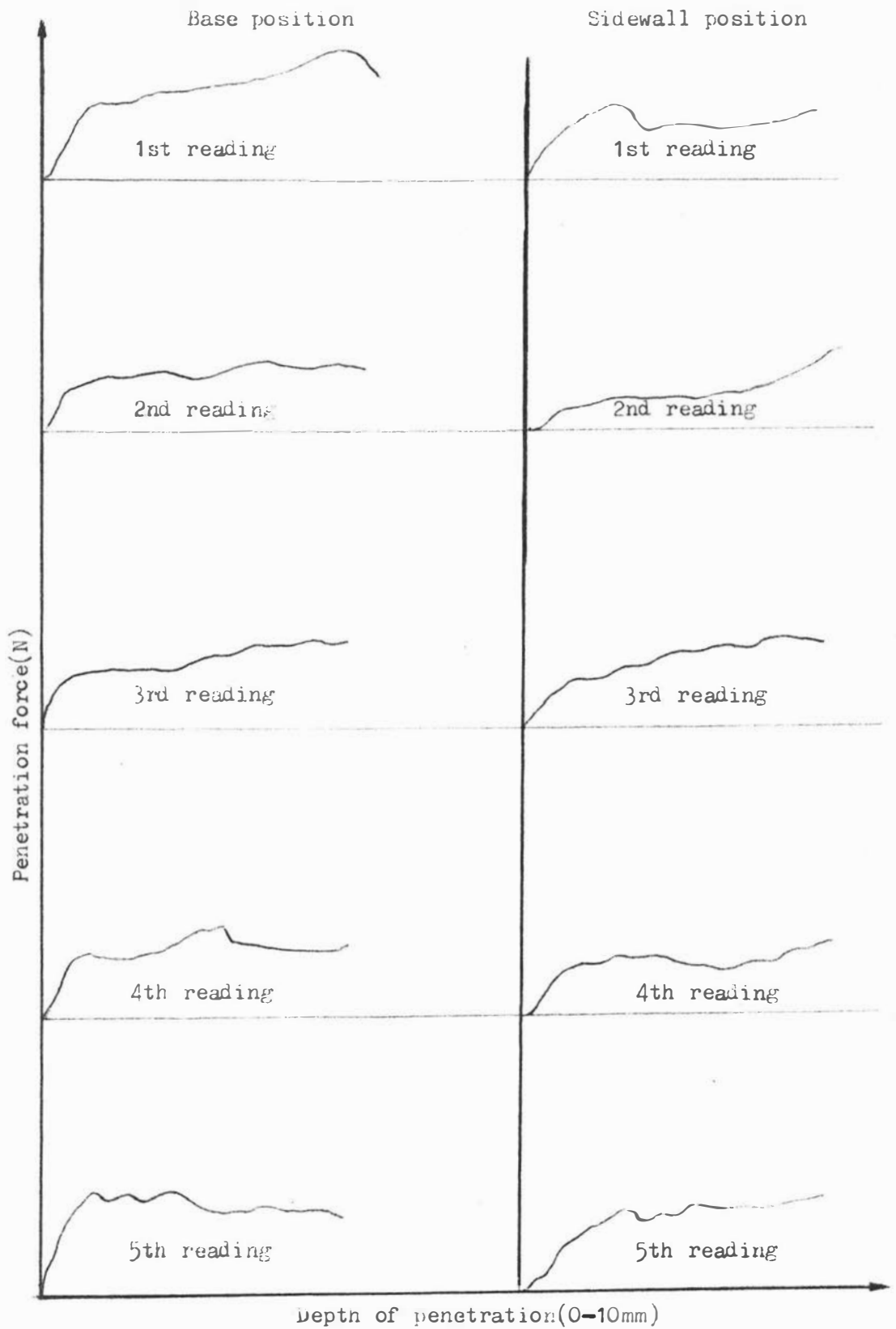


Fig.11. Typical soil strength curves obtained with the multipoint-penetrometer apparatus(triple disc coulter).

2.3.3 The instantaneous zone of influence

No attempts were made to measure the pore water stress or the effective stress which was responsible for compaction in this investigation. Rather, a technique was developed based on the behaviour of soil under load, to monitor the instantaneous zone of influence at both sides of the direct drilled groove created by the passing coulter. Stress and stress propagation developed by the passing coulter was expected to be transmitted through the soil at the points of contact between adjacent particles. These forces could be expected to comprise both normal and tangential components at each point of contact. Measurements in this study were however restricted to the normal components, to facilitate ease of measurement.

2.3.3.1 Description of the equipment.

As an indicator of the instantaneous zone of influence in the horizontal plane perpendicular to the direction of travel of drill coulters, soil stress measurements were taken. Pressure sensing tubes were constructed using a rubber sensing diaphragm in the end of a brass tube.

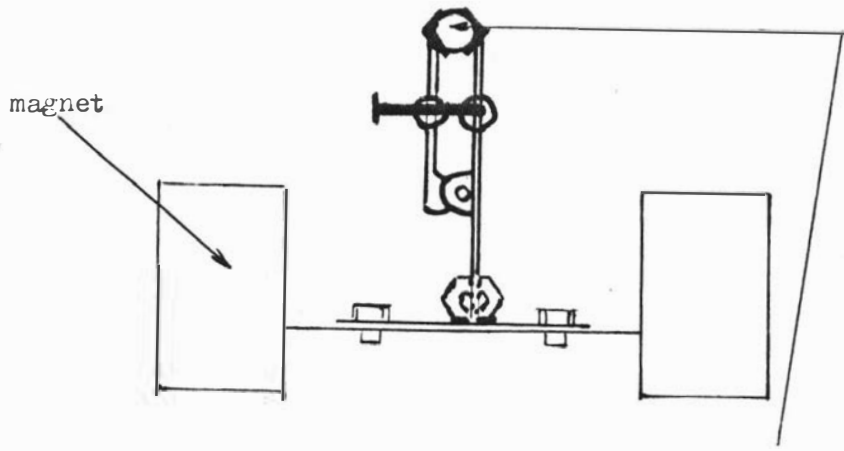
The surface diaphragm (figs. 12 and 13) represents a plane on which the stress vector acts. The device was not designed to measure shearing stresses and responds only to the normal component of the stress vector. The brass tube with its rubber diaphragm held in place by a wire ring, is filled with water which acts as the pressure transmitting liquid. To eliminate entrapped air in the tube, bleed valves are provided on a detachable threaded end boss. A syringe is used to inject water into the tube through one valve while the whole pressure tube assembly is submerged vertically underwater and air is allowed to discharge from the other valve.

A miniature strain gauge pressure transducer, measuring 6mm in diameter and 7mm long (fig. 13), is sealed within the detachable end boss. By this means, internal pressure is relayed to a recorder. This design was used in preference to direct placement of the transducer within the soil to lessen the extent of damage to the expensive transducer units in the event of contact with a coulter travelling through the soil.

2.3.3.2 Procedures.

Each pressure tube was inserted carefully into the test soil through holes drilled in the steel tillage bins prior to the passage of coulters. Two holding magnets and clamps (fig. 12) located each pressure tube in contact with the soil surface at the end of the hole, but also allowed for mechanical release in the event of excessive horizontal deformation of soil and occasional vertical contact with some coulters.

Each hole was drilled a predetermined distance into the soil. In this way the rubber diaphragm was located at a pre-selected distance from the centre of the anticipated coulter path. With the tillage bin and tool testing apparatus used the coulter path was known in advance, so that the diaphragm was able to be located laterally with a tolerance of ± 5 mm. Where vertical holes were used to insert tubes from beneath a tillage bin, the tolerance margin was increased because coulter depth, although controlled by depth wheels travelling on the soil surface, was influenced by minor contour changes of the undisturbed soil sample and could not therefore be anticipated with the same accuracy.



End view of the pressure sensing tube

Fig.12.Holding magnets with adjustable clamp

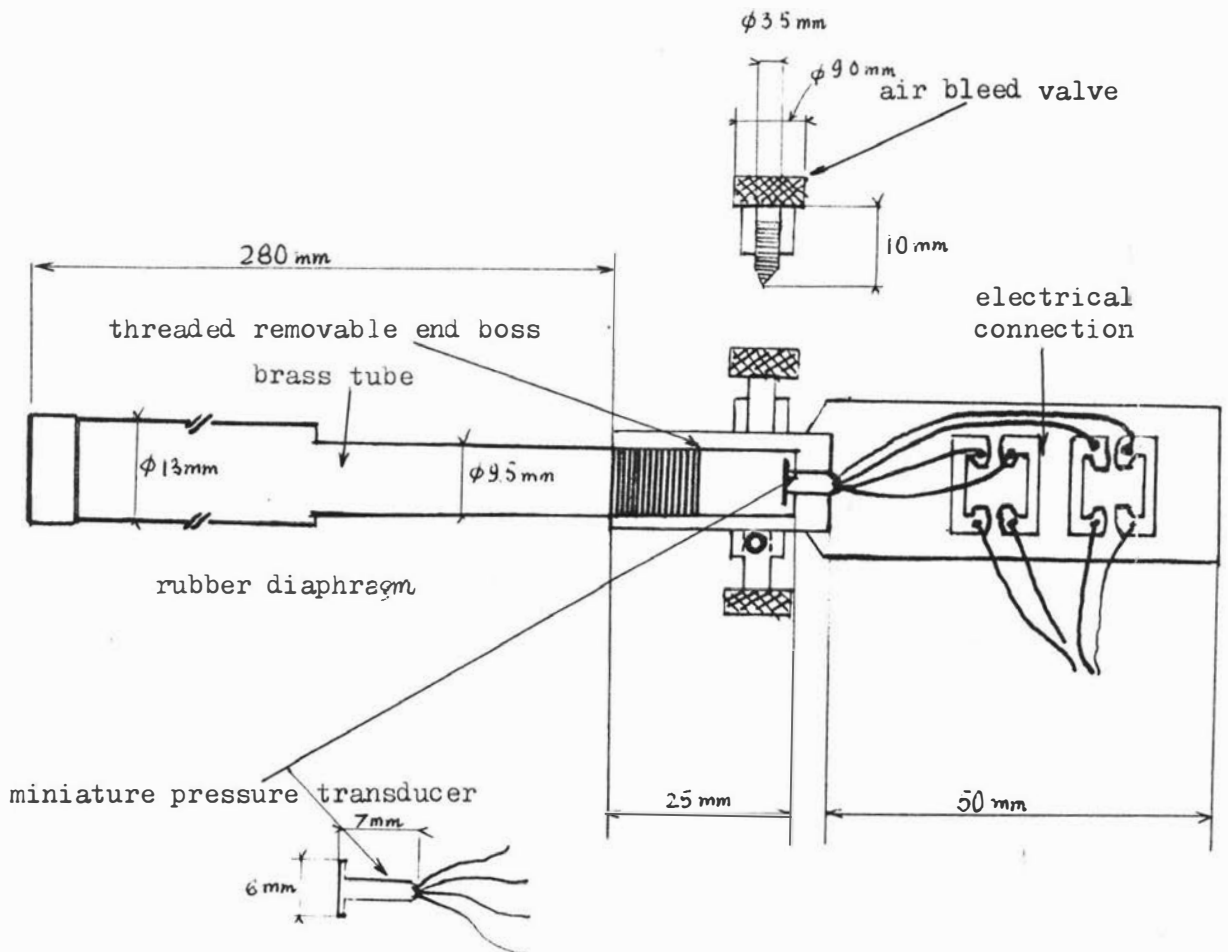
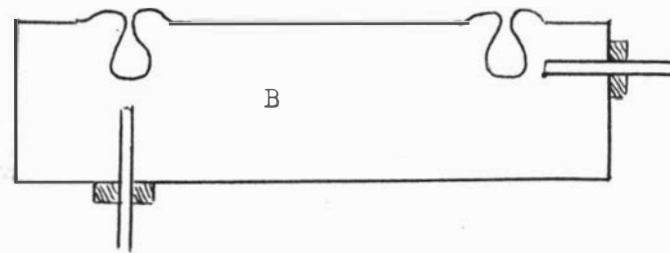
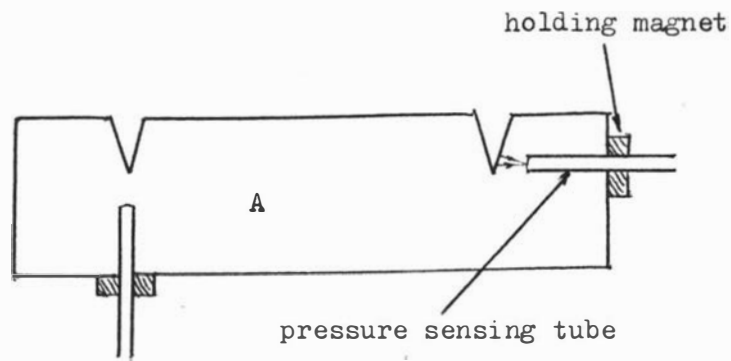


Fig.13.Soil pressure sensing tube assembly.

Six (17.5mm ϕ) holes (four through the sidewall and two through the base of each steel bin) were drilled prior to filling the bins with turf blocks from the field. Once filled with the turf blocks, small diameter pilot holes were drilled through the soil from the holes in the walls and base of the steel bin. These holes were then enlarged to accommodate the pressure tube devices. (figure 14)

Just prior to drilling, a pressure tube was inserted and securely held by its magnetic clamps. (figure 12). After the passing of each coulter (during which time continuous recording of stress was made), the same procedure was repeated for the next reading. In this way, the number of sensing devices required was reduced. This procedure could even be used to obtain several readings in a single row by stopping the coulter travel and moving the sensing tube to another position ahead, in sequential steps. The signals from the pressure tube were amplified through a microvoltmeter and traced on a chart recorder.



end elevations

Fig.14. A:the position of the pressure sensing tube in the groove created by the triple disc couler.
 B:the position of the pressure sensing tube in the groove created by the chisel couler.

2.3.4 The assessment of macrostructural changes by visual methods

2.3.4.1 Materials and Methods.

The aerial components of herbage and organic debris which are left after the passing of a drill coulter were carefully removed prior to the introduction of liquid air to the surface of drilled grooves and also into the grooves. Small quantities of liquid air (50mls) were repeatedly introduced in the above manner until frosts appeared, indicating the soil was adequately frozen and therefore rigid enough to be excavated. Frozen soil blocks were then isolated from the surrounding soil by a sharp knife and scalpel and were marked to indicate their orientation in relation to the drilled grooves. They were wrapped in plastic bags for protection and kept in a vacuum flask for transportation to the laboratory.

Study of the soil samples in the laboratory was by one of the two following methods:

- (a) Thin sectioning
- (b) Electron microscopy

a. Thin sectioning.

Frozen soil blocks were trimmed to a rectangular shape having the approximate dimensions of 3cm³. These were transferred to a drying room at 27°C and left to air dry for 72 hours. After drying, the blocks were carefully transferred to a vacuum impregnation apparatus (fig. 15b). This consisted of a glass cylinder, connected by means of a three-way cock to a water jet vacuum pump which provided a negative pressure of 15-20mm Hg.

An air-tight packing flange, onto which could be fitted various glass cups for the impregnation process, was in contact with the lower end of the cylinder.

Impregnating.

The impregnation resin, which was a mixture by volume of 8 parts of Epofix" resin ^{*} and 1 part of "Epofix" hardening liquid was passed into a disposable cup and mixed by stirring with a disposable spatula. The soil specimen was placed on a piece of cardboard and affixed to the cup wall one third of the distance from its top. The cup was then filled to just beneath the cardboard with "Epofix" mixture and placed on the packing flange. Figure 15a illustrates the arrangement at this stage.

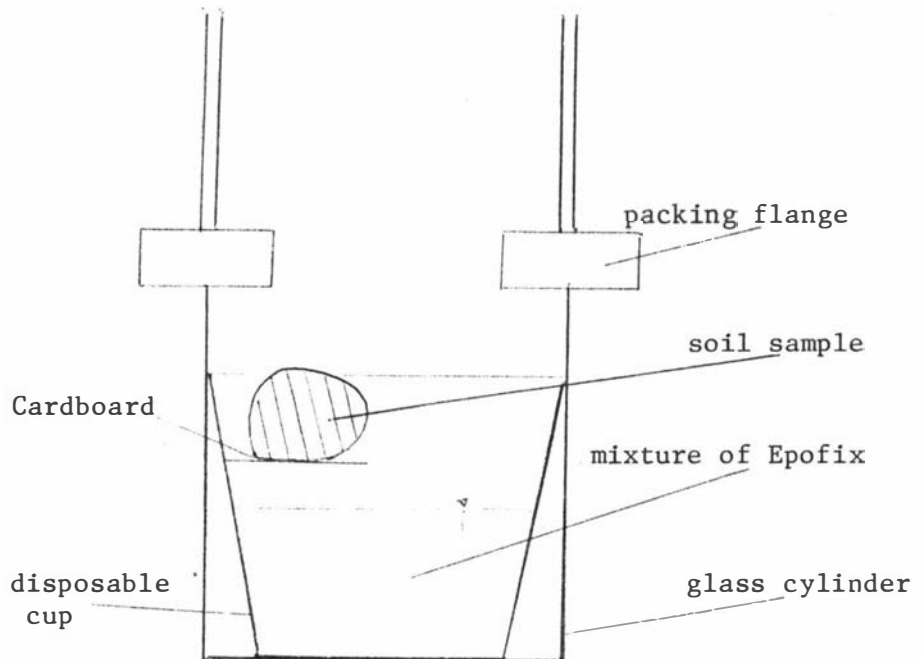


Figure 15a: The arrangement of a soil specimen in the glass cup.

* Manufactured by Struers, Denmark.

(Specifications given in Appendix 10).

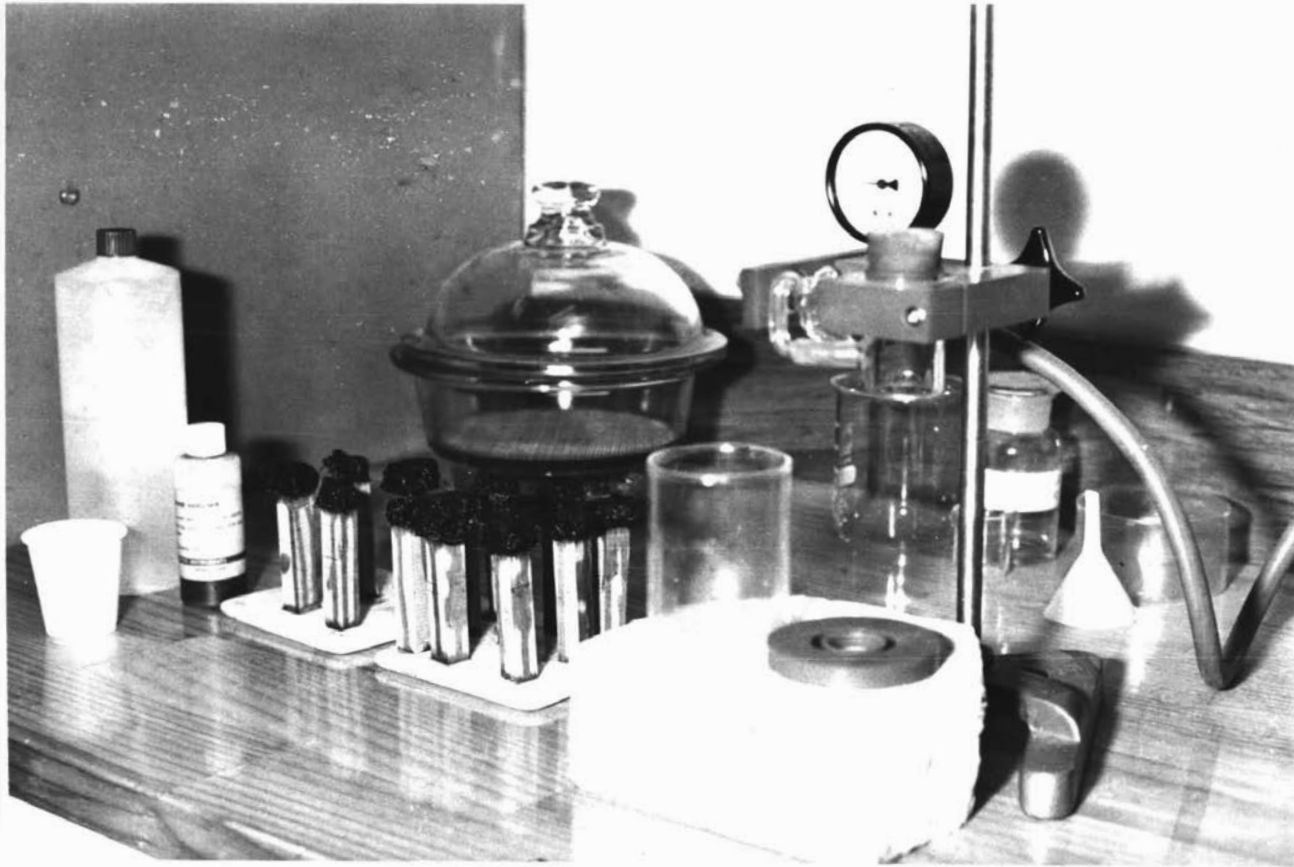


Fig.15b. The impregnation apparatus. Impregnated soil samples were mounted on wooden pegs on the left hand.

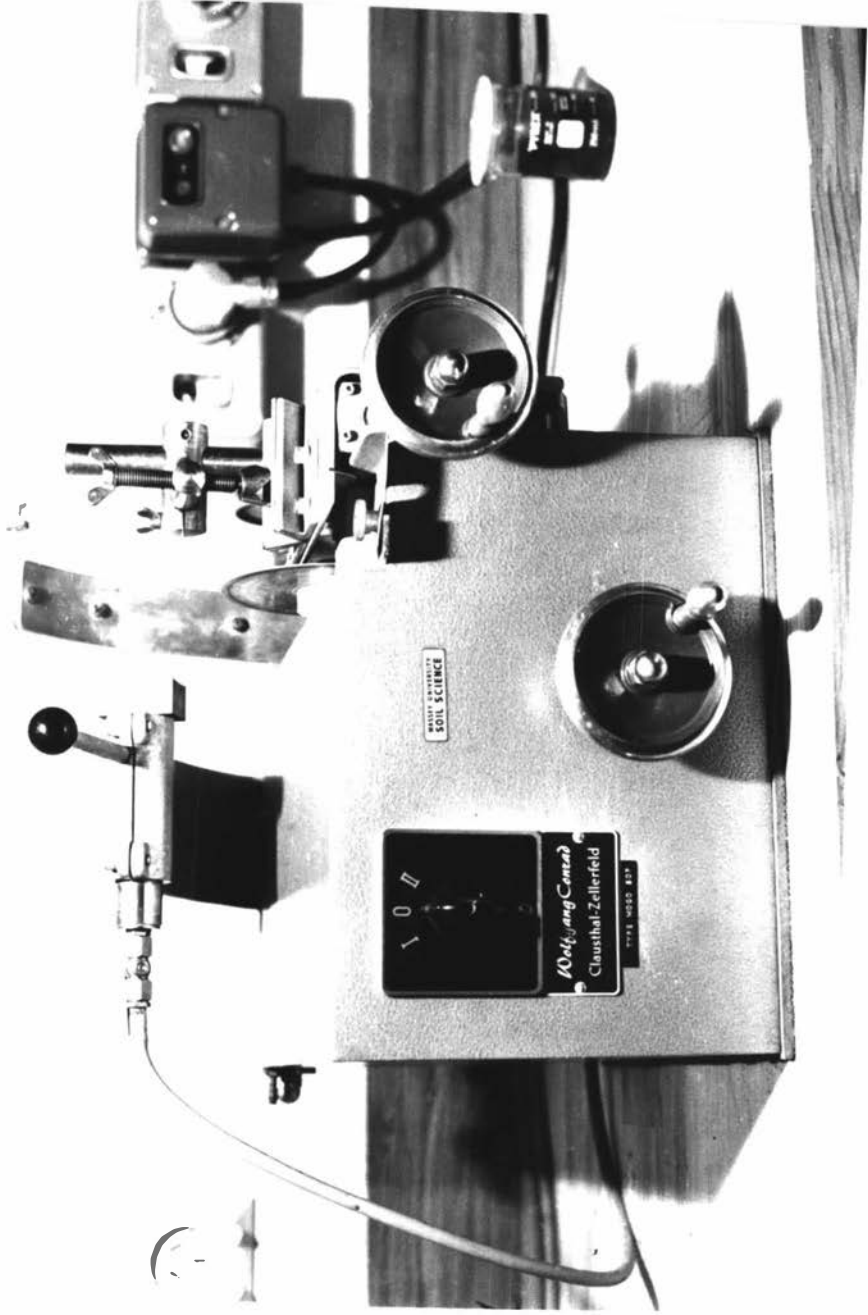


Fig. 15c. The diamond saw for thin sectioning soil samples.

Any air trapped in the cylinder and soil specimen was removed by evacuation of the impregnation apparatus which had been closed and sealed. The specimen, which was then under vacuum was tipped into the disposable cup so that it was completely immersed in "Epofix", by gently tilting the whole apparatus to one side.

With subsequent introduction of air through a three-way cock, resin was forced into all open cavities. The specimen became impregnated and was removed from the "Epofix" after forty seconds. The specimen, at that stage still wet, was then glued onto a 25mm x 25mm x 80mm piece of wood and left to air dry for 72 hours.

Sectioning.

Full strength hardened soil specimens were sliced using a 80mm diameter diamond saw, operating at 4000 rpm. (fig. 15c)

Three soil slices of 2mm thickness, 10mm apart were cut for each of the chosen specimens. With the use of the diamond saw, slice thicknesses of 1 to 5mm were possible, but a 2mm slice was preferred for examining with standard photographic techniques.

b. Electron microscopy.

Small soil samples of 3mm^3 were either taken directly from the direct drilled grooves using scalpels, or from frozen samples using the method described above. The cube samples were placed in labelled containers depicting their orientation and positions in the grooves and kept in a desiccator. Prior to coating with gold each 3mm^3 sample was fractured. Extreme care was exercised while choosing a smoother surface of the sub sample and while mounting it on a stub, artificially loosened particles

were removed while naturally loose particles were retained where possible. Four such sub samples were mounted on one stub and marked before being examined under an electron scanning microscope.

2.3.5 Draft Measurements

In this study attempts were made to compare the draft forces developed by two direct drilling coulters designs. The two designs contrasted in their actions within the soil. Because of this, direct measurements were felt to be important as support data for the direct measurements of soil parameters described earlier. The two coulters chosen were the commercially available triple disc coulters Koronka (loc.cit) and an experimental chisel coulters Baker (loc.cit). A brief description of these coulters is given in appendix 9.

2.3.5.1 Draft force measurement apparatus.

The draft measuring instrumentation was designed to be attached to the slightly modified tool testing apparatus developed by Baker (loc.cit). The basic tool testing apparatus consisted of an inverted stirrup shaped moving gantry which straddled a series of tillage bins on a raised support bed. The special facilities provided on the gantry for draught force measurement in this study are described below:

A horizontal rectangular subframe is mounted beneath the upper horizontal member of the gantry. The method of mounting uses four pairs of sealed roller bearings placed above and below the machined faces of both ends of the subframe so that the entire frame can move horizontally fore and aft with minimal frictional drag (fig. 16). A vertical rectangular frame with three pairs of trailing parallel arms (for coulters attachment) is pivotally attached to the end of the horizontal rectangular frame. It can be angled 20° either side of the vertical position by two threaded adjustment shafts which complete the triangular mounting.

At the trailing end of the horizontal subframe, mountings are provided on both sides for insertion of a standard strain gauge load transducer. * A screw adjustment block is interchangeable with this load cell and is used at the other end for alignment purposes and for pre-loading to ensure good contact between the subframe and load transducer.

When measuring draught force, the pair of trailing arms which are attached to the centre of the vertical subframe (fig. 17) are usually used in preference to either of the two trailing arms alongside, to avoid the necessity for corrective calculations due to the lack of symmetry.

Vertical components of draught were considered to be isolated by the use of parallel trailing arms which were adjusted to be horizontal when a drill coulter was in operation, and by the roller bearing mounting of the horizontal frame.

Signals received from the transducer are amplified and fed to a chart recorder. The speed of chart paper was set at 0.18 X the speed of the testing rig. The mean draught is calculated from the area bounded by the recorded curve and any two convenient ordinates. The calibration curve was obtained by dead load tests and is shown in appendix 6.

* Kyowa model LU1TE

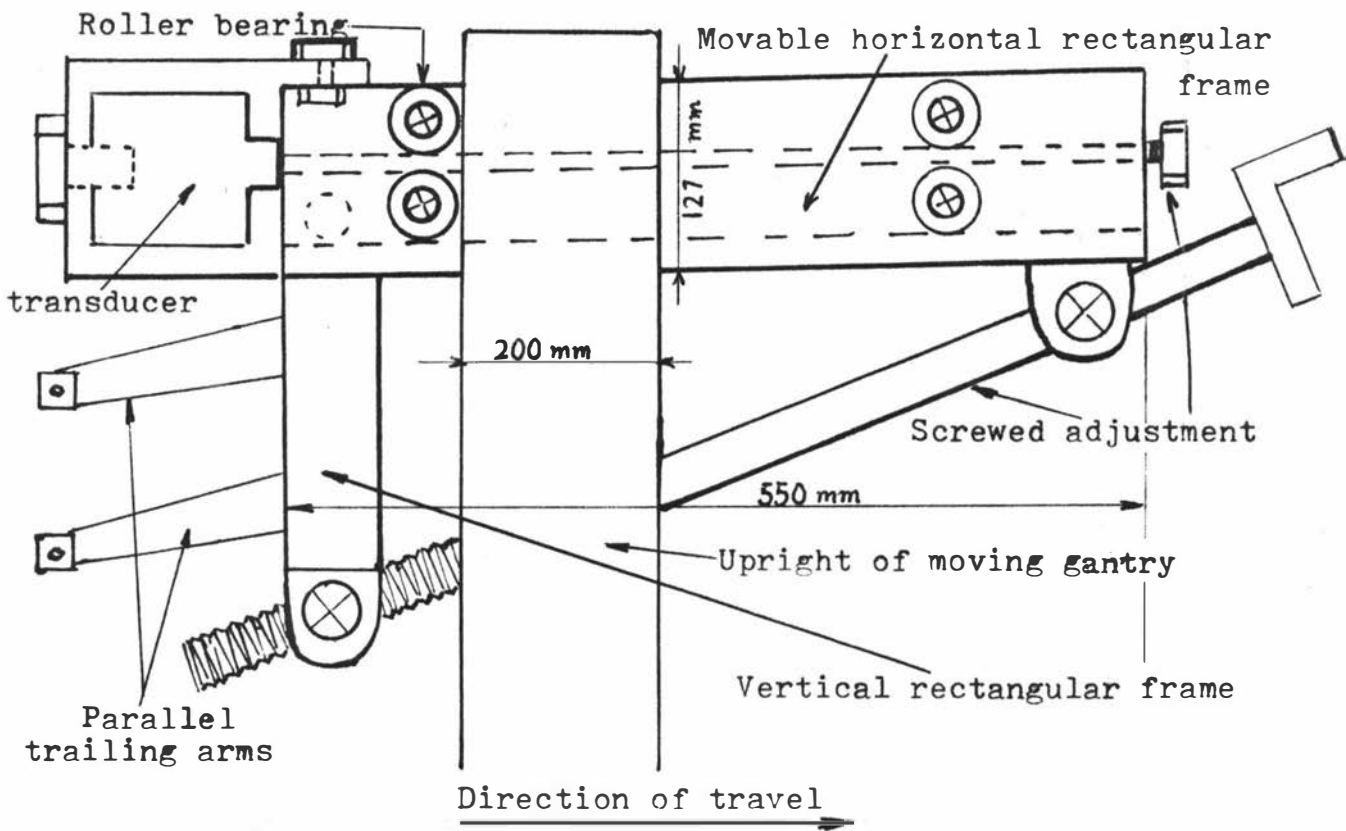


Fig.16. Side view of draft measuring apparatus

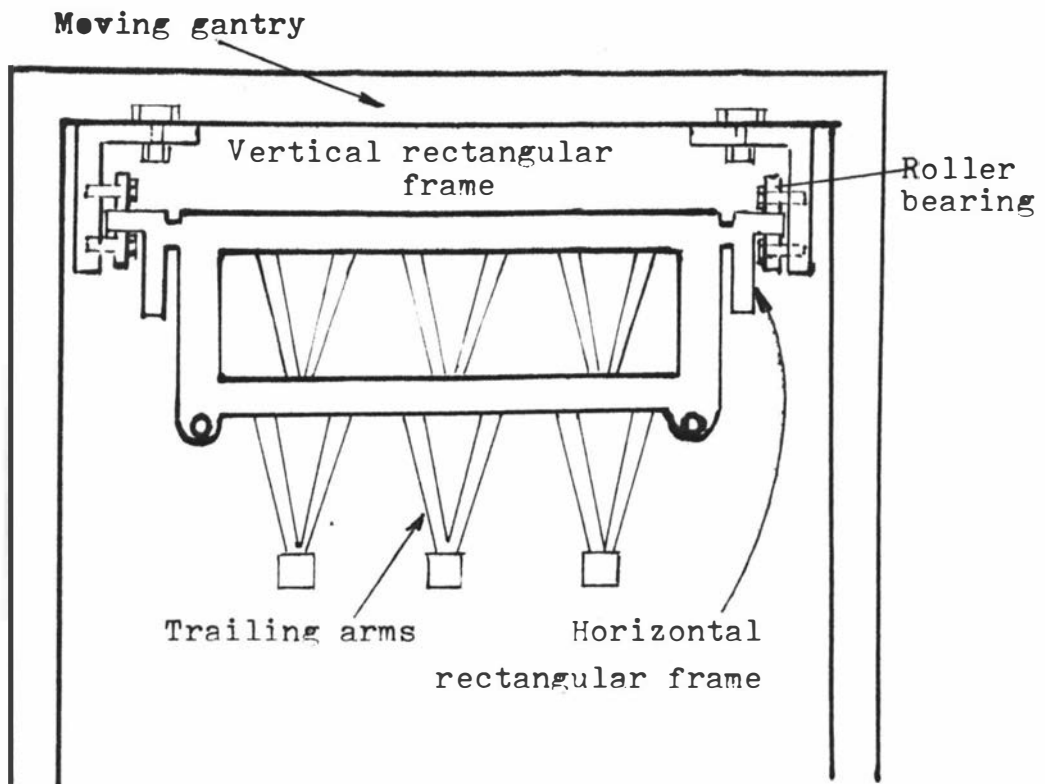


Fig.17. Rear view of moving gantry and tool testing apparatus

2.3.5.2 Procedures.

Draft measurements were taken at the same time as the apparatus was being used to drill seeds into the soil bins. Penetration of individual coulters (which was controlled by depth wheel at 35mm) was provided by weights loaded on top of the coulter assembly (fig. 18). Variations in depth due to the unevenness of the soil surface on which the depth wheels travelled were unavoidable but were considered to be only of minor significance. Measurements indicated that depth varied between 35 to 40mm.

A very slow forward speed of 1m/min with the tool testing apparatus was chosen to permit observation of seed placement and to facilitate the various measuring operations which took place while the coulters were passing through the bin. Greater speeds could be expected to alter the dynamic properties of the individual coulters but such speeds would also have been expected to introduce soil inertia as another variable. While consideration of this variable is understandably important, accurate measurements of its extent or influence was beyond the scope of this study.

2.3.6 Assessment of the zone of disturbance at the soil surface.

To gain some understanding of the extent of the disturbed zone at the soil surface within the bins during the passing of any one coulter, a simple displacement instrument was developed. (fig. 19) The apparatus consists of a 90mm long cylindrical probe of 1.5mm diameter which is inserted 50mm deep into the soil at a preselected distance from the anticipated path of coulters. An unstretchable thread, which was also insensitive to humidity, was attached to the top of the probe and was passed over a 40mm diameter pulley. The free end of the thread was

attached to the moveable magnetic core of a displacement transducer. Horizontal displacement of the probe (through soil displacement) caused displacement of the core, thus inducing an electrical signal which was fed through a converter to a chart recorder. By placing probes at predetermined distances from the anticipated centreline of the drilled groove, the extent of soil disturbance could be observed.

Results obtained by this method were not considered to be quantitative as only the horizontal component of disturbance of the needles was measured. They were however of value as indications of the magnitude of the disturbed zones at the surface of the soil in the bin. Interpretation of this data was subject to the sensitivity of the instrument, which was not high, but the technique was useful in seeing if, for example, the influence of one coulter had extended beyond the mid point of the inter-row space.

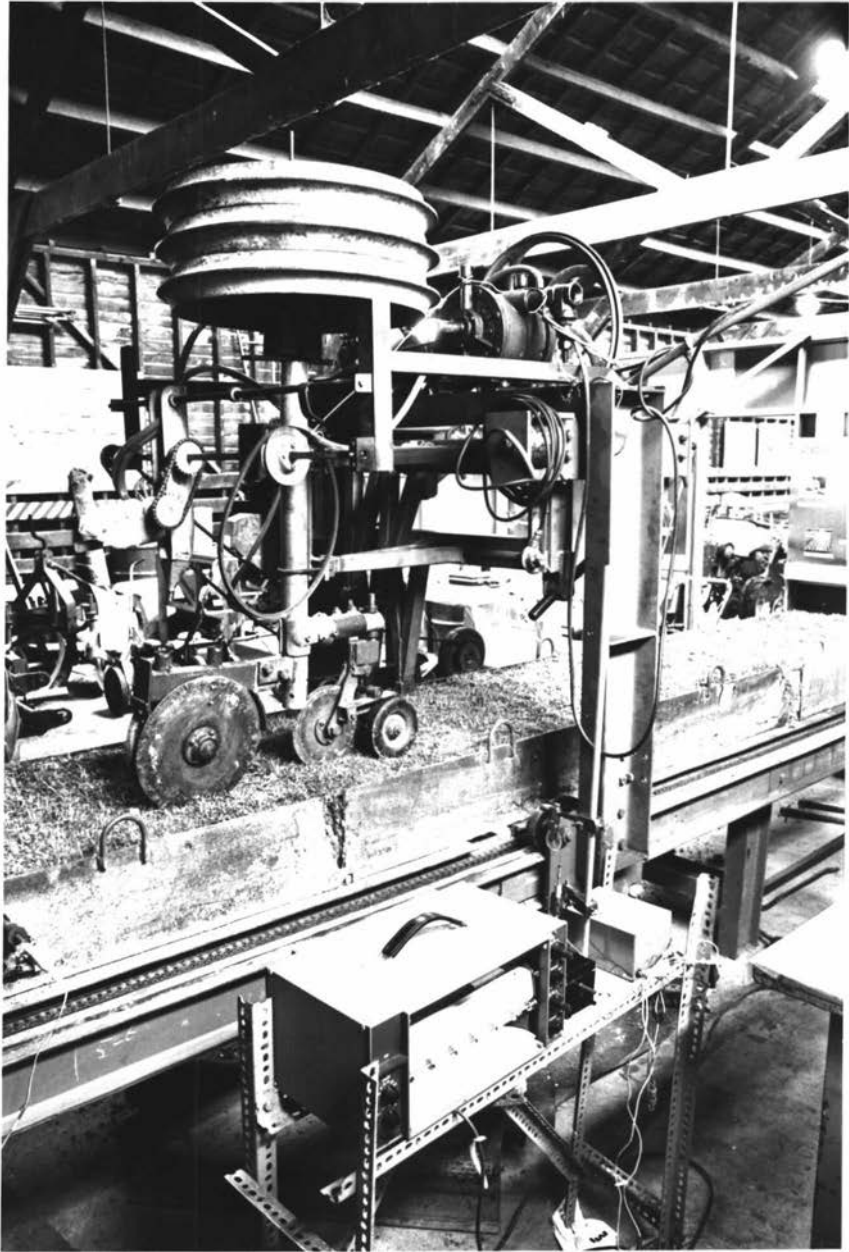


Fig.18.The vertical penetration force obtained by
dead load.

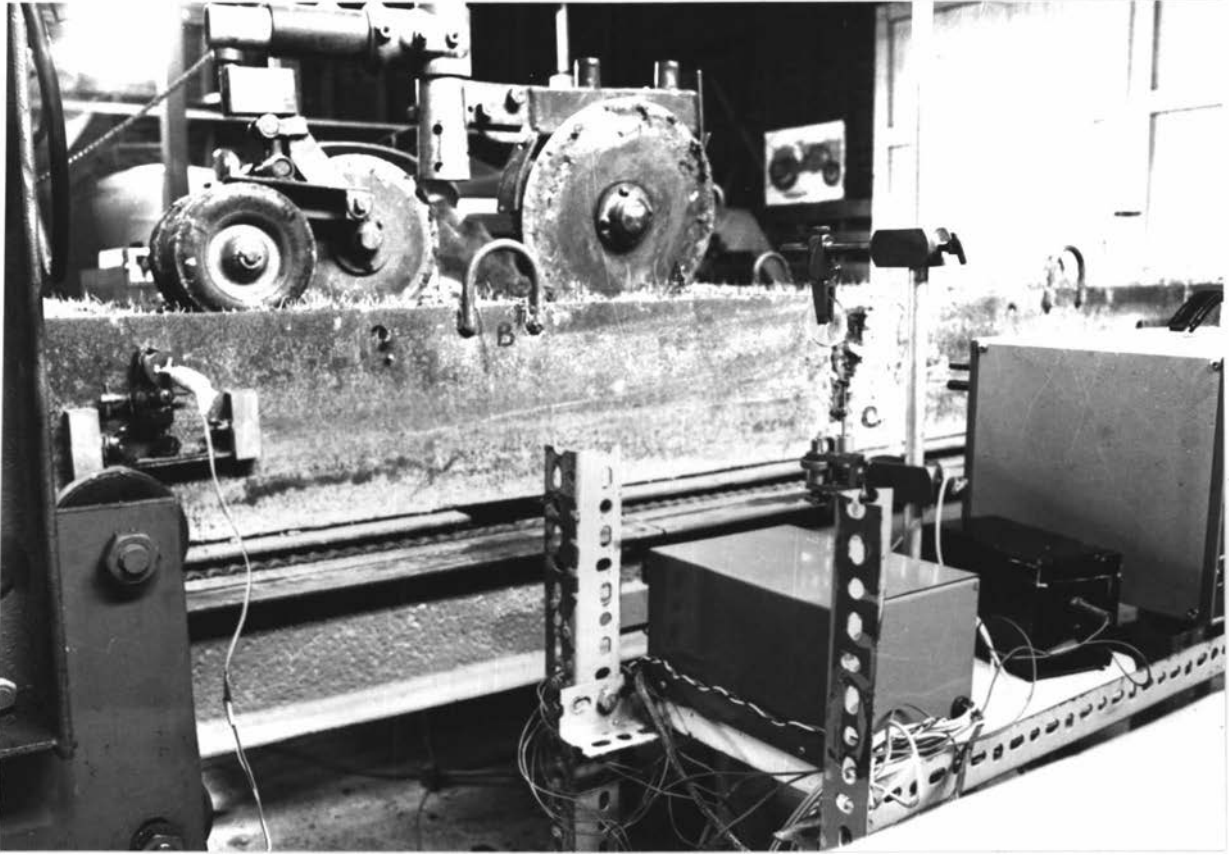


Fig.19.The instrumentation for monitoring the zone of influence around coulter (A)and the disturbance zone on the soil surface,(B)the probe,(C)the transducer.

3. THE RESPONSE OF PLANTS AND ROOTS TO CHANGES IN SOIL
 PHYSICAL CONDITIONS AT SEED LEVEL

3.1 INTRODUCTION AND REVIEW.

Although the literature reveals studies of the effects on root growth of each major physical property of soil in isolation, less importance seems to have been given to the interdependence and interactive nature of these properties. A survey of 93 reports in the literature since 1960, on the subject of the effects on root growth of soil bulk density, soil strength, mechanical impedance and liquid and gas status, has shown that in approximately 30 papers the emphasis was on the effects of bulk density on root growth; 40 papers on soil strength or mechanical impedance; 8 papers on soil pore spaces or pore size distribution, and 15 papers on liquid and gas status.

In 60 English language papers, dealing with all aspects of direct drilling since 1960, most of the work appears to have originated in U.K., particularly during the period of 1970-1976. Other countries, for example U.S.A., Netherlands, Germany and New Zealand, have also made substantial contributions.

A summary of the inter-relationship of soil roots is given in the flow diagram shown in Fig. 20 which was compiled from a review of 91 reported studies, 63 of which were in part concerned with direct drilling.

Apart from the genetic character of the plant, soil factors such as moisture, temperature, aeration and soil strength considerably influence root growth. Carns (125) reported that insufficient anchorage

frequently resulted from mechanical impedance to root growth. Roots were also found flattened or growing in a distorted manner when they encountered severe restraints.

Under extreme conditions the root might grow in a small pocket until that was filled, with the result that the roots became severely distorted. Branching of roots was also less when they encountered impedance and the roots were often thick and shortened. (126)

In direct drilling, the early growth of cereal roots was reported to be usually restricted in their distribution down the soil profile. (127) 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.

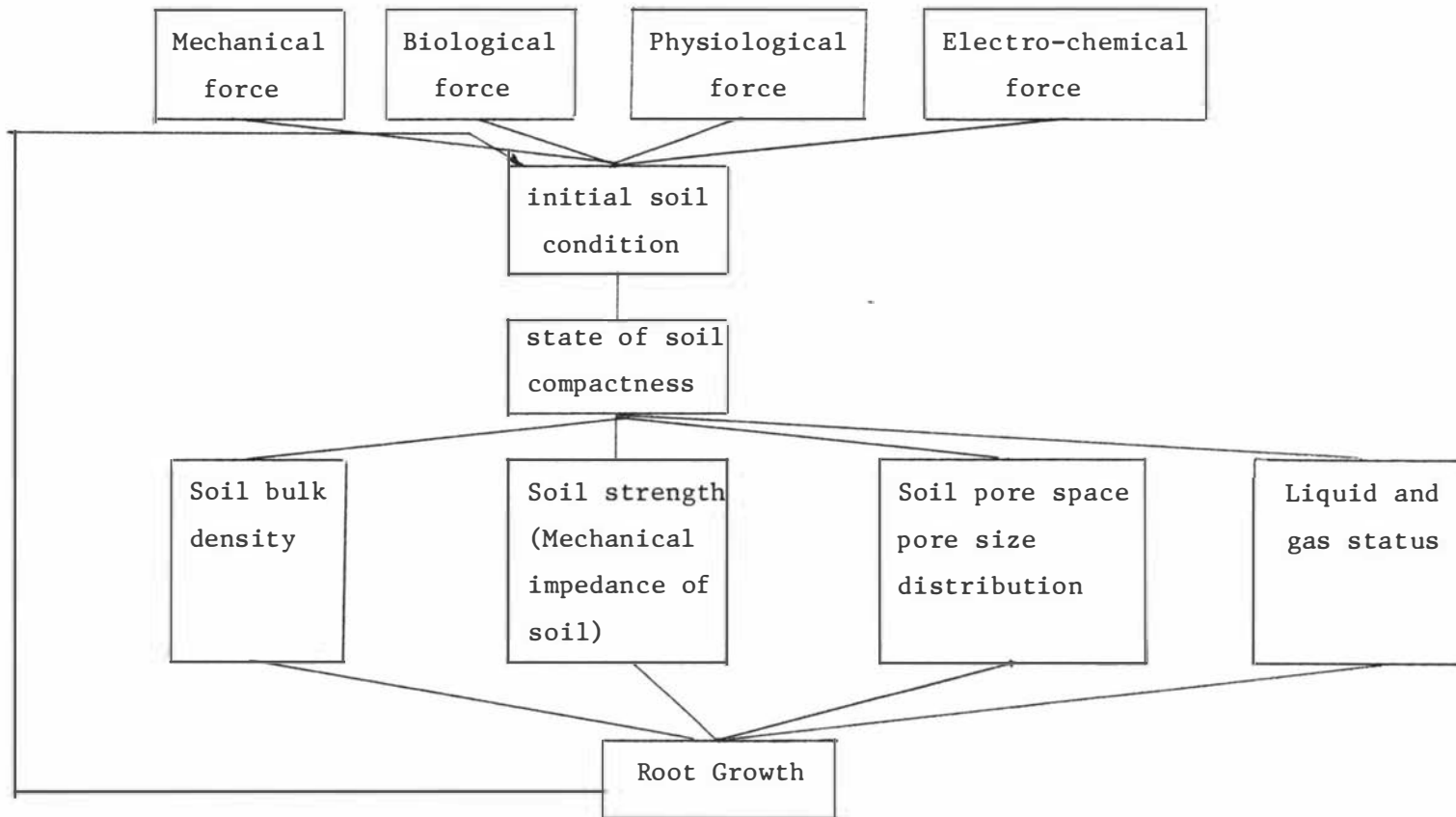


Figure 20: The inter-relationships of soil physical parameters and root growth under compaction.

3.1.1 The effects of soil bulk density on root growth.

Bulk density and pore space are the most common indices of soil compaction. Numerous research reports have shown that where an increasing soil bulk density was associated with a decreasing porosity a decrease in root growth usually resulted. (7,8,9) However, roots of different species have shown varying abilities to penetrate soil of different bulk densities (128) and different types of clays. (7,11,4) Roots of "common plants" were found impeded in soil of bulk density 1.9 g/cm^3 (131) and could not penetrate a silty clay of 1.5 g/cm^3 (131,132).

Although there do not appear to have been reports in the literature relating to lupin and wheat crops specifically in their responses to soil mechanical impedance and soil bulk density, reports on the effects of soil compaction with other species may have some relevance and are therefore reviewed.

Phillips and Kirkham (9) noted that the rate of corn seedling root elongation was decreased with increased bulk density and with decreased depth of penetration. The rate of elongation was found to decrease linearly as bulk density of clay increased from 0.94 g/cm^3 to 1.30 g/cm^3 . Branching of tomato roots was found to have been restricted to the top 25mm in pots of soil compacted to a bulk density of 1.7 g/cm^3 while they extended to the 100 to 150mm layer when the bulk density was 1.40 g/cm^3 . (134) Maximum rice seedling root growth and penetration occurred when soil bulk density was 1.6 g/cm^3 . A subsequent increase in bulk density above this level decreased root growth. (135) These authors also introduced an index called penetration pressure. The critical value of this index, which equated with 1.6 g/cm^3 bulk

density, was 36 Kg/cm³.

Compacted zones in the furrow bottom after mouldboard ploughing have been found to impede root penetration in many crops (136,137), but roots were able to penetrate the furrow bottom of a fine sandy loam if the bulk density was less than 1.76 g/cm³. (138)

Uncultivated soil was reported to be denser and firmer than cultivated soil. (66,33) The overall compaction caused by natural or mechanical sources may have been greater with uncultivated soil but it has also been pointed out that channels left by dead, decaying roots and by earthworms may have facilitated root elongation. (65) Goss and Drew (139) suggested also that even when roots were impeded, absorption of nutrients and shoot growth may not have been affected.

In the direct drilling situation smearing of groove walls, incomplete groove closure and water logging had been noticed with a triple disc coulter. (66) Wilkinson (27) also suggested that an induced smear and compaction of the groove sides, particularly after drilling into soil of plastic consistency, may have increased surface compaction which affected the bulk density and mechanical strength of the soil at the interface. However, no corresponding root growth results were reported in either of the latter studies.

Baker (68) and Dixon (103) suggested that localised compaction at the bottom of the groove, which was created by some direct drill coulters may have affected root growth but again no quantitative data was given to support their observations.

3.1.2 The effects of mechanical soil strength on root growth.

Extensive work has been undertaken to investigate the effects of increased soil strength on root growth and development. From the experimental data reported, it is apparent that several different approaches have been adopted in search of an understanding of mechanical impedance as it affects root exploration.

Pfeffer in 1893 (128) was probably the first to study the maximum pressure that a growing root could exert on the soil and reported that this was in the range of 5-12 bars.

Eavis et al. (23) found average axial root growth pressures of cotton (*Gossypium hirsutum* L.) and pea (*Pisum sativum* L.) were 11 and 12 bars respectively. They also reported that root growth pressure was influenced by ambient oxygen concentrations.

The above results were reportedly obtained in an atmosphere of 21% oxygen and at $-1/3$ bar matric potential. Root growth pressures of peas were similar at 8% and 3% oxygen but the 3% oxygen level reduced the root growth pressure of cotton to 5 bars.

An unbonded strain gauge force transducer was used to measure cotton, pea and peanut root growth forces (35). It was found that root growth pressure averaged 9.4, 13.0 and 11.5 bars respectively, but the values varied widely within each variety. These findings confirmed earlier findings of Taylor and Gardner (128) who also reported that the root penetrating ability of legume roots was not significantly greater than those of non legumes.

As a means of assessing resistance to root penetration the pressure experienced by a penetrating probe could not be considered as equivalent to that experienced by the actual growing root according to Barley et al. (123). Even if the probe was made to resemble the root shape, other characteristics could not be simulated, because of :

- (1) The capacity of the root apex to deform in response to external pressures.
- (2) The ability of the root to curve round obstacles.
- (3) The lubricating effects of the root cap.

Greacen (14) reported that Eavis had suggested that the growth force was less than $\frac{1}{4}$ of the force opposed to a fine cylindrical metal probe in a weak soil and less than $\frac{1}{8}$ of that opposed to the probe in strong soils. Barley and Greacen (123) described how estimations of the mechanical resistance must be based on a type of deformation produced by the plant root and this would determine both the soil properties to be measured and methods of measurement.

Nevertheless, the mechanical impedance in soil has usually been characterised by the results of penetrometer studies.

Taylor and Gardner (loc.cit) measured the strength of the soil surface by a force-gauge static penetrometer, and reported that no roots penetrated core samples of soil strength greater than 30 bars.

Taylor et al. (116) also found that no cotton roots penetrated a "Samarillo" soil (silty loam) with soil strength greater than 25 bars as measured with a force gauge static penetrometer. Their further work on the relationship between soil strength and cotton root penetration through soil materials with different textures confirmed previous findings

and claimed that root penetration was reduced drastically as soil strength increased to 25 bars. There was no root penetration when the soil strength was greater than 25 bars, regardless of soil type. Carp et al. (13) gave a critical value of soil strength of 22 bars, above which no cotton root penetration was expected.

Other groups of researchers believed that an understanding of a minimum applied pressure which may have reduced root extension was of more importance. However, major difficulties arose because an increase in the strength of soil (compaction) was felt likely not only to alter its mechanical resistance to root penetration, but it was also often associated with an altered solid-liquid phase in the soil structure.

Gill and Miller (99) claimed that an applied soil stress of 5×10^6 dynes/cm² was necessary to retard root elongation.

Barley (21,140) applied stress to elongating roots by using a flexible membrane and found that a stress of 4 to 5×10^6 dynes/cm² was necessary to retard root growth. He further suggested that this finding did agree with the proposition that cellulose expansion of root exerted a pressure of 1/10 of imbibitional pressure.

Barley (142), and Barley, Farrell and Greacen (140) again found that a stress of 6×10^5 dynes/cm² caused retardment of root expansion. In further experiments of Barley and Greacen. (123) they indicated that the mature root of maize, when undergoing cellulose expansion, was capable of exerting a maximum pressure of $5-10 \times 10^6$ dynes/cm².

Goss and Drew (139) studied the effects of mechanical impedance on the growth of seedlings, and found that when germinating roots and

shoots had to exert very small pressures, their rate of elongation was slowed down.

Another group of researchers investigated the capability of roots to decrease their diameter in order to penetrate pores which could not be readily expanded but were of smaller cross-sectional areas than the roots. The work of Wiersum (20), Aubertin and Kardos (165) Scott - Russell, Cannell and Goss (45) all provided a clear negative answer to this problem. The latter authors claimed that roots were incapable of decreasing their diameters to enter pores narrower than themselves and instead suggested that the rate of extension of roots was much reduced if they had to resist a small pressure to expand the pores. A presence of 0.2 bar was apparently sufficient to reduce the elongation by 50%.

The mechanical resistance of direct drilling soil between rows was reported to be five fold greater than similar cultivated soil. This could help explain root growth data obtained by Ellis and Elliot (65) as they found that the elongation of seminal roots was slower after direct drilling than after conventional cultivation.

Perhaps the most helpful guide to root penetration as affected by soil conditions was given by Eavis et al. (loc.cit) who completed the following table.

TABLE 2: Values of probe pressure at which root elongation ceased.

Eavis et al. (loc.cit)

Plant	Soil Texture	Soil suction (bar)	Soil density (g/cm ³)	Soil pressure (bars)	Reference (number in the bibliographies)
Corn	Clay	.01-0.1	0.9-1.3	8	35
Cotton	Fine sandy loam	0.2-0.7	1.55-1.85	34	114
Pea and	loam	0.3-0.7	1.5-1.7	36	140
Wheat	loam	0.3-0.7	1.5-1.7	36	140
Pea	Sandy loam	0.05-0.2	1.1-1.7	33	141
Corn				18	142
Corn and Soya bean	loam	0.15-8.6	1.0-1.8	50	143
Cotton	loam			25	144

3.1.3 The effects on root growth of the interactions amongst soil moisture, soil compaction and soil strength.

"Given that other soil physical factors are favourable when soil is compressed, the total pore volume is reduced". This statement (114) was particularly true with pores the diameters of which were comparable to the root axes. Thus, this author concluded that an inverse relationship between bulk density and the ease with which root penetration could occur in any one soil was to be expected. Similarly as a soil was compacted, resistance to penetrometers and restriction of roots could both increase in a related manner.

Barley and Greacen (140) stressed the importance of soil water potential in determining the ability of roots to penetrate compacted soil. However, recent findings by Greacen and Oh (146) suggested that this aspect may have been important only when the potential was low.

Reduction in the percentage of air filled pores when water content of soil was high may have resulted in lack of oxygen and the accumulation of toxic substances (including ethylene) which may have had detrimental effects on root growth. (145)

Hopkin and Patrick (161) found that compaction and oxygen content interacted in their effects on root penetration. At the highest compaction levels, or at the lowest oxygen content, they found that little or no penetration occurred.

Crossett et al. (164) reported that, the rate of root extension of a number of species was markedly reduced also by concentrations of ethylene of less than 1ppm in soil air. However, they speculated that ethylene at these concentrations may not have reproduced all the symptoms of water logging, such as injury to shoots.

3.1.4 The effects of direct drilling on crop yield.

There have been reports investigating yields produced by direct drilled crops and more conventional cultivation techniques. However, the yield results of direct drilled crops were not consistent and varied from superior (154,155) to equal or less than (156), compared to other conventional techniques.

Davies et al. (158) made a review on reduced cultivation and direct drilling in U.K. and suggested that yields varied with soil and weather conditions but also with agronomic experience with the newer techniques and poor performance of drills.

To support this view he further reported that after 1970 the mean yield of direct drilled winter wheat was 7% higher than earlier experiments. A similar 7% increase had also been found with winter-spring barley.

Other researchers went further to suggest that direct drilling may have required more nitrogen fertiliser to reach their maximum yield. (147) However the rate of mineralisation of nitrogen could be slower after drilling and that the nitrogen requirement of direct drilled crops may have been less after several years. (148) This highlighted the need for further research into this field. Little research, however was reported comparing yields produced by seedbeds prepared by different coulter shape treatments.

3.2 EXPERIMENTAL METHODS USED IN ROOT STUDIES

Extraction of samples for root studies from both field and bin soils used shovels, spades, sharp knives and pinboards. A pinboard was constructed of 5mm thick Perplex measuring 200^{mm} x 300^{mm} with pinholes in a square pattern 10mm apart. (Fig. 21) Use of the pinboard technique was found to be of limited value because it proved difficult to retain the fine root system of young seedlings 3 to 5 weeks of age.

When sampling, care was taken to avoid disturbance of adjacent seedlings. Samples were soaked in gently flowing water for 24 hours, after which, the remaining soil was separated from the roots by a hand held fine low pressure jet of water.

Care was taken to minimise the loss of fine root material during washing.

3.2.1 Laboratory tillage bin experiments.

Twelve turf blocks were drilled with lupin and wheat seeds and placed under four rain canopies. (Fig. 5) Each turf block was then partitioned by driving a 2mm thick steel wall into the soil. This effectively isolated the two halves of the bin for different soil water treatments (wet and dry regimes).

The wheat crop was harvested at two intervals (3 and 7 weeks) in experiments 1 and 2 while the lupin crop was harvested only at the end of week 3. Lupin harvests were ceased at this time because of the possibility of root elongation being impeded by the steel base of the bin after this time.



Fig.21.Extraction of samples for root studies with perspex pinboards.

In experiment 3, both crops were harvested at the end of the third week.

Due to the limited number of emerged seedlings in some treatments (an eventuality which was not foreseen) only two or three seedlings per experimental plot were taken at each sampling for measurement of root dry weight and other parameters. It would have been desirable to be able to harvest a greater number of plants in these situations and the results reported should therefore be interpreted with some caution. The sequence of root related measurements is given in table 3.

TABLE 3: The Sequence of root related measurements.

	Wheat	Lupin
Experiment 1	Root dry weight (3 and 7 weeks)	Root dry weight and penetration. (3 weeks)
Experiment 2	Root dry weight (3 and 7 weeks)	Root dry weight and penetration. (3 weeks)
Experiment 3	Root dry weight (1,2,3 weeks)	Root dry weight, root penetration, height of aerial portion of seedlings, seedling stem diameter. (1,2,3 weeks)

3.2.2 Box experiments (experiment No. 4)

In the box experiment, lupin roots reached the base of the experimental boxes (measuring 450mm long x 300mm wide x 100mm deep) quickly. This is shown in figure 63.

Accordingly, one measurement only of root dry weight for each crop was made. This was on day 7 after sowing.

3.2.3 Field experiments (experiments 5 and 6)

The following measurements were undertaken during the two field experiments which involved all seasons of the year.

- (1) Root dry weight; at the end of 5 weeks
(experiment 5, Autumn-Winter).
- (2) Root dry weight; at the end of 3, 5 and 7 weeks
(experiment 6).
- (3) Seedling population; at 10 days and 15 days
(experiment 6)

three separate meter lengths of plant roots were randomly sampled by counting, and the results pooled.

- (4) Earthworm populations at 14 and 35 days
(experiment 6)

Soil samples measuring 140mm x 120mm x 120mm, were taken in areas which were bisected by the drilled rows in each plot. These soil blocks were broken open and the number of earthworms counted.

3.3 Seedling emergence.

Seedling emergence counts were taken for the field experiments (experiments 5 and 6) and were used as complementary data to the studies of root growth.

No attempts were made to determine germination per se; nor to correlate seedling emergence and germination counts with seedling root growth data; or to examine the effects of soil parameters on seedling emergence and germination. These studies have been adequately reported elsewhere by other workers (56, 85).

It was however felt that measurements of early seedling establishment in the field could be of some value when considering the whole plant establishment process.

Counts of seedling emergence were therefore taken in experiments 5 and 6 at different intervals during the plant growth cycle. Three separate metre lengths of row per treatment were randomly sampled for these counts.

4. THE INFLUENCE OF SOIL FAUNA IN DIRECT DRILLED SOIL.

4.1 Review.

The effects of earthworm populations in direct drilled soil have only been investigated recently. Earthworms often had a beneficial influence in soil structure by improving aeration and producing stable aggregates. (149) They brought considerable quantity of subsoil to the surface and took down decaying organic matter into soil. Moreover, they created channels which favoured root elongation and helped to improve drainage. (150,151,152 and 153) However, the problems of identifying a number of useful species of soil animals and minimising soil pests was one of complexity. In disturbed soils these animals may have included earthworms, insects, spiders, milipedes, woodlice, mites, springtails and similar insects. (152) Springgett (152) indicated that surface feeder earthworms (*Lubricus terrestris*), in contrast to subsurface feeders (*Allolobophora caliginosa*), fed by dragging the trash from the surface down into their burrows, making many deep vertical tunnels.

Edwards (134) reported that the total earthworm population was greater in direct drilled plots than in ploughed plots. These were between two and five times more surface feeder earthworm in direct drilled plots than in ploughed plots.

5.1 OBJECTIVES AND RESULTS OF INDIVIDUAL EXPERIMENTS

4.1 GENERAL OBJECTIVES.

The techniques used in the experiments can be grouped in two main categories: (a) laboratory and (b) field experiments.

(a) Laboratory experiments.

Experiments conducted in the laboratory utilised two different soil containers; tillage bins and smaller boxes.

- Tillage bins (experiments 1, 2 and 3).

Some selected soil properties, such as bulk density, soil strength and soil pressure were measured during and after the passage of direct drilling coulters under partially controlled conditions in order to identify the soil and/or seedbed properties thought most likely to effect root growth in a direct drilling situation. At the same time the development of root systems of selected plant species were measured. Close observation was made of the pattern of soil reactions to the passage of coulters of different designs.

- Box experiment (experiment 4).

These smaller "undisturbed" blocks of soil were used to investigate the effects on root growth of a larger number of seed groove exposure and smearing treatments, than was possible with the larger bins. The latter, however, was considered to be more accurate as they represented larger samples of turf.

(b) Field experiments. (experiments 5 and 6)

The objectives of the two field experiments were :

- (1) To investigate the effects on root growth of soil bulk density and different seed drill coulter designs.
- (2) To investigate the extent to which any differences in soil bulk density and root development at, or soon after sowing persisted throughout the productive life of selected plant species.

5.2 EXPERIMENT 1.

5.2.1 Objectives.

The objectives of this experiment were to gain an understanding of the different effects that a commercially available triple disc coulter and an experimental chisel coulter had on some selected soil physical properties in the soil microenvironment at seed level. The changes in soil conditions in turn might be expected to affect root elongation and root growth. The physical factors measured were those arising from (a) permanent soil deflection; which were soil bulk density (core sampling) and soil strength (penetrometer), and (b) instantaneous soil deflection; which was soil pressure (pressure sensing tubes). In addition, the draught force (load cell) of each coulter was measured.

Twelve "undisturbed" soil bins of initial soil bulk density 1.00g/cm^3 were dried to an average soil moisture potential of 0.5 bar which corresponded to a soil moisture content of 23% ww. In order that the different effects of soil drying after drilling, compared with remaining moist throughout the experiment, could be measured, each soil was partitioned after drilling, by a steel wall at the mid point. One end of the bin was kept at the moisture content at which it was drilled throughout the experimental period (wet regime) and the other end was left to air dry (dry regime).

It was felt that the effect on root growth of any localised smearing within the groove, could be dependent upon whether or not the smear dried or stayed moist. This too might interact with the coulter design according to the ability of the latter to protect the smear from drying in the first place.

Lupin (*L. angustifolius*), as an example of a tap rooted system, and wheat (Karamu) which exhibits a fibrous root system, were sown for comparison. Samples from each were taken at the end of the third week and later from wheat at the end of seven weeks.

5.2.2 Results and Discussion.

(a) Bulk density (permanent deformation).

Results Table 4 lists the soil bulk density data before drilling, and at the base of the groove after drilling, as affected by coulter design. Detailed data are also given in appendix 1.

TABLE 4: The effects of drill coulter designs on soil bulk density at the base of direct drilled groove.

	Triple Disc Coulter	Chisel Coulter	Statistical Significance of differences
Soil moisture content at drilling w/w	25%	23%	NS
Soil bulk density before drilling g/cm ₃	1.00	1.00	NS
Soil bulk density after drilling g/cm ₃	1.18	1.07	**

** P = 0.01

DISCUSSION:

From a common starting point, there appeared to be a clearly, and significantly greater increase in bulk density produced by the triple disc coulter at the base of the groove than was produced by the chisel coulter. While the absolute increase created by the triple disc coulter was only 11%, this must be viewed against an acceptable upper bulk density limit of 1.4 to 1.5 g/cm³ (or in this instance an increase of 40 to 50%), above which root growth could be expected to be retarded. (see experiment 3)

(b) Soil Strength (permanent deformation).

Results Soil strength data at the bases and sidewalls of the groove, are given in table 5. Detailed data are given in appendix 2.

TABLE 5: The effects of drill coulters designs on soil strength around the groove.

	Triple Disc Coulter	Chisel Coulter	Statistical significance of differences
Original soil strength (N)	0.372	0.353	NS
Soil strength at the base of the groove (N)	0.637	0.279	**
Difference from original soil strength	+41.6% **	-20.9%*	
Soil strength at the sidewall of the groove (N)	0.409	0.146	**
Difference from original soil strength	+9% *	-58.6%**	

* significant at P = 0.01

** significant at P = 0.05

DISCUSSION:

The data suggest that the triple disc coulter increased soil strength, at both the base and walls of the groove while the chisel coulter decreased it. Visual appraisal confirmed that soil was pulverised and disturbed at both sidewalls of the chisel coulter created grooves which contrasted with the triple disc coulter where the sidewalls appeared to be consolidated.

Measurements of soil strength on either side of the groove were also taken in an attempt to locate any possible localised compacted soil layers that may have been created at the soil surface due to the dynamic action of the passing coulters. These data are presented in Table 6 and figure 22. In addition figure 23 is included here to illustrate the variability between replicates for these trends.

TABLE 6: The effects of different coulter designs on soil strength on either side of the groove.

Distance away from groove center (mm)	Penetration force (N)				
	15	25	35	45	55
Triple disc coulter	.372	.456	.479	.485	.515
Comparison with soil strength before drilling		+.084	+.107	+.113	+.143
Chisel Coulter	.156	.190	.251	.260	.279
Comparison with soil strength before drilling	-.197	-.163	-.102	-.093	-.074

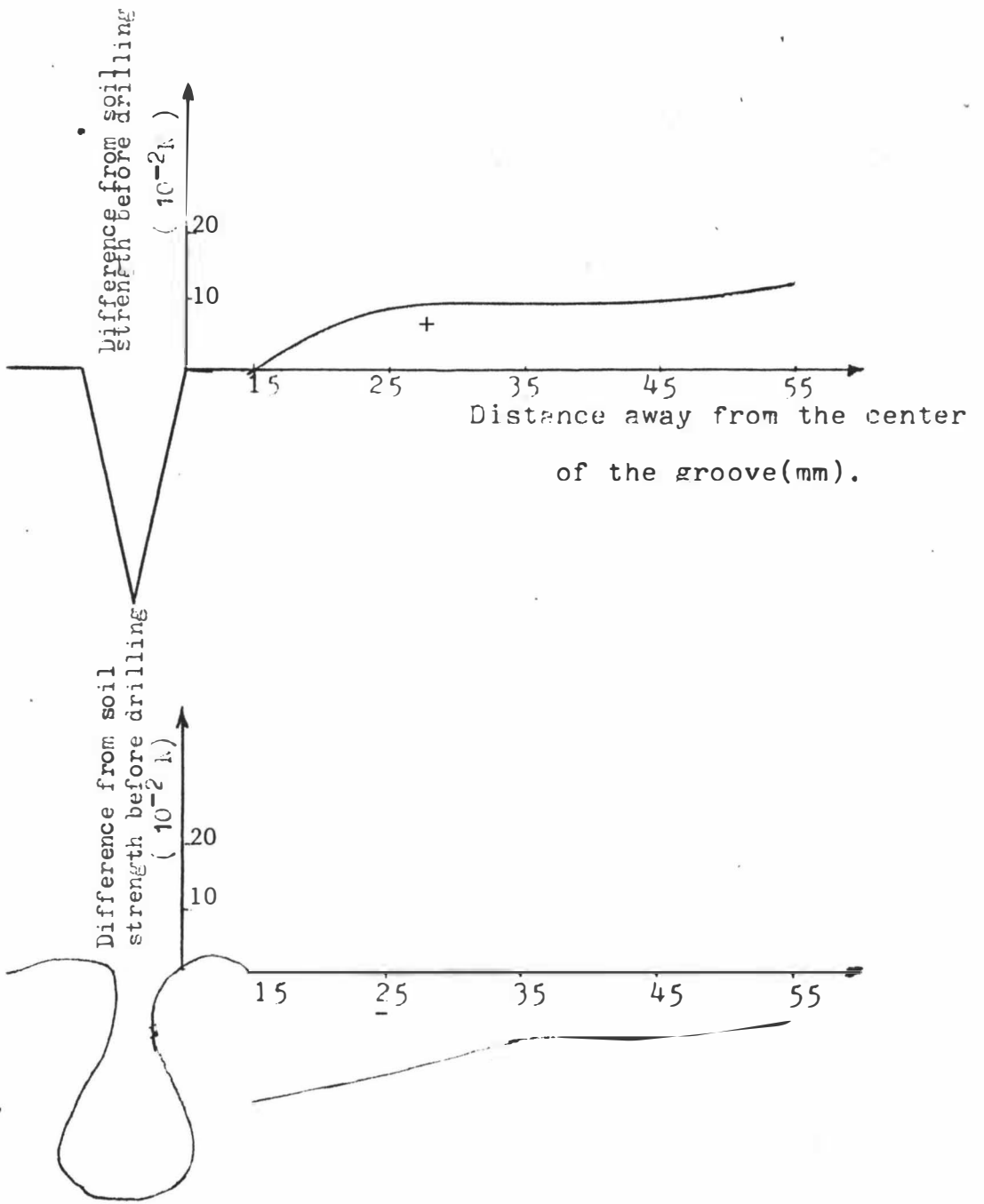


Fig.22. Soil resistance at either sides of the triple disc and chisel coultter grooves.

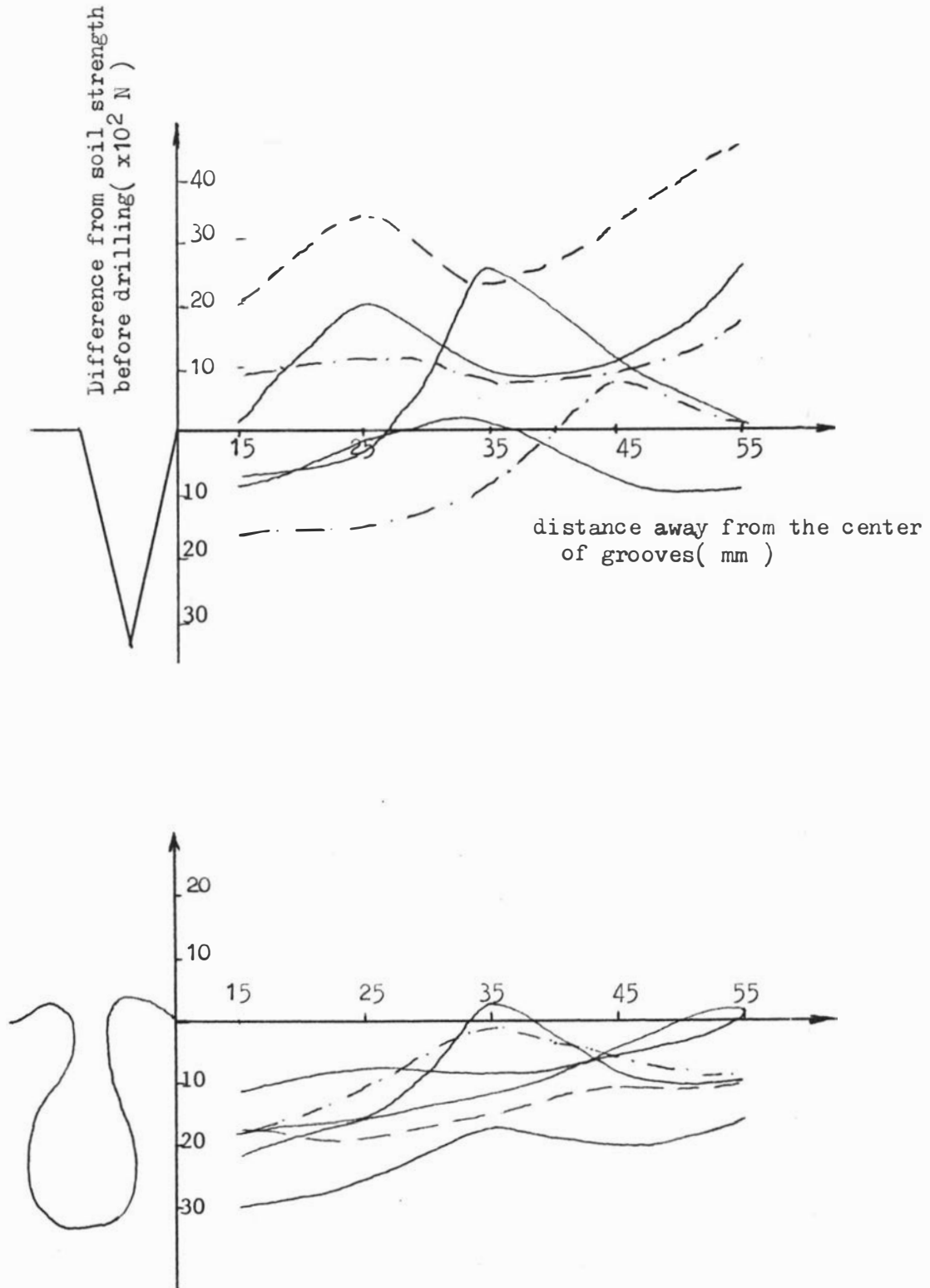


Fig.23. Variation of soil resistance at either sides of the triple disc (upper) and chisel coulters. Each curve represents one replicate.

DISCUSSION:

From Table 6 the data suggests that soil was shattered and decompacted on both sides of the groove created by the chisel coulter. This shattering effect was more visible nearer to the soil/coulter interface where soil was noticeably loose and fluffy. In contrast, the triple disc coulter produced a groove where the soil adjacent to the groove was less disrupted and of greater density than the soil before drilling. A greater proportion of kinetic energy of the passing triple disc coulter appeared thus to have been expended in consolidating soil around it than was the case with chisel coulter. On the other hand, more energy in heaving and bursting appears to have been expended by the chisel coulter. The triple disc coulter appeared to have its greatest compacting effect 55 mm from the groove centre, which is also the distance at which the chisel coulter produced its least pulverization. Surprisingly, the triple disc coulter appeared to have its least compacting influence at the closest measuring site (15 mm), although this was reflected by the chisel coulter which had its greatest pulverizing effect at the zone.

It is reasonable to view pulverizing as roughly the reciprocal of compacting, and in this respect the patterns of influence of both coulters is not unlike. The curves for both coulters also appeared to plateau between the extremes.

A complete understanding of the soil dynamics alongside each coulter path would require a study of different orientation and a background of soil dynamics. The absolute dynamic values of the parameters measured in the present study were not considered to be of sufficient importance to justify such a changed approach to the study. Rather, the comparative data obtained were considered to be of direct relevance to the agronomic implications of the drilling techniques used. Accordingly this study has utilized only the comparative data and no importance should be placed

on the absolute figures of membrane pressure or coulter loading from a soil physical viewpoint.

(c) Soil pressure (instantaneous deformation).

Results Results of measurements of the maximum instantaneous zone of influence at the base of the grooves are given in Table 7.

In this and the sidewall measurements reported later, no attempt is made to infer that the values given for stress normal to the sensing membranes are meaningful in any other context than as strictly comparative values.

TABLE 7: The effects of coulter designs on maximum soil pressure at the base of the drilled groove. (kPa)

		Triple disc Coulter	Chisel Coulter
Distance from the centre of the groove	30mm	not measured ^t	35
	50mm	116	27

t = malfunction of equipment

DISCUSSION:

Not unexpectedly, the chisel coulter appeared to exert less pressure than the triple disc on the base of the groove. Although these data were not statistically analysed they appeared to confirm the permanent deformation (i.e. bulk density) results given in Table 4.

What was perhaps unexpected was the magnitude of the difference between the two coulters. At 50 mm from the coulters the chisel counter produced approximately one quarter of the pressure produced by the triple disc coulters. This four-fold difference is difficult to explain as forces required for the two coulters differed only by two-fold (see Table 38).

The results of sidewall pressure measurements are given in Figure 24 and Table 8.

TABLE 8: The effects of coulters designs on maximum soil pressure at the sidewall of the drilled groove. (kPa)

		Triple Disc Coulters	Chisel Coulters
Distance from	30 mm	123	124
centre of groove	50 mm	69	not measured ^t

t = malfunction of experimental equipment

The maximum sidewall pressures showed no difference between the two coulters designs, suggesting that the resultants of all soil forces for the two designs were largely, vertically downwards. Soil pressures in the vertical planes were not compared.

It would be reasonable to expect the total energy input to each coulters to be dissipated in a different manner by each of the contrasting coulters shapes. In these cases the energy input was comprised of the vertical penetration force indirectly

measured from the loading weights plus the horizontal draught force. However it is difficult to explain by what means the triple disc coulter exerted four times more soil pressure than the chisel coulter when the former required only twice the penetration loading and approximately 0.8 times the draft force.

The patterns of build-up and decrease of instantaneous diaphragm pressures at the base and sidewalls of the grooves are shown in figures 25 and 24 respectively.

Both the base and sidewall pressures created by the passing chisel coulter assembly were first detected when the assembly was approximately 100 mm away from the recording position. The first peak shown on both curves for that coulter assembly appeared to record the leading disc, the purpose of which was to cut trash. The second peak appeared to be from the coulter body itself. This larger peak (as for the triple disc) was the value extracted for Tables 6 and 7. This peak commenced when the tip of the coulter body was less than 30 mm away from the recording position, indicating that there was an appreciable zone of influence ahead of the coulter itself even though there was a more extensive zone ahead of the pre-disc. By comparison, the compressive stresses propagated by the passing triple disc coulter were first recorded when the assembly was 150 mm away from the recording position. The first peak appeared again, to rise from the leading disc and the second peak arose from the double disc coulter when it was 50 mm away.

Fig 24. The pattern of sidewall pressures detected 30mm away from the groove during passage of direct drilling coulters.

Unit of chart paper (mm)

Chisel coulters

Triple disc coulters

Direction of travel

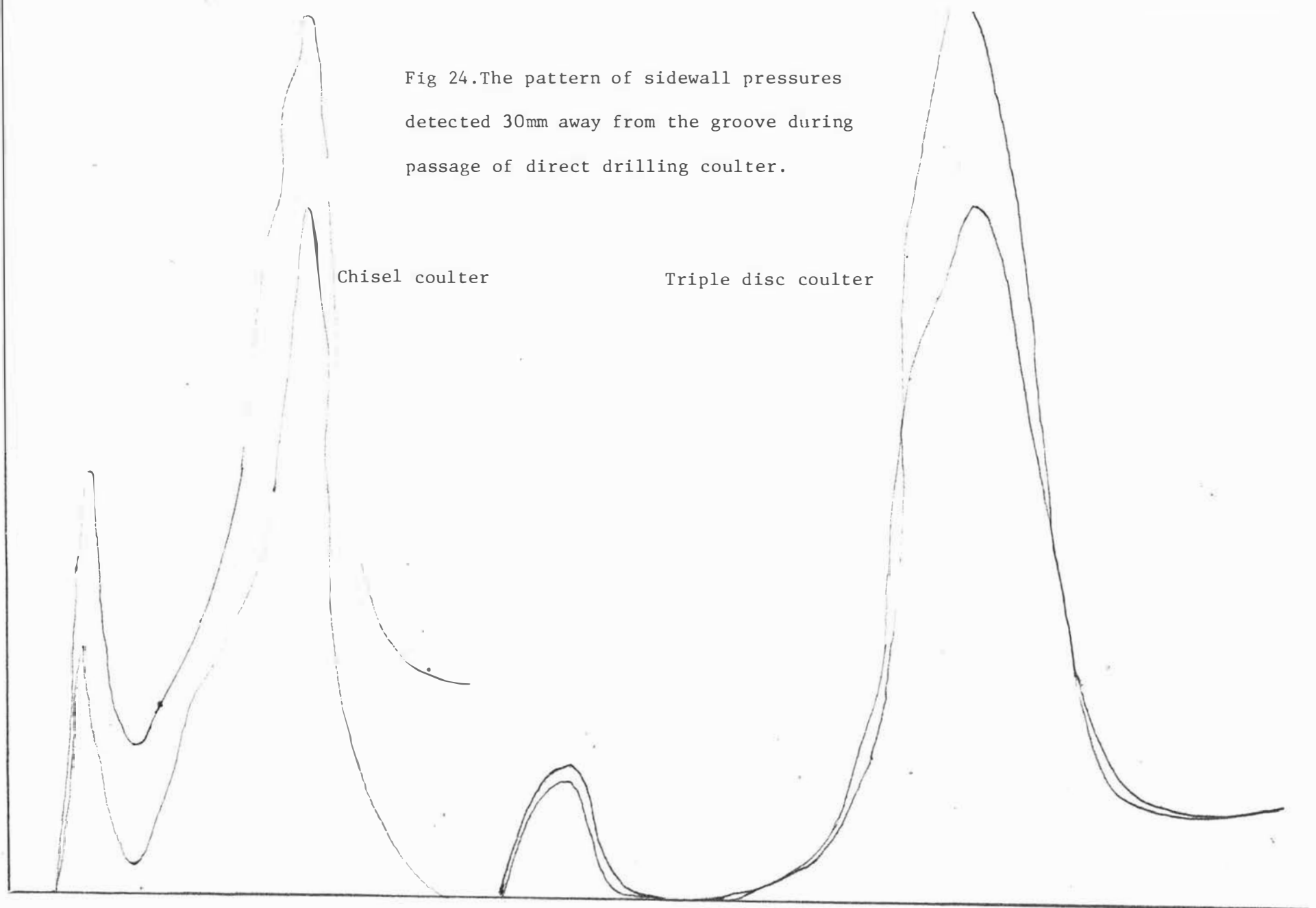
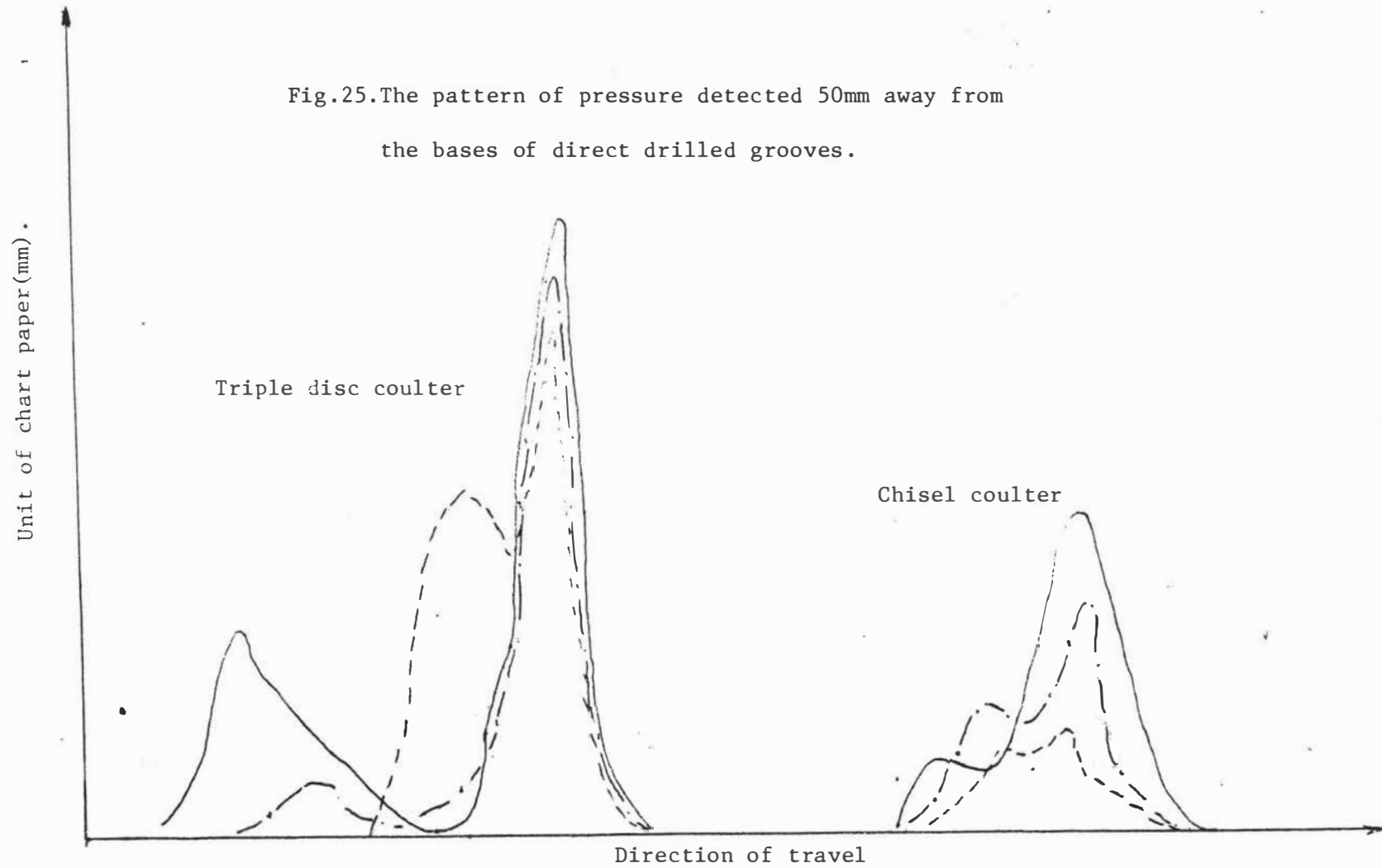


Fig.25.The pattern of pressure detected 50mm away from the bases of direct drilled grooves.



It would not be reasonable to attempt a complete explanation of these different effects as the collection of data relating to the forward propagation of soil stress was not one of the major objectives of this study. Furthermore, the validity of such data, even if it had been available, would be questionable as one coulter assembly was totally rolling while the other was rigid with only a rolling pre-disc. Payne (120) studied the formation of soil wedges ahead of rigid bodies and reasoned that shear failure surfaces existed, which passed along the side of the tool as well as the bottom of the tool. The vertical shear surfaces intersected each other as well as the bottom curved surfaces. If such a wedge was created by the chisel coulter it would be expected to have been pushed forward and upward as the coulter advanced. While this might account for the noticeable heaving effect characteristic of this coulter it must be appreciated that unlike the triple disc coulter, the chisel coulter was not vertically symmetrical in design and thus the interaction of the various soil forces which this lack of symmetry is likely to have created is likely to have been quite complex.

It should also be pointed out that the studies of Payne (loc.cit) did not involve heterogeneous natural soils in which root and organic matter might have been important. In the direct drilling situation, the extent of disturbance created by the passing chisel coulter in particular (and other rigid coulters in general) might be expected to be not only dependent on the geometry of the coulter but also on the abundance and strength of root and organic matter, the type of soil and its moisture content.

There was no apparent heaving of soil with the triple disc coulter assembly and very little loose soil was observed in its grooves. In moist soils, in fact, smearing at the soil coulter interface was observed in the groove.

As the forward stress propagation of neither coulter body appeared to pass ahead of their associated pre-discs, (the centres of which were located 50mm and 100mm ahead of the chisel and double disc bodies respectively), the first peaks can be safely assumed to have represented the passing disc in isolation. On the testing apparatus used, the pre-disc assembly was in fact common to both coulter bodies. Thus, the only logical explanation of the difference in forward propagation of stress from this common disc in the two situations appears to arise from the different net vertical loadings on the depth wheels which operated alongside the disc. This would not be unexpected, as the forces balance between the penetration resistance of any one coulter assembly and the applied vertical loading changes and readjusts itself constantly in a field situation.

Even though care was taken in the measurement of pressure around the groove, some errors were found to be unavoidable. Apart from those discussed above, the sources of errors were thought to be due to the difficulties experienced in accurately placing the pressure sensing tubes, the imperfect contact surface between the soil and the rubber membranes, the heterogeneity of the soil, and variation in operating depth of the coulter assemblies.

Occasional malfunctions of the delicate measuring equipment were encountered when measurements were being recorded while the coulter passed through the two predetermined measuring locations within each bin.

The readings of two locations were abandoned when the coulters encountered small stones or gravel. Such occurrences were difficult to predict due to the heterogeneous nature of the undisturbed soil in the bins. On two occasions, pressure sensing tubes were destroyed by the approaching coulter and on the other occasion the rubber diaphragm was overstressed.

(d) Draft Force.

Results Draft measurements were taken while the tested coulters travelled at an operating speed of 1m/min. Clearly because of the slow speed, the absolute values of draught recorded are of comparative value only and have no direct relationship with field practice. The data are shown in Table 9. Mean draft values were calculated from the combined areas of curves traced for each run. Individual replicate runs for each coulters are shown in appendix 3.

TABLE 9: Draft forces required by two drill coulters in a silt loam at 23% ww moisture content.

	Chisel Coulters	Triple Disc Coulters
Draft Force (N)	2094 **	1684

** P = 0.01

DISCUSSION:

The data suggests that significantly more force (2094 N) was needed for the chisel coulters (which was decompacting, breaking and pulverising a band of soil) than was required by the triple disc coulters (1684 N) which appeared to be compacting and smearing soil particles within a band containing the groove.

This data, together with the previously discussed data concerning the dissipation of forces exerted by the two coulter, suggests that the energy required to heave, decompact and pulverise the soil (at least to the extent that the chisel coulters achieved this) was greater than the energy necessary for the triple disc coulters to bring about almost the complete opposite effect (i.e. smearing and compaction).

(e) Root Studies.

Results One sampling of the lupin crop (at the end of week 3) and two samplings of the wheat crop (at the end of week 3 and 7) were taken. Results of root studies are presented in figures 26, 27 and 28.

DISCUSSION:

Figure 26 indicates that there were no significant differences in lupin root dry weight per plant between coulter treatments in both soil moisture regimes at the 5% level of probability. In the wet regime the difference was, however, significant at the lower order of probability $p = 0.10$.

In figure 27, it is apparent that no significant differences in the depth of lupin roots penetration per plant were found between the coulter in both moisture regimes at $p = 0.05$. In the wet regime, however, the difference was significant at the lower order of probability $p = 0.10$.

Figure 28 shows no significant differences between the dry weight per plant of wheat roots as a function of coulter type at both sampling dates. Penetration of wheat roots was not measured for practical reasons.

However, it is noteworthy that a general visual appraisal suggested that there had been a considerably greater emergence of both seedling species in all chisel coulter treatments than with the triple disc coulter, particularly in the dry regime treatments. If this observation was correct, it would confirm the previously reported data of Baker (68) and Choudhary (95).

It is also noteworthy that overall, root dry weights for lupin and wheat were lower in the dry soil regimes than in the wetter regimes. These differences were significant ($p = 0.05$) in the following situations, and were also mirrored by lupin root length measurements:

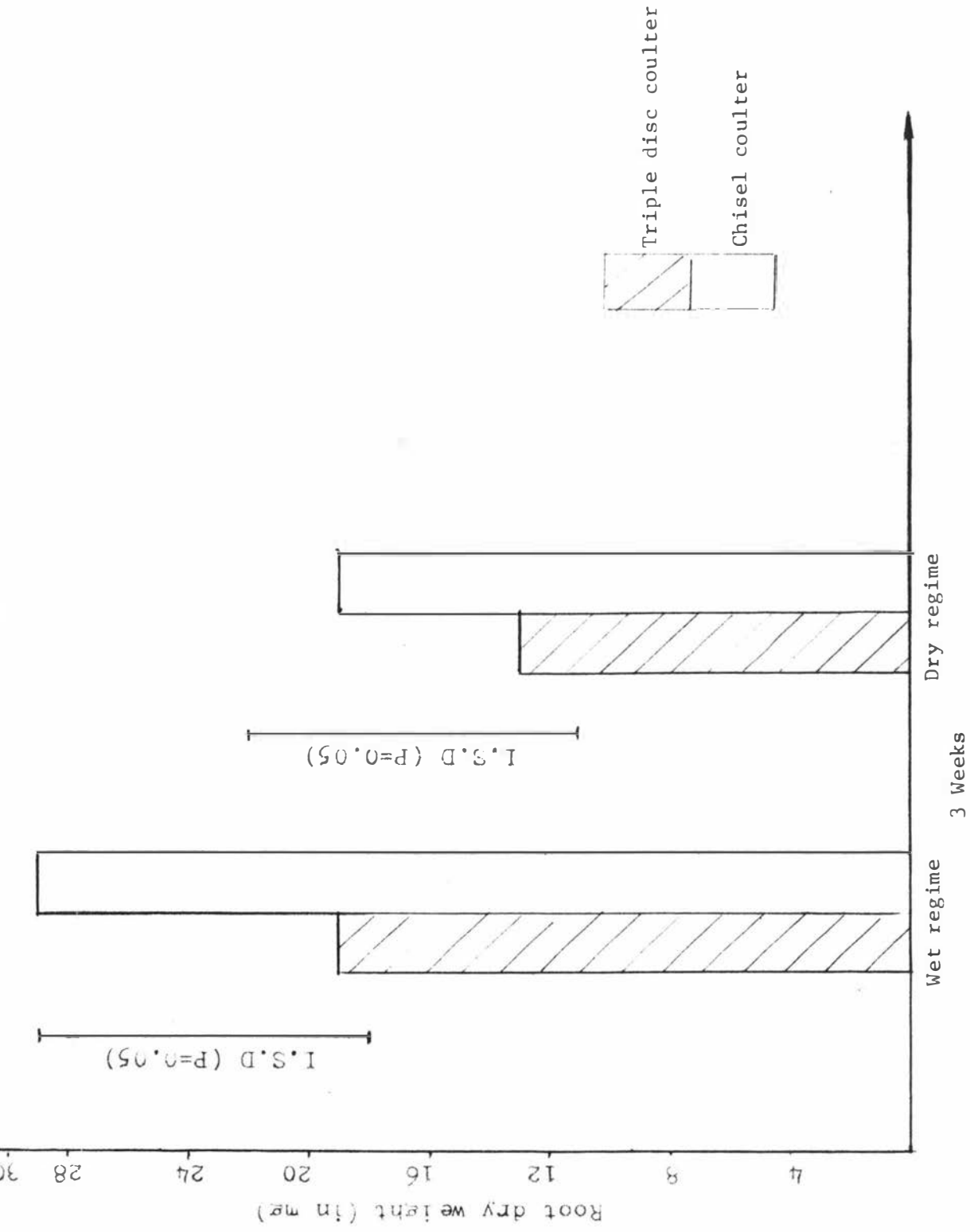


Fig 26. The effects of direct drilling coulters designs on lupin root dry weight

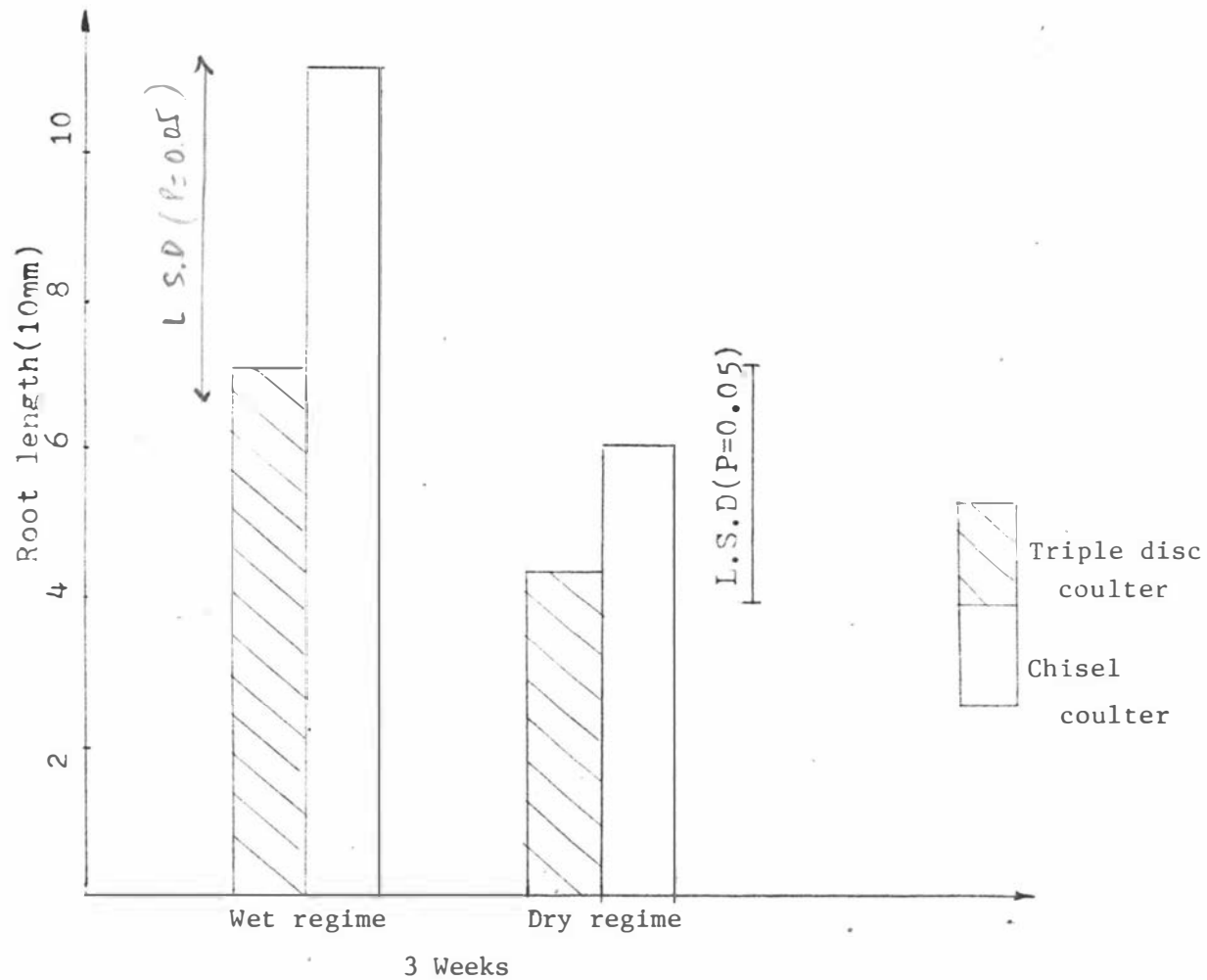


Fig.27. The effects of direct drilling couler designs on lupin root length

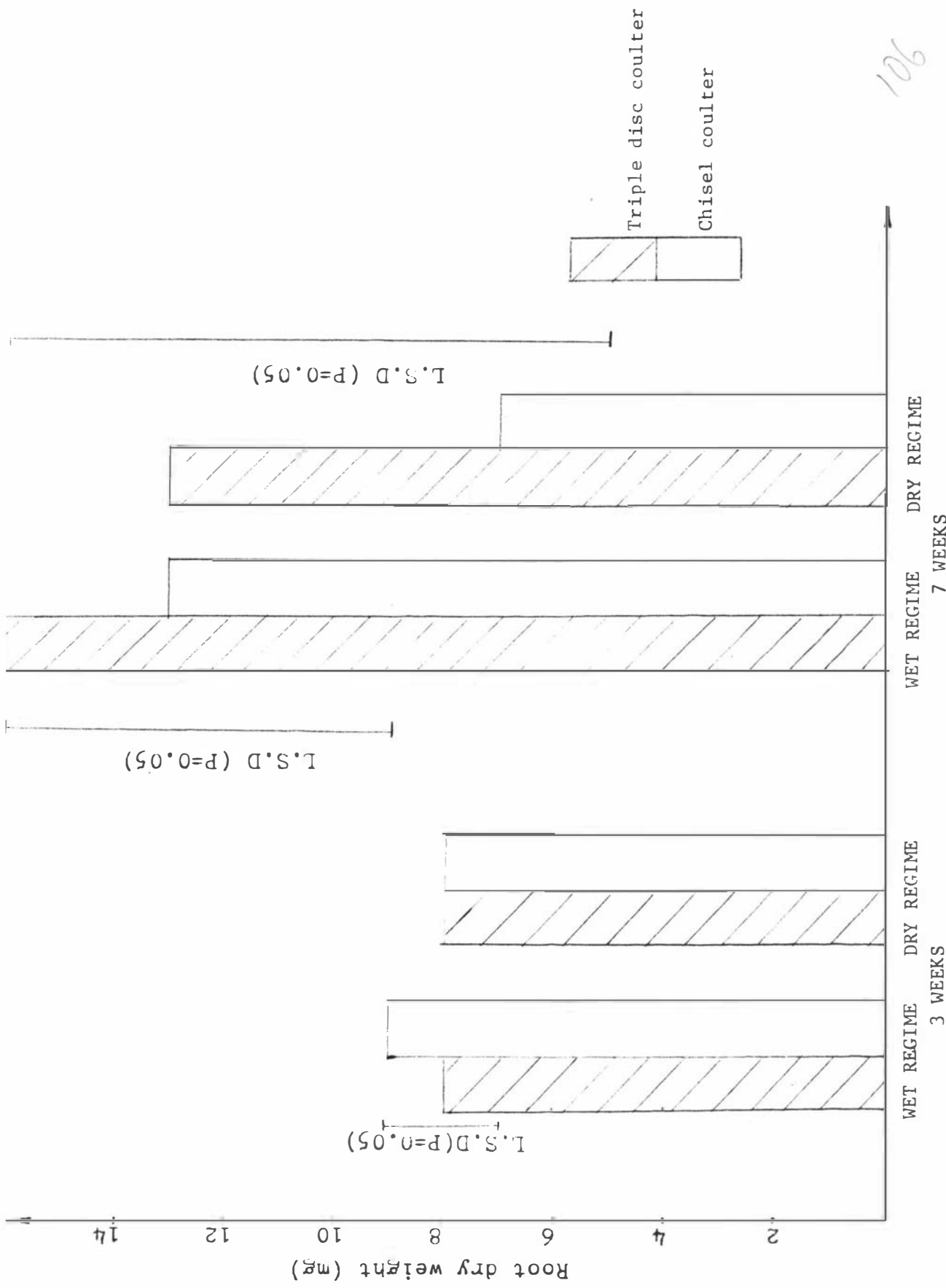


Fig.28. The effects of direct drilling coulters designs on wheat root dry weight.

Lupin dry weight (3 weeks)

Wheat dry weight (7 weeks)

Lupin root length (3 weeks)

5.2.3 Brief summary of experiment 1.

Even under the favourable climatic conditions under which this experiment was conducted (even in the dry regime), the two coulters resulted in contrasting soil physical conditions at seed level. The mechanical impedance to root growth (as indicated by soil strength measured with the multipoint penetrometer) and bulk density differences created by these coulters appeared to have affected seedling emergence more than they affected per plant root growth.

5.3 EXPERIMENT 2.

5.3.1 Objectives.

It was felt that the results obtained from experiment 1, as a means of characterising the performance of the two chosen drill coulters (i.e. triple disc and chisel coulters) using bulk density and mechanical impedance as indicators needed further study. Although some significant differences in the physical parameters were observed the biological data were inconclusive. The second experiment was therefore designed to examine the repeatability of the physical measurements and to attempt to highlight the changes in the soil macrostructure as it affected seedling root growth. The same methods and equipment used in experiment 1 were applied, except that in experiment 2, the soil moisture was increased to an average of 29% w/w which corresponded to 0.1 bar matric potential.

All physical measurements as in the previous experiment were repeated. In addition, any in-groove smearing effects, due to the wetter soils, were investigated using thin sections and electron microscopic techniques.

5.3.2 Results and Discussion.

Results The effects that the contrasting drill coulter designs had on soil bulk density, soil strength and soil pressure are given in Tables 10, 11, 12, 13 and 14 respectively and figures 29 and 30.

Detailed data are given in appendices 1 and 2.

TABLE 10: The effects of direct drilling coulters designs on soil density around the groove.

	Triple Disc Coulter	Chisel Coulter	Statistical significance of differences
Soil moisture content at drilling % ww	28	28	NS
Soil bulk density before drilling g/cc	1.04	1.04	NS
Soil bulk density after drilling g/cc	1.15	1.03	**

** P = 0.01

TABLE 11: The effects of direct drilling coulters designs on soil strength.

	Triple Disc Coulter	Chisel Coulter	Statistical significance of differences
Original soil strength (N)	.330	.356	NS
Soil strength at the base of the groove (N)	.427	.342	**
Difference as compared with original soil strength	+29.4%	-3.9%	
Soil strength at the sidewall of the groove	.391	.249	**
Difference as compared with original soil strength	+18%	-30%	

** P = 0.01

TABLE 12: The effects of direct drilling
coulters designs on soil strength
on either side of the groove.

Distance away from the groove centre (mm)	15	25	35	45	55
	Penetration force (N)				
Triple Disc coulters	.427	.473	.438	.357	.374
Comparison with the soil strength before drilling	+0.097	+0.143	+0.108	+0.027	+0.044
Chisel Coulters	.199	.263	.333	.308	.327
Comparison with the soil strength before drilling	-.139	-.075	-.005	-.030	-.011

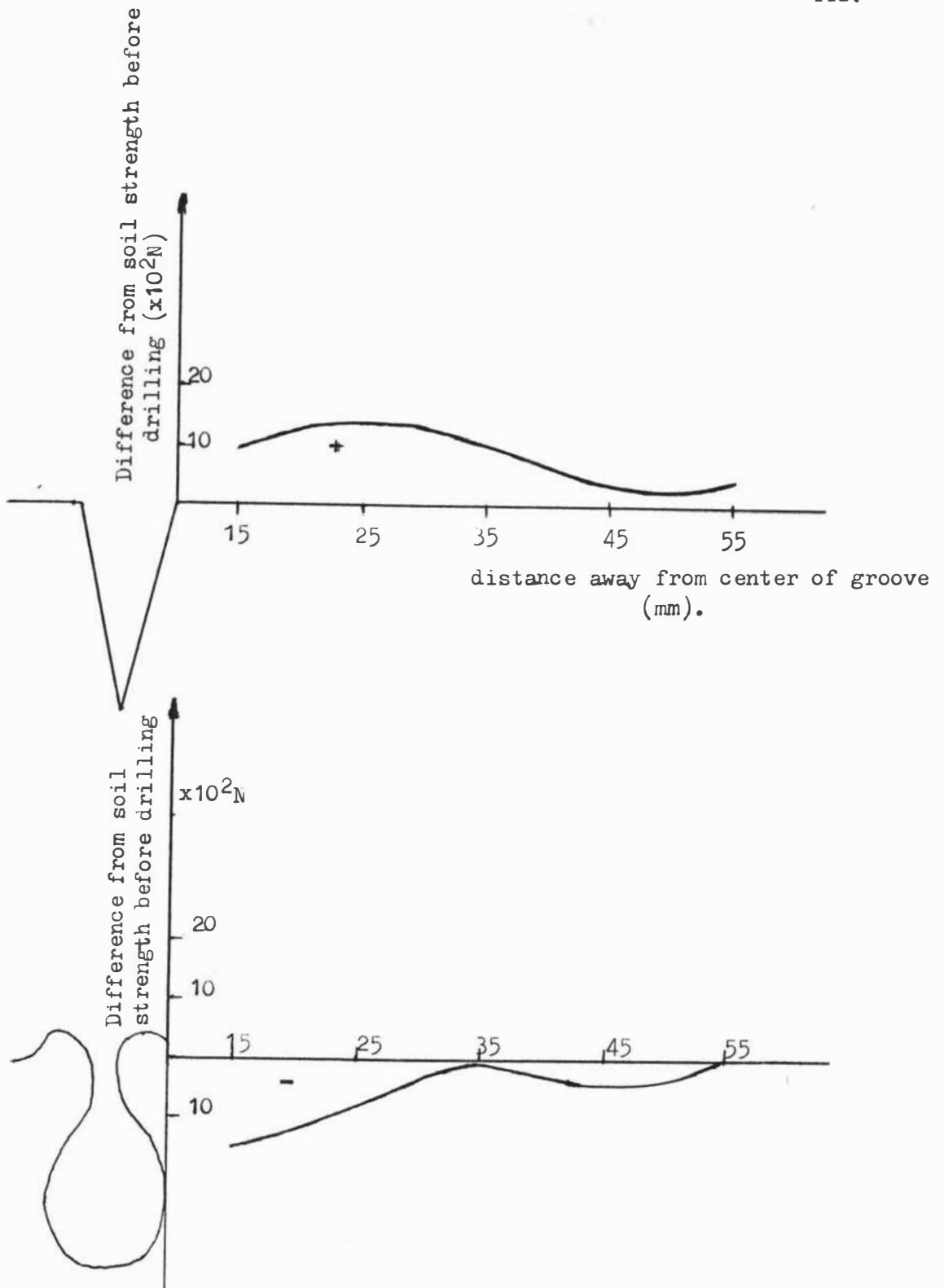


Fig.29. Soil resistance at either sides of the triple disc (upper) and chisel coulter.

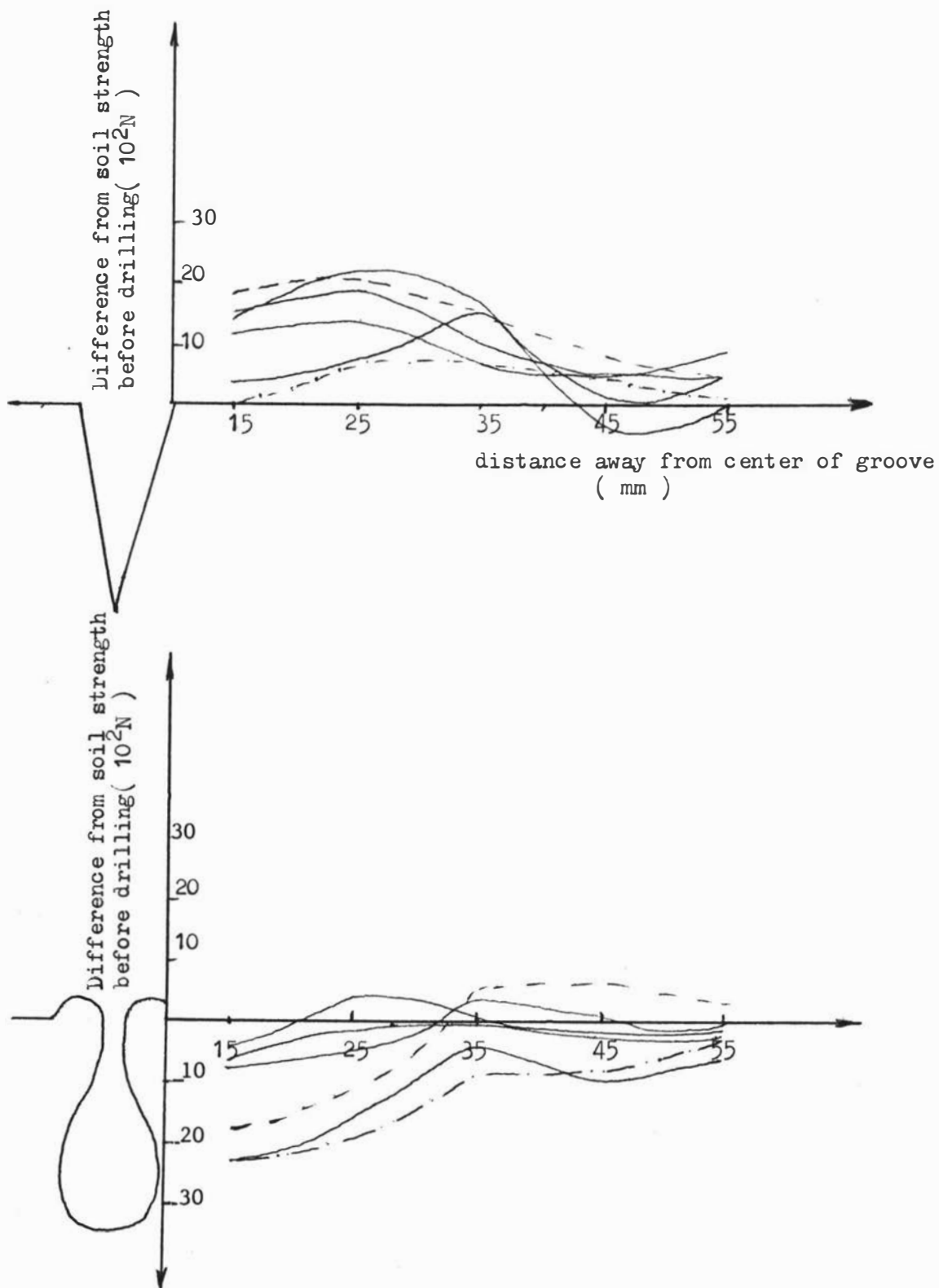


Fig.30. Variation of soil resistance at either sides of the triple disc (upper) and chisel coulters. Each curve represents one replicate.

TABLE 13: The effects of direct drilling
coultter designs on maximum soil
pressure at the base of the
drilled groove (kPa)

		Triple Disc Coulter	Chisel Coulter
Distance from the centre of the groove	30mm	167	59
	50mm	124	31

TABLE 14: The effects of direct drilling
coultter designs on maximum soil
pressure at the sidewalls of the
groove (kPa)

		Triple Disc Coulter	Chisel Coulter
Distance from the centre of the groove	30mm	96	64
	50mm	50	not measured ^t

t : malfunction of equipment.

DISCUSSION:

All physical measurements (i.e. bulk density, soil strength and soil pressure) indicated a high level of consistency when compared to experiment 1, although the magnitude of the differences was not necessarily the same. For example, in the soil strength data, although the trends are identical to those of experiment 1, in experiment 2, the triple disc coulter appeared to compact the groove base less and the sidewalls more than previously recorded. The chisel coulter appeared to decompact both the base and sidewalls less than previously. Most of these differences were not unexpected as the higher initial soil moisture content could be assumed to have increased the plasticity of the soil.

With the instantaneous measurements (i.e. soil pressure) the greater soil plasticity could also have accounted for the greater recordings as the coulter passed by the sensors. This would also correspond to lower permanent readings than in experiment 1 when the more plastic soil had had time to recover and reach a new equilibrium.

At the groove sidewalls, an almost opposite effect appears to have taken place. The more plastic soil resulted in less instantaneous transmission of soil pressure with both coulters and a correspondingly greater final soil strength increase above the original soil at least with the triple disc coulter (i.e. +18% in experiment 2, compared to +9% in experiment 1).

The pattern with distance from the groove centre was also altered in experiment 2. Maximum compaction (triple disc) and minimum pulverisation (chisel) occurred in the 25 to 35mm zone but again was roughly comparable in both instances. Both patterns were wave like

about these maxima and minima. This pattern is again difficult to explain.

5.3.4 Draft force

Results and Discussion

Typical draft curves are shown in appendix 3. The mean draft values for each coulter are given in Table 15. The table indicates that draft force for the chisel coulter was 40% higher than for the triple disc coulter. These findings support those of the first experiments. The reduced difference between the two coulters in this experiment is attributed to the weaker soil strength of the wetter soil. (28-30%^{w/w}).

TABLE 15: The effects of direct drilling coulter designs on draft force in a silt loam at 28-30% ^{w/w}.

	Chisel Coulter	Triple Disc Coulter
Draft Force (N)	1853	1210 **

** P = 0.01.

5.3.4 Macrostructural changes of soil under compression.

The structural changes arising from compression of the soil matrix was studied with two techniques (a) thin sectioning and (b) electron microscopy.

5.3.4.1 Results and discussions.

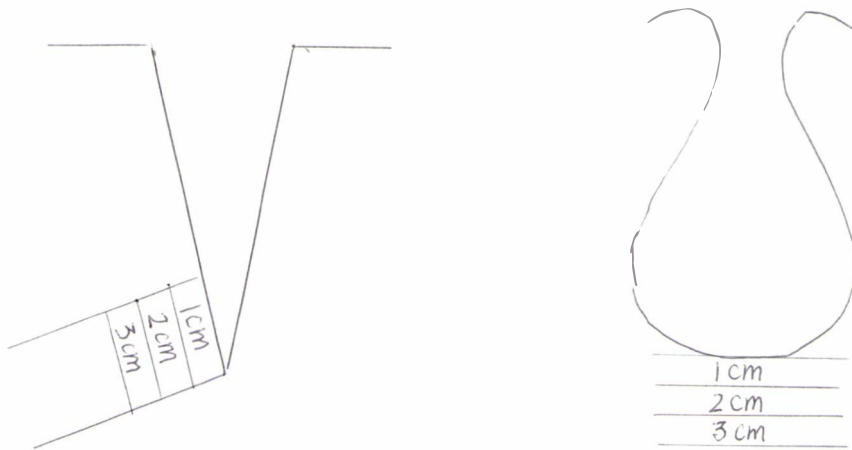
(a) Thin sectioning.

The effects of different coulter designs on the geometrical arrangement of soil particles and their associated voids (soil fabric) were investigated by macro and micro morphological analyses. Using the techniques and equipment described in 2.3.4. photographic prints were obtained which are presented in figures 32-38.

Figure 31 illustrates the positions from which the thin sections were removed in relation to the groove.

Although soil fabric changes could be expected to be amongst the most obvious effects of compaction, the determination of fabric and fabric changes are one of the most difficult measurements to make. Thus, in this investigation, only qualitative information is given. This is presented photographically in an attempt to illustrate differences in soil fabric which arose due to the passing of the two coulters (viz triple disc and chisel coulter).

Figure 32 shows two sections of soil in their original "undisturbed" conditions. A high proportion of voids, root holes and cracks can be seen in these samples which were taken 20mm beneath the top soil surface. Figures 33 and 34 show the difference between the soil fabrics after mechanical disturbance by the two coulters. Both samples were taken 10mm away from the soil coulter interfaces in the positions shown



Triple disc coultter

Chisel coultter

Fig.31. Thin section sampling sites.



Fig.32. Sections of soil in their original conditions.



Fig.33. Soil sections taken at 10mm from the soil/triple disc coulter interface.



Fig.34. Soil sections taken at 10mm from the soil/chisel coulter interface.



Fig.35. Soil sections taken at 20mm from the soil/triple disc coulter interface.



Fig.36. Soil sections taken at 20mm from the soil/chisel coulter interface.



Fig.37. Soil sections taken at 30mm from the soil/triple disc coulter interface.



Fig.38. Soil sections taken at 30mm from the soil/chisel coulter interface.

in figure 31. The actual sampling sites in each groove were chosen according to the ease of the removal of the subsamples. For example, sampling from the base of the triple disc groove was impractical because the groove base was in fact the apex of an inverted triangle. Sampling from the groove wall of the chisel coulter was also impractical because it was shattered and not well defined. While the arbitrarily chosen sampling sites could thus be argued as not being truly representative of each groove, the soil strength data obtained previously (see experiments 1 and 2) suggested that the walls of the triple disc groove was the least compacted of that groove. Thus any apparent difference between thin sections from that zone and the base of the chisel coulter groove are likely to be conservative.

In figure 33, the soil is seen to be more closely packed and the volume of voids, root holes and cracking is relatively small. This was probably due to the collapse of the larger pores and root holes.

By comparison, figure 34 shows that the chisel coulter had not compacted the soil. In fact comparison with figure 31 suggests that it may have shattered the soil somewhat at the base of the groove.

Most noteworthy is the presence of a larger number of pores and root holes than can be seen in figure 33. These observations are in agreement with the data obtained for the measurements of soil bulk density and soil strength.

The same trends can be seen in figures 35 and 36; and 37 and 38 which were taken 20mm and 30mm away from the groove interfaces respectively. Soil again appeared to be more compacted with fewer pore spaces under the triple disc treatments than under the chisel coulter treatments.

(b) Electron microscopic technique.

The technique of electron microscopy, which was described earlier, was found useful in providing supportive qualitative comparisons of soil fabric changes.

All micrographs were obtained at the magnification of 170. The greater (x520) and smaller (x50) levels of magnification were also tested but found not to be useful for the purposes of this study.

Four sets of micrographs were taken of 3mm³ subsamples of soil removed from the four different positions illustrated in figure 39. Again, the choice of these positions was arbitrary, being governed by the ease and practicality of subsample removal.

The micrograph taken from soil before drilling (figure 40) revealed that a number of pores (a) and silt particles (b) were surrounded by organic and clay particles (c). There was no apparent orientation of clay particles into stratified layers, indicating that the soil was not compacted.

Figure 41 shows soil particles at the groove interface after passage of the triple disc coulter. Pore number and volume appear to have been reduced and smearing effects can be observed with some cementing of the soil. By contrast, soil at the base of the chisel created groove can be seen to contain void spaces between soil particles (fig. 42).

Figures 43 and 44 show micrographs taken at 10-20mm from the soil coulter interfaces. Figure (triple disc) reveals a larger number of soil particles compacted and surrounded by organic matter than does figure 44. Also some orientation of clay particles is apparent in figure 43 which contrasts with the micrograph of the original soil (fig. 40) and the chisel coulter treatment (fig. 44), where soil was much

less compacted and the pore systems remained abundant. Similar trends can be seen in figures 45 and 46 which were from sites 20-30mm from the interfaces.

The contrasting effects on soil aggregates found with this technique are considered to be comparable to those obtained with the thin section techniques.

Figures 47 and 48 illustrate micrographs of subsamples taken from each of the groove bases. This was possible in a few instances because of the very small samples required. Similar trends to those described for the sidewalls are again apparent.

Any beneficial or detrimental effects which might result from the operation of either of these two coulters in undisturbed soil would depend on many other factors than are illustrated in the figures presented herein. Both photographic techniques, however, proved to be useful as support information in characterising the effects of the drill coulters in a given soil, and information of a quantitative nature could be extracted from the micrographs with further refinement of the techniques. No attempts have been made to quantify the photographic evidence in this investigation.

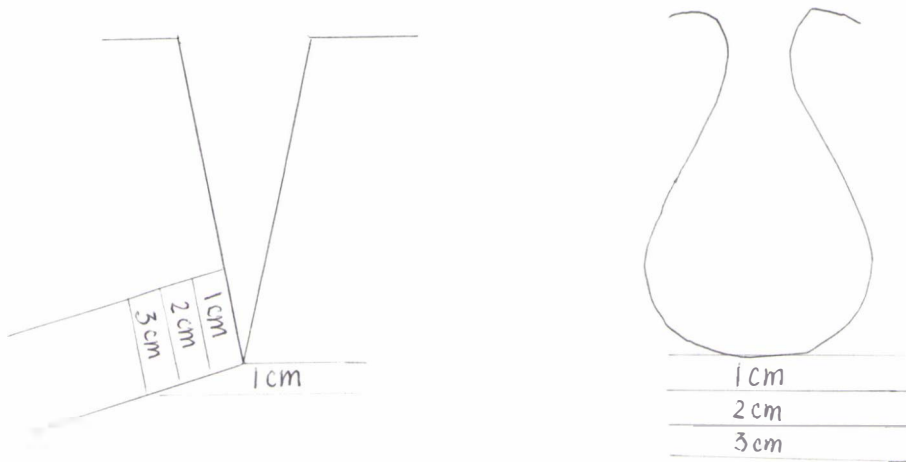


Fig.39.Subsampling sites for electron microscopic study.



Fig.40.Micrograph(x170)of soil in the original condition.

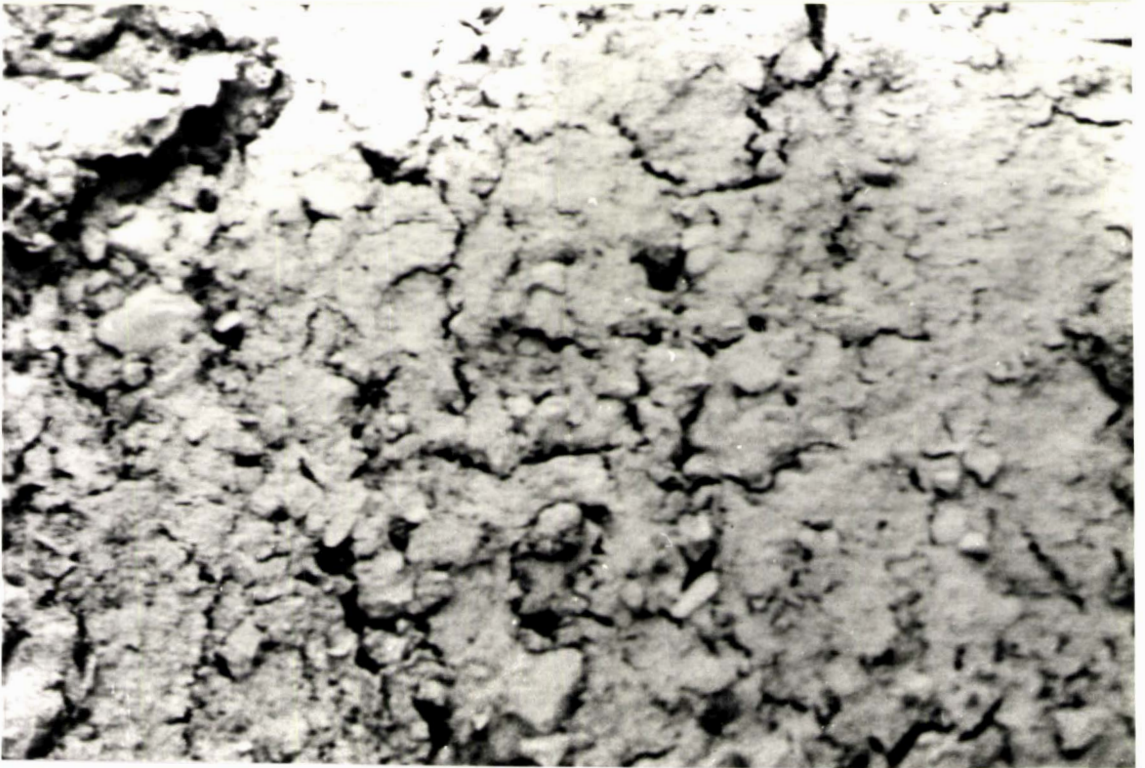


Fig.41. Micrograph(x170) of a soil/triple disc coulters interface.

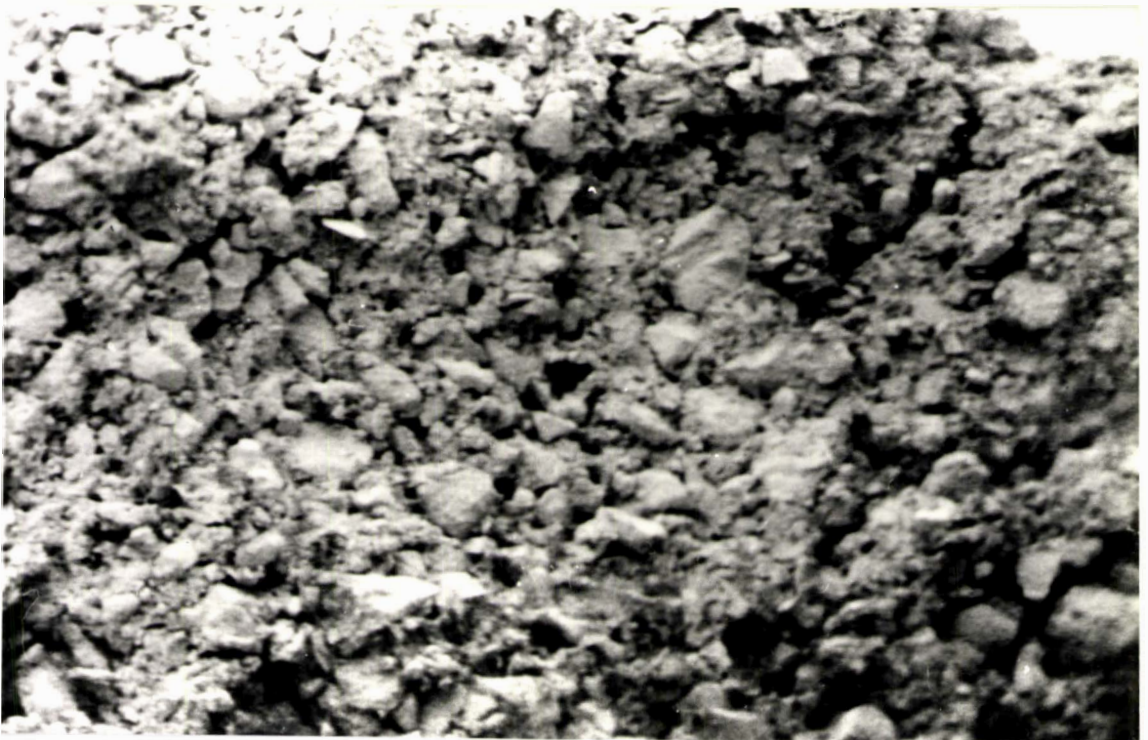


Fig.42. Micrograph(x170) of a soil/chisel coulters interface.



Fig.43. Micrograph(x170) taken 10-20mm from
the soil/triple disc coultter interface.



Fig.44. Micrograph(x170) taken 10-20mm from
the soil/chisel coultter interface.



Fig.4 5. Micrograph(x170) taken 20-30mm from
the soil/triple disc coultter interface.



Fig.46. Micrograph(x170) taken 20-30mm from
the soil/chisel coultter interface.



Fig.47.Micrograph(x170)of a soil at the base of
the triple disc coultter created groove.



Fig.48.Micrograph(x170)of a soil at the base of
the chisel coultter created groove.

5.3.5 Root responses.

Results Wheat and lupin species were drilled in this experiment in the same manner as in experiment 1. Results of root and plant responses are shown in figures 49, 50 and 51.

DISCUSSION.

No significant differences were apparent at three weeks between lupin per plant root dry weights for the two coulters types (fig. 50). With per plant root length of lupin (which was also sampled at 3 weeks) however, those in the triple disc treatment at both wet and dry soil regimes appeared to be significantly larger ($P = 0.05$) than those in the corresponding chisel treatments. This trend contrasted with experiment 1.

It should be noted that even the maximum bulk density produced by the triple disc coulters (an increase from $1.04\text{g}/\text{cm}^3$ in original soil to $1.15\text{g}/\text{cm}^3$ after passage of the coulters), is well within the accepted root limiting range of $1.4\text{--}1.5\text{g}/\text{cm}^3$. Thus it was not unexpected that the roots were not retarded in the triple disc treatments. However to explain their increased root length relative to the chisel coulters treatment is more difficult. It is possible that within the limited depth of the tillage bin used (200mm) the wedging action of the triple disc coulters may have produced a microscopic vertical crack beneath the groove. Certainly Dixon (103) suggested that this had occurred in his similar experiments, but if this was a factor in the investigation reported herein, it is difficult to see why this had not also happened in the drier soil of experiment 1. Figure 51 indicates that there were no significant differences between the dry weight per plant of wheat roots as a function of coulters types in both moisture regimes

(dry and wet) at 7 weeks. Although there was also no significant differences, in term of wheat root dry weight, at three weeks with the dry regime treatments, a statistical difference (at the lower order of probability $P = 0.10$) was found between the two coulter treatments in the wet regime. The triple disc coulter in this condition appeared to produce more root weight than the chisel coulter.

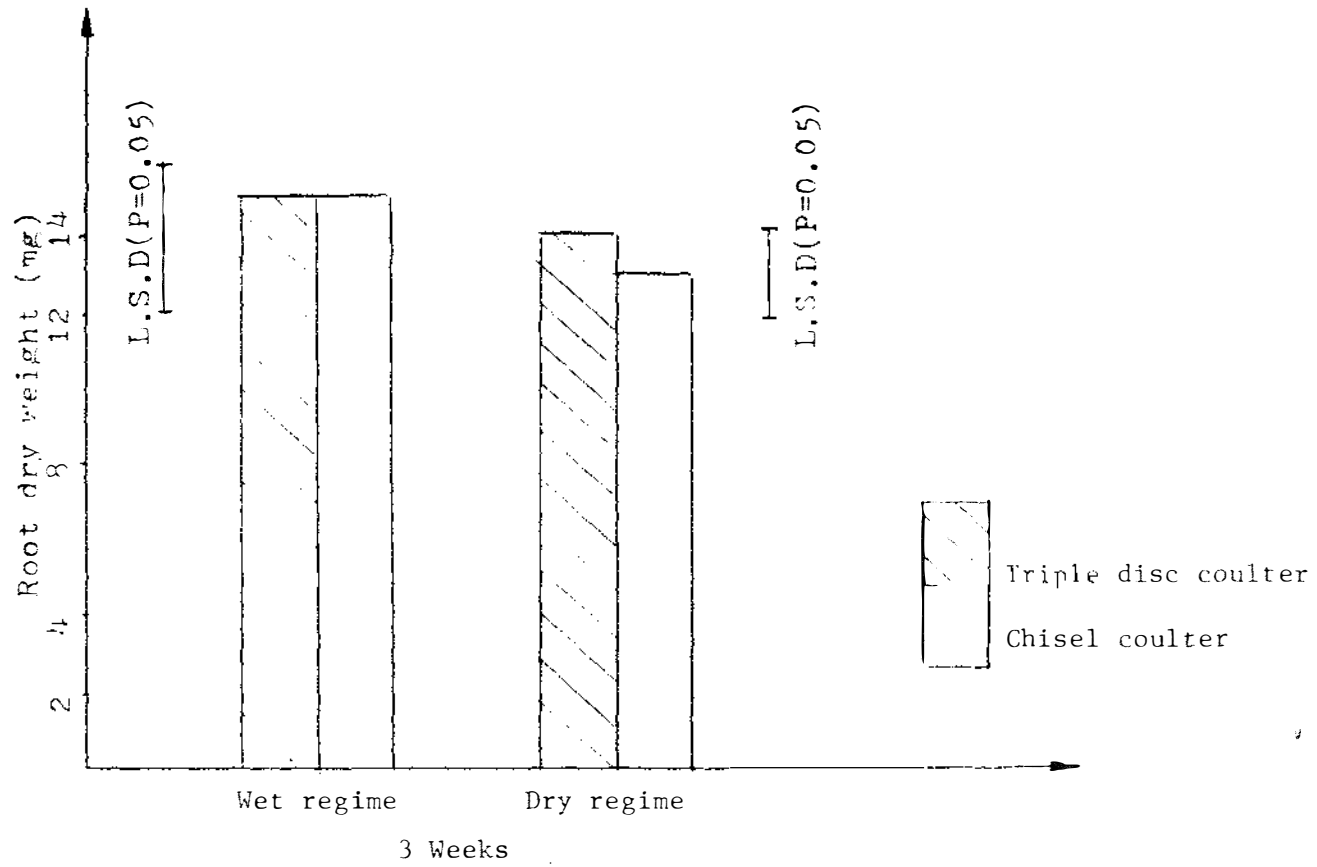


Fig.49.The effects of direct drilling coulters designs on lupin root dry weight.

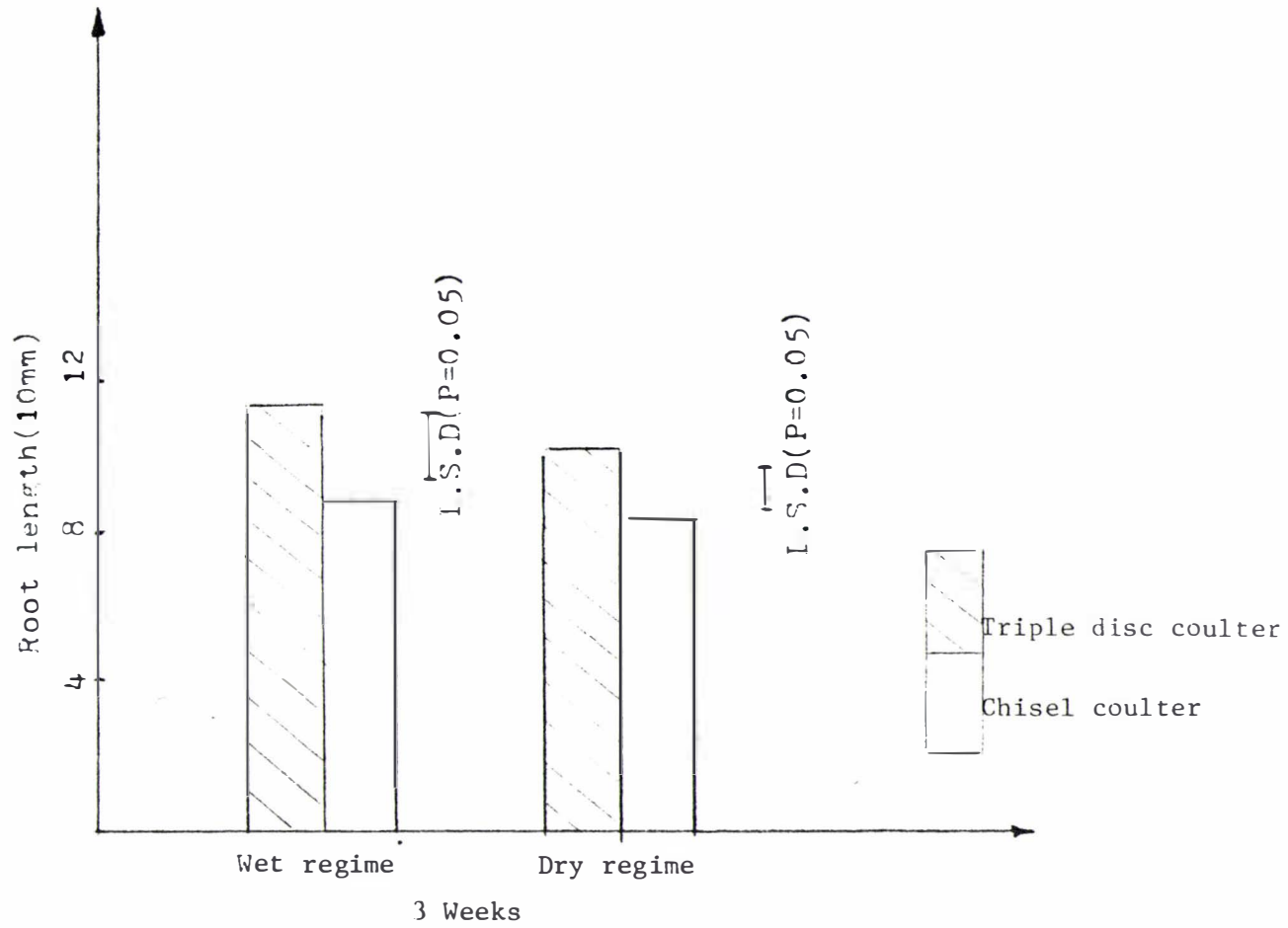


Fig.50.The effects of direct drilling coulters designs on lupin root length.

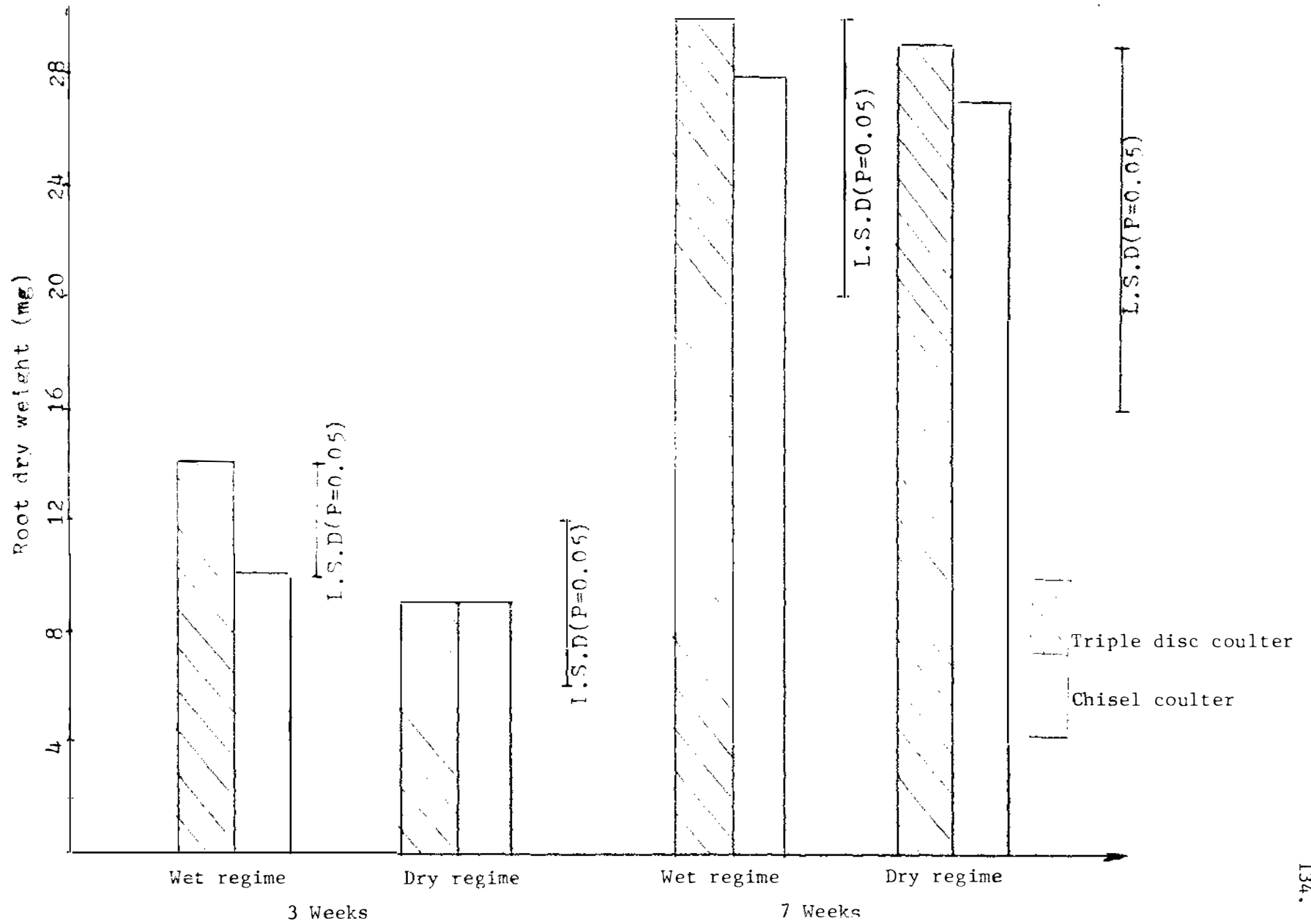


Fig.51.The effects of direct drilling coulters designs on wheat root dry weight.

5.4 EXPERIMENT 3.5.4.1 Objectives.

Data obtained from the previous two experiments indicated that the soil had reacted differently to the different shapes of coulters. The triple disc coulters gave a narrow (smeared if wet) and compacted groove with little loose soil. The chisel coulters tended to pulverise the soil and leave more loose soil in the groove. However, the effects of mechanical impedance and/or compaction on root growth were inconclusive, largely because the soil had been of low strength and bulk density to start with. The third experiment which was conducted in the Spring/Summer seasons of 1976 was therefore designed to investigate the effects of coulters on a hard strong soil and the subsequent influence on the development of roots. The same "Tokomaru" silt loam soil as was used previously was precompacted with a 1.4 tonne vibrating roller prior to extraction of the tillage bins from the field. A pilot study on compaction by this roller indicated that the slower the operating speed or the longer time the roller was in contact with the soil the higher the bulk density appeared to be attained. The number of passes and speed interactions to give a bulk density of 1.32 g/cm^3 in the 0-50mm layer are given in Table 16.

TABLE 16: The effects on soil compaction of multiple runs with a vibrating roller (final bulk density in each case = 1.32 g/cm^3)

	Operating Speed (Km)		
Number of	3.5	5	8
Passes	6	7	9

For the purpose of this experiment the combination of 3.5km/hr was used. The same physical measurements, procedures and equipment as for experiment 1 and 2 were applied. The measurement of the instantaneous zone of influence was not carried out in this experiment as it appeared to be of limited value. However, measurements were introduced of the soil surface disturbance, in an attempt to better investigate the disturbing effects on both sides of the grooves at the soil surfaces.

5.4.2 Results and Discussion

(a) Bulk density.

Results.

The results of bulk density and soil strength measurements are given in Tables 17 and 18.

DISCUSSION.

The triple disc coulter appeared to increase soil bulk density at the base of the groove from 1.32 to 1.44g/cm³. This was significantly greater than the effect of the chisel coulter which appeared not to alter the bulk density from the original value. This trend further confirms the previous findings and was again supported by the soil strength data obtained by penetrometer studies which are presented in Table 18.

TABLE 17: The effects of direct drilling
coulter designs on soil bulk
density.

	Triple Disc Coulter	Chisel Coulter	Statistical significance of differences
Soil bulk density before drilling g/cm ³	1.32	1.32	NS
Soil bulk density after drilling g/cm ³	1.44	1.32	**

** P = 0.01.

Penetration forces.

Not unexpectedly, more force was required for both coulters to penetrate the stronger soils, although the triple disc coulter still maintained its higher force requirement over the chisel coulter (Table 39). The respective penetration forces required were 1210 N and 416 N for triple disc and chisel respectively.

TABLE 18: The effects of direct drilling coulter design on soil strength.

	Triple Disc Coulter	Chisel Coulter	Statistical significance of differences
Original soil strength (N)	2.82	2.85	NS
Soil strength at the base of the groove	3.38	3.04	**
Difference as compared with original soil strength	+19.8% *	+6% NS	
Soil strength at the sidewall of the groove	3.11	2.43	**
Difference as compared with original soil strength	+10% *	-14% *	

* P = 0.05

(b) Soil surface disturbance.

Results

With the "Tokomaru" silt loam used in its compacted state prior to the drilling operation, the organic root percentage was 1.4g/100g of oven dried soil. Results are given in figure 52. The instrumentation described in section 2.3.6 was used to detect disturbance zones on the soil surface.

DISCUSSION:

The curves in Fig. 52 depict the lateral displacement of the probe tops away from their original positions which were 30mm from the anticipated groove centres in both treatments. The twine was attached to each probe 40mm above the soil surface which was as close to the surface as practical without interference by surface vegetation. However, because the measurements of displacement were not at the soil surface they could reflect either angulation of the probes or bodily displacement of the probes, or both. Furthermore to prevent breakage or permanent bending of the probes, resilient stainless steel was used. The resilience could have also contributed to deflection of the probe tops. Thus it is difficult to interpret the causes of the apparent greater displacement recorded with the chisel coulter, compared to the triple disc coulter. Nevertheless the magnitude of the difference between the two was large. These readings were replicated only twice (because of the limited number of displacement transducers available), so no analysis of variance was applied to the raw data.

Of particular interest is the magnitude of total deflection shown by the chisel coulter. The subsurface acting components of this coulter

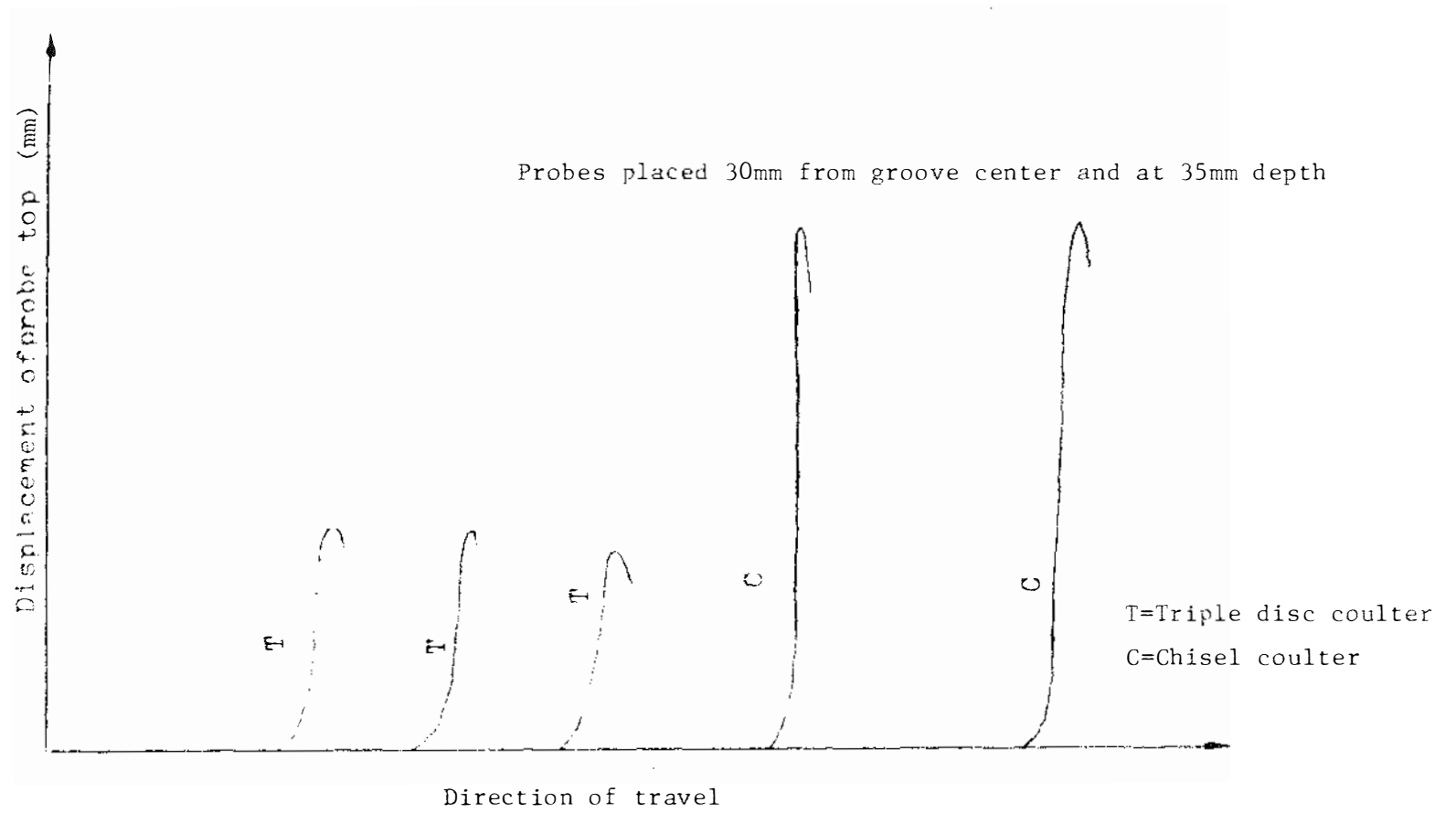


Fig.52.The effects of direct drilling coulters designs on soil surface disturbance

(wings) were much wider than the surface acting shank. It is reasonable, therefore, to have expected greater disturbance beneath the surface which might have either tilted the probe tops inwards towards the groove, or at least partly countered any outward total displacement of them. However, clearly the net displacement effect was to tilt and/or displace the probes outwards by an appreciable amount. This suggests that soil disturbance by the chisel coulter, whatever its nature was indeed quite severe, and lends support to the permanent soil deformation characteristics measured by other means.

Another point of interest is that, the triple disc coulter appeared to generate soil movement when the coulter assembly was 150mm away from the recording position. The chisel, however, shattered a soil region which was dispersed more in the lateral direction, and the forward propagation of stress was detected when the coulter was only 100mm away from the recording position. The differences in this respect may have been due to greater geometrical contact of the triple disc coulter with the soil and its noticeable wedging action.

Figure 53 indicates the large and symmetrical longitudinal contact zone of the double disc component of the triple disc coulter assembly with the soil. Figure 54 shows how the chisel coulter bursts the soil upwards, and also indicates that contact throughout the length of the rigid coulter is not symmetrical, being relieved around the centre point.



Fig.53.The triple disc coulters has a greater longitudinal soil/coulters contact.



Fig.54.The chisel coulters shatters soil abruptly on both sides of the coulters.

(c) Root Responses.

Results

Root harvests of both the lupin and wheat crops were carried out on days 4, 7, 14 and 21, using the same methods as for experiments 1 and 2. The results are presented in Tables 19 and 20.

DISCUSSION:

After four days, wheat roots in the chisel coulter treatment seemed to be growing more strongly than in the triple disc treatment (elongation of 11mm and 3mm respectively). The day four data, however, were not statistically analysed because insufficient plants had emerged at that stage, particularly in the triple disc treatment. Those wheat and lupin seedlings which had emerged in this latter treatment appeared thinner and weaker than their counterparts. This failure to emerge also limited the number of plants which could be destructively harvested at later sampling dates and resulted in the termination of the lupin trial after 3 weeks, and abandonment in the case of wheat.

From Table 19 there appeared to be a general trend towards larger and more extensive root system of lupin with the chisel coulter compared to the triple disc coulter. These differences were highly significant in the dry regime at day 21. Aerial shoots followed a similar trend and were also highly significant at day 21. The trends were not affected greatly by soil moisture content and appeared to be similar in the wet regime, although the levels of statistical significance were lower ($P = 0.05$).

The larger root systems were reflected in stem diameter as well as height of the aerial portion of the plants above ground.

The maximum increase in any parameter at day 21 due to the chisel coulter was a 100% increase in height of the plant in the wet regime, while the minimum increase was 32%, being root dry weight in the dry regime. All other percentage increases were within this range and could therefore be regarded as large as well as statistically significant.

The limited data available from the abortive wheat sowing (Table 20) suggests that a similar significant superiority, to that shown with lupin also existed with the chisel coulter when sowing wheat. The increased soil strength and bulk density measured at the groove base for the triple disc coulter appeared to have affected lupin root branching. Almost all of the observed lupin tap root systems were somewhat flattened and distorted which is shown in figures 55, 56 and 57. In these figures the affects from impedance of hardened soil layers is seen where the root had had to negotiate cracks in the soil and had, as a consequence, become bent or distorted (figures 55 and 56). A cross section of a root which was seen to be distorted thus is shown in fig. 57. The flattened nature of the root can be seen and this contrasts with a cross-section of a lupin root specimen grown in uncompacted soil. (Fig. 58)

TABLE 19: The effect of direct drilling coulter design on plant and root properties of lupin seedlings sown in wet and dry soils.

		Triple Disc Coulter			Chisel Coulter			Statistical significance of difference at 21 days
		7 days	14 days	21 days	7 days	14 days	21 days	
WET REGIME	Root length (mm)	28.30	77.20	88.20	83.60	99.50	114.10	*
	Height of aerial plant (mm)	51.00	57.20	50.90	53.60	76.70	102.10	**
	Root dry weight (g)	not measured	0.033	0.045	0.012	0.035	0.077	*
	Plant stem diameter (30mm above the ground) (mm)			20.00			26.70	**
DRY REGIME	Root length (mm)	25.00	70.00	72.50	40.00	95.70	103.20	**
	Height of aerial plant (mm)	44.00	47.20	58.50	45.70	68.50	89.70	**
	Root dry weight (g)	not measured	0.032	0.062	0.010	0.033	0.082	*
	Plant stem diameter (30mm above the ground) (mm)			18.00			28.10	**

** P = 0.01

* P = 0.05

TABLE 20: The effects of direct drilling coulter design on root length of wheat seedlings at day 4 in wet soil.

	Triple Disc Coulter	Chisel Coulter	Statistical significance of differences
Root Length (mm)	2.90	11.34	**



Fig.55. Distorted root growth of a lupin seedling
in the triple disc groove.

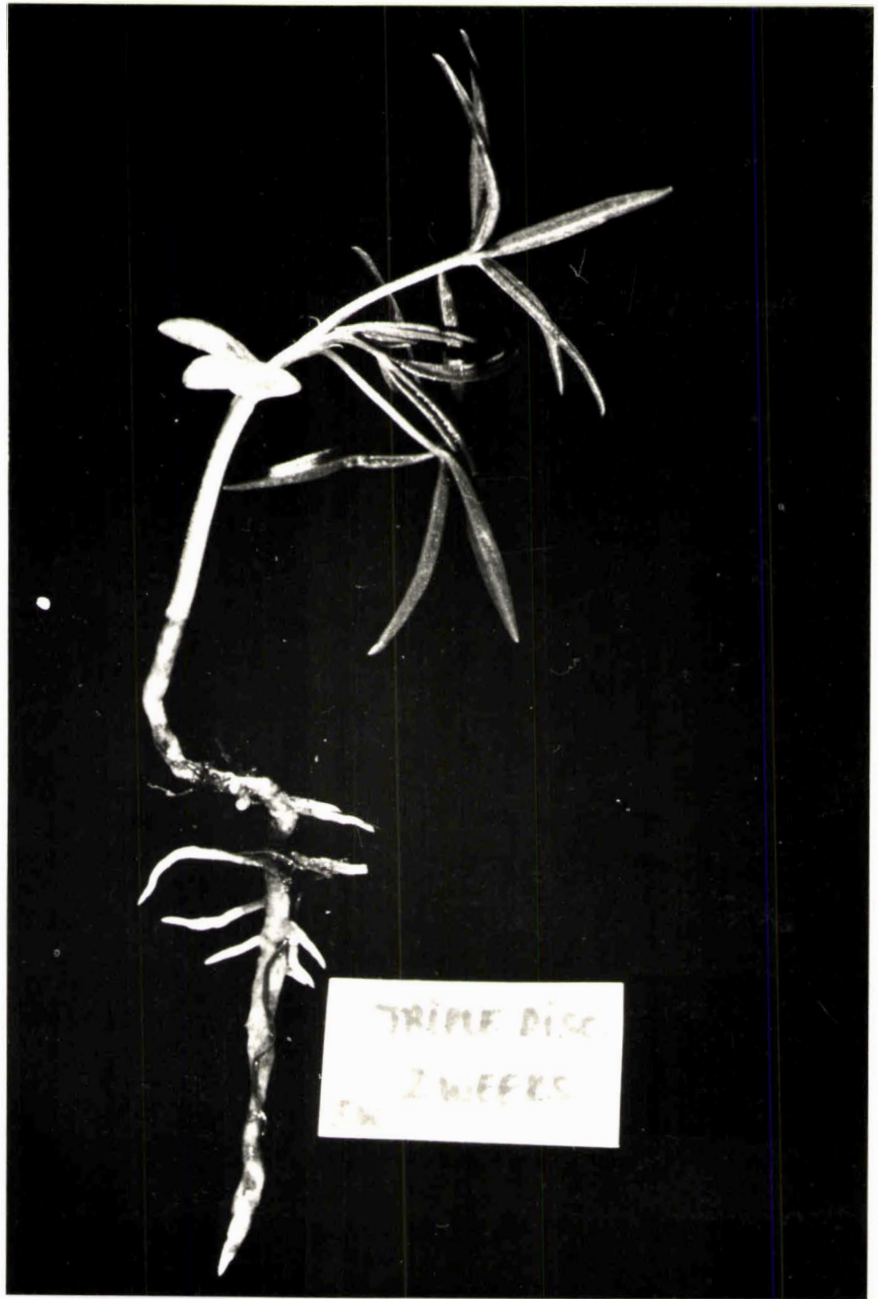


Fig.56. A lupin root which has been deflected at the base of a triple disc groove.

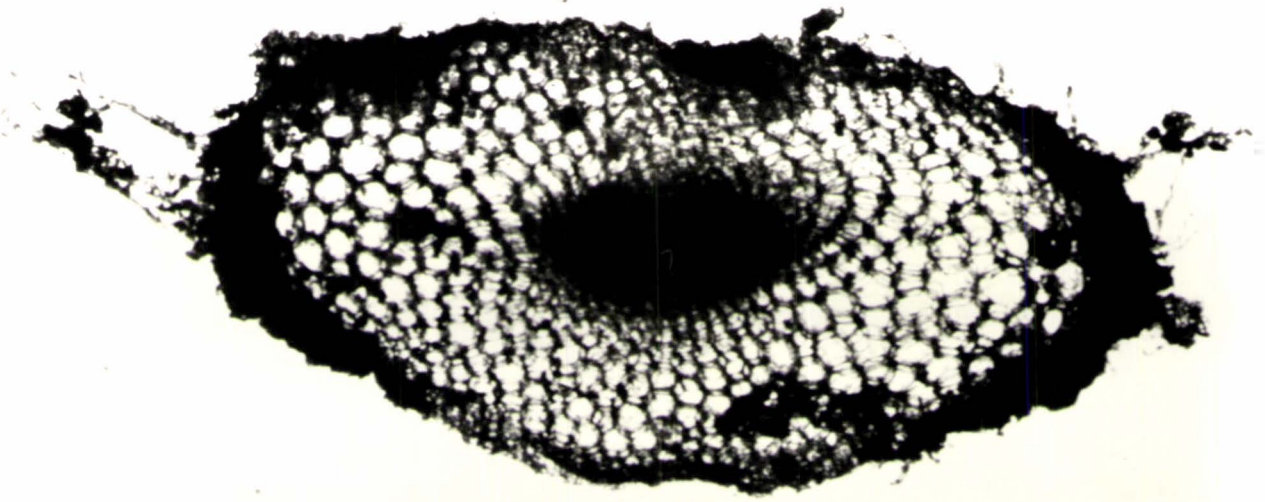


Fig. 57. Cortex portion of lupin cross section flattened because of hard soil (less than 14 days).

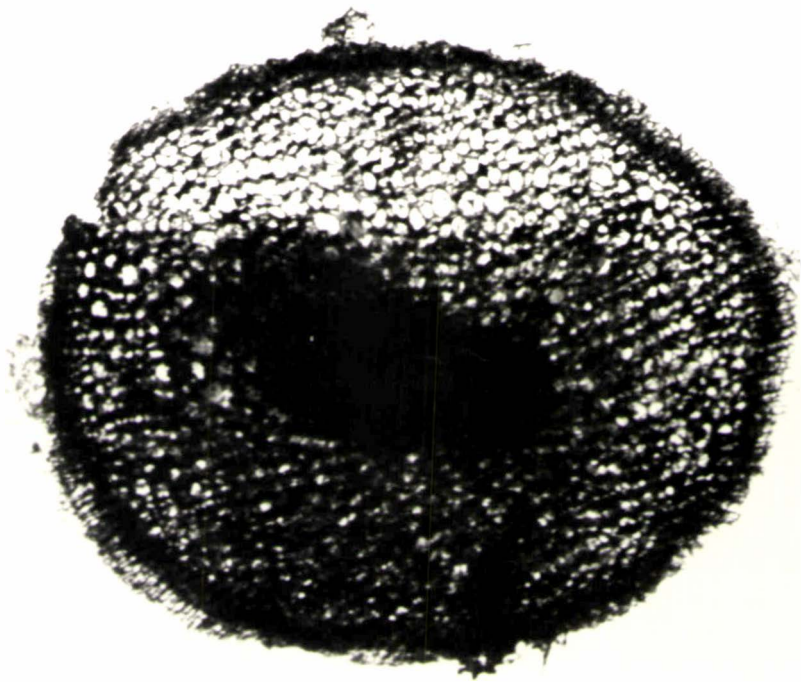


Fig. 58. Lupin root cross section grown in uncompacted soil (less than 14 days).

5.4.3 Brief Summary.

The widely opened groove observed with the triple disc coulter appeared to be a disadvantage in this experiment, particularly in the dry soil conditions. This may have been associated with more rapid evaporation of drying of seeds due to their exposure to the air.

In the more moist soils however, smearing of triple disc groove walls was observed and this supported the observation of Dixon, Baker, Ellis et al, B.D. Soane (loc.cit). This smearing effect in a soil of initial high bulk density combined with the additional compaction at, and near the base of the grooves was clearly detrimental to the development of lupin root systems (and possibly also wheat) and may also somehow have affected emergence of these seedlings. The effect was more severe when an induced dry period followed the drilling.

Figures 59 and 60 illustrate the poor emergence of wheat in the dry regime of the triple disc treatment and the better (though still weak) emergence in the chisel coulter treatment by comparison.



Fig.59.Poor seedling establishment in the triple disc coulters treatment.



Fig.60.Improved seedling establishment in the chisel coulters treatment.

5.5 EXPERIMENT 4.

5.5.1 Objectives.

Although experiments 1, 2 and 3 showed consistent differences between the two tested coulter designs, these experiments were not able to provide answers as to how the performance of the triple disc coulters might be improved, although some observations were made. For example, the grooves of that coulters gave the appearance of being open after drilling (Fig. 61), and did not improve in this respect even after harrowing when the soil was moist. The chisel coulters grooves were also not always closed in moist soil either, but the drilled seeds in the grooves seemed to be less exposed to the drying air and radiation because of the basic shape of the groove itself.

In order to investigate more closely, the effects of smearing, compaction and groove exposure within different grooves on root growth and seedling emergence, an experiment was conducted using small scale soil blocks. Each of the "undisturbed" blocks was contained in a wide wooden box measuring 450mm long x 300mm wide and 100mm deep.

The specific objectives of this box experiment were aimed at gaining an insight into the underlying causes of the following effects, first noticed in experiments 1, 2 and 3.

- (1) Under dry conditions, seedling root growth in exposed grooves was poor.
- (2) The seedling emergence and root growth performances of the "V" shaped triple disc coulters treatments were poorer than those of the chisel coulters treatments which had a cross-sectional shape between an inverted "V" and an inverted "T". (fig. 62)

- (3) Smearing, as observed on both sidewalls of the V shaped grooves created by the triple disc coulter may have contributed to the decreased seedling root growth noted in this treatment.

The six treatments used in experiment 4 were as follows:

- (1) V shaped grooves were cut by hand with a sharp knife so as to ensure that the groove walls were not smeared and the bases were not compacted.
- (2) The chisel coulter was used unmodified to create its characteristic groove.
- (3) V-shaped grooves were cut by hand with a knife and then trowelled carefully to create a degree of smearing and then rolled with a V-shaped press wheel to compact the base.
- (4) V-shaped grooves were cut by hand with a knife and then trowelled only, to smear the groove walls without base compaction.
- (5) V-shaped grooves were cut as for treatment 4 but after seed deposition the grooves were well covered by loose soil to the ground surface level.
- (6) W-shaped grooves equal in width to the chisel grooves were cut with a knife so that neither the sidewalls nor bases were smeared or compacted.



Fig.61.
The characteristic
shaped groove of the
Triple disc coultter.



Fig.62.The characteristic subsurface shattering of
the chisel coultter.

All grooves were cut 35mm deep and the experiment was conducted using a "Tokomaru silt loam" soil at an initial moisture content of 25% ww. The initial soil bulk density was 1.04g/cm^3 and this was increased where appropriate at the base of the groove to 1.25g/cm^3 with 8 passings of a 10kg V-shaped press wheel. Exertion of higher pressures on the groove base was not applied, to avoid possible cracking at the base of the shallow soil blocks.

Lupin and wheat seeds were sown by hand into the grooves of all treatments. All except treatment 5 were covered by a thin layer of soil, just sufficient to hide the seeds from the naked eye (and thus avoid direct exposure to radiation), but not sufficient to fill the grooves with loose soil. Four blocks of 6 treatments in a randomised block design, were kept under rain canopies throughout the experiment. Observations and measurements were taken only on the seventh day after sowing, because it was found that the roots in some treatments had already reached the base of the boxes by that time.

Results.

The results of seedling emergence are presented in Table 21. The results of plant height, root length and root dry weight are given in Table 22. Due to poor seedling establishment in treatments 3 and 6, these two treatments are not included in Table 22.

DISCUSSION:

Seedling emergence from the U-shaped groove appeared to be negligible (Table 21) and significantly poorer than all other treatments except treatment 3. This might appear to be due to the effects of excessive exposure in that groove. However, treatment 6

had in common with treatment 1, 3 and 4, exposure above the seed. It is not likely therefore that this factor alone, was responsible for the poor performance as treatment 4 and 1 were significantly better than treatment 6. Perhaps the exposure effect was partly offset because the seed was wedged at the base of a V (and thus in better direct contact with the sidewalls as well as the base of the groove), whereas seed in treatment 6 lay on essentially a flat groove base. This explanation too is not complete in entirety as seed in treatment 3 was also wedged and yet was not significantly superior to treatment 6. In this case, base compaction of the groove was an additional factor and may have played an important role.

Apart from the effects of wedging, there was also a significant contrast between treatments 3 and 6, and treatment 2. The soil flaps on both sides of the chisel coulter groove (treatment 2) may have helped to prevent seeds from being exposed to the air and certainly appear to have played a part in the superior performance of that treatment. Covering (treatments 5 and 2) appeared to have been more important to seedling emergence than the avoidance of smearing (treatment 1). In fact, the smeared but not well covered V-shaped groove (treatment 4) was not significantly inferior to the two covered treatments (5 and 2). Nor was treatment 4 significantly superior to the non smeared poorly covered groove (treatment 1). Smearing alone, in the V-shaped grooves therefore, is unlikely to have been the dominant factor in the different performance of the V-shaped treatments under these soil moisture and climate conditions, which were generally favourable.

There were no significant differences between treatments 1, 2, 4 and 5 in terms of root dry weight, plant height or root length of individual plants (Table 22). Thus it seems that with those plants which did emerge, groove shape etc, had no further effect on their development.

The conclusions concerning seedling emergence were largely supported by visual appraisal and photographs of the grooves which are shown in figures 63 and 64. The photographs also depict early root growth, data for which are given in Tables 21 and 22.

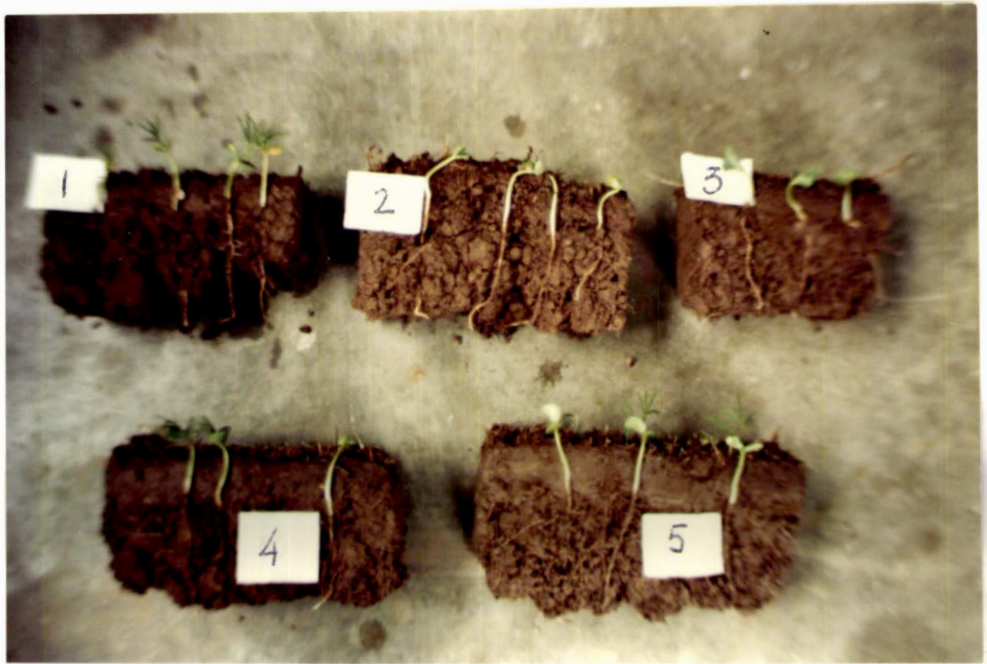


Fig.63.The effects of smearing on seedling performance from various shapes of grooves(trts 1,2,3,4 and 5).



Fig.64.Close-up view of seedling emergence from the smearred V shaped grooves(trt.5.).

TABLE 21: The effects of direct drilling groove formation techniques on seedling emergence.
(No. plants per row)

Treatment and No.	Chisel Coulter groove 2	V Shaped knife-cut grooves				U shaped groove 6
		smeared and well covered 5	smeared not well covered 4	non-smeared not well covered 1	smeared and compacted 3	
Lupin	7.5 <u>ab</u> *	10.25 <u>a</u>	9.75 <u>ab</u>	6.50 <u>be</u>	3.50 <u>ed</u>	0.25 <u>d</u>
Wheat	10.75 <u>m</u>	9.5 <u>m</u>	4.25 <u>n</u>	2.0 <u>np</u>	1.25 <u>p</u>	0 <u>p</u>

* Unlike letters in a row denote significant differences (P = 0.05)

TABLE 22: The effects of shape, smear, compaction and cover of direct drilled grooves on wheat and lupin plants.

		LUPIN	WHEAT
Chisel (2)	R.D.W. *	0.018 a	0.014 f
	P.H. *	51.50 c	87.00 h
	R.L. *	90.00 e	104.50 j
Knife-cut V shaped well covered (5)	R.D.W.	0.024 a	0.014 f
	P.H.	44.70 c	90.00 h
	R.L.	93.50 e	102.50 j
Knife-cut V shaped groove smeared groove walls (4)	R.D.W.	0.029 a	0.016 f
	P.H.	40.20 c	97.00 h
	R.L.	107.50 e	123.20 j
Knife-cut V shaped groove non smeared groove walls (1)	R.D.W.	0.023 a	0.017 f
	P.H.	40.20 c	77.00 h
	R.L.	89.5 e	85.00 j

* R.D.W. : Root dry weight (grammes) * P.H. : Plant height (mm) * R.L. : Root length (mm)
 Unlike chronological letters in a column depict significant differences (P = 0.05).

In the photographs, the smeared surfaces of the V-shaped groove walls (treatments 3, 4 and 5) did not appear to affect the growth of roots any more than the non-smeared walls (treatments 1 and 2), the smear was generally above the seed position and the roots tended to grow and elongate towards, and through the base of the groove. The smeared surfaces did not therefore appear to present a mechanical impedance problem to seedling root growth.

5.5.2 Brief Summary

The above results suggest that of the four groove factors which were partly or wholly isolated (viz. smear, compaction, shape and cover), cover and compaction were the most influential on seedling emergence. There were no significant differences in terms of seedling emergence between the chisel coulter groove and any of the forms of the simulated triple disc coulter grooves except where the latter was smeared, compacted and uncovered. It was felt that those contrasting groove shapes may have been more important than the data suggested but the small sample plots and destructive sampling techniques limited the amount of useful data collected and thus limited examination of the interactions of shape and cover. Smear was the least important factor considered.

5.6 EXPERIMENT 5. (Field experiment)

5.6.1 Objectives.

Evidence obtained in experiment 3 suggested that coulter types and their effect on soil physical properties at the seed level micro-environment could be important to root growth. However, it was felt that these effects in the top soil might be relatively short-lived if time allowed the effects of natural soil and biological changes to take place in field conditions.

This field experiment was designed to investigate:

- (a) The repeatability of the plant responses of the tillage bin results in a field situation, and
- (b) To what extent the natural growth cycle of the plants and biological activity of the soil would modify, over time, the short term changes in soil parameters brought about by different coulter shapes.

The factorial experiment with 4 randomised complete blocks involved 2 coulters, 2 soil bulk densities and 2 crop species (lupin and wheat). It was laid down in the middle of Autumn 1977 on a "Tokomaru" silt loam soil.

Prior to the experiment (and having regard to the root retardations recorded in experiment 3 when using a relatively high bulk density soil) an extensive survey was conducted in the district to attempt to locate a field soil of bulk density approximating 1.30 to 1.40g/cm³. Enquiries were also made from districts as far away as 150km to see if soils of this nature could instead be transported in tillage bins to Massey University. Eventually, the most satisfactory

experimental site chosen was a field site on the Massey University No. 4 dairy farm. This soil in its natural state had a bulk density of 1.10 to 1.25g/cm³ in the top 8cm. Although this was at the lower end of the arbitrary bulk density range preferred, it was found that the bulk density could be increased sufficiently using a 1.4 ton vibrating roller before drilling.

Six passes of the roller were found necessary to increase top soil density from 1.10g/cm₃ to 1.32g/cm₃. Three days before drilling all experimental plots (measuring 3m x 5m) were sprayed with Glyphosate at 6l/ha in 350l/ha of water.

Harrowing was carried out after drilling with a bar harrow to help cover those grooves still exposed to the air. Slug pellets were also applied as a blanket treatment.

The triple disc grooves appeared not to be well covered despite harrowing. The open nature of these grooves appeared to be largely due to the high soil water content (24% ww), the abundance of root material in the soil and the slow operating speed of the drill (2km/hr) which was limited because of the plot size. The soil flaps on both sides of the chisel groove were also not very effective in covering the groove in these soil conditions.

Differences in the apparent pre-drilling grass kill by glyphosate were noticed. The greatest kill appeared to be on those plots where the roller was used. This was possibly partly due to the grasses having been pre-damaged when compacted by the roller, and also partly due to the increased surface contact of the grass leaves with the herbicide droplets.

It was intended that samplings would take place at weeks 5, 7 and 9, but slow and poor seedling emergence due to the poor seed placement (and compounded by unusually wet winter weather) and serious fulsarium attacks on roots resulted in most of the experiment being abandoned.

Climatic data for the experimental period are given in appendix 8.

Results. Only the week 5 samplings of lupin and wheat crops were taken. These are presented in Tables 23 and 24.

DISCUSSION:

Poor seedling emergence was generally found in all coulter treatments although from observation, the emergence of wheat seedlings may have been slightly superior to all others in the compacted plots of the triple disc coulter treatments. Per plant measurements of root dry weights were possible at week 5 but because of the low number of plants and their isolation in term of intra specific competition, the validity of this data is by no means sure if it was to be extrapolated to a "normal" density field crop.

There were no significant differences in wheat root dry weights between any of the 4 treatments (Table 23) and their interactions. With lupin, however the trends were difficult to understand. The triple disc coulter operating in compacted soil appeared to produce significant larger ($P = 0.05$) roots than its counterpart in uncompacted soil.

The interaction (soil coulter) for lupin, shown in Table 24 is highly significant. The treatment combination of triple disc coulter and rolled soil appeared to be superior to all other treatments.

It is possible that the soil compaction produced by rolling after both coulter was alleviated by the high soil water content. The soil water molecules acting as a lubricant within the soil matrix could be expected to decrease the soil strength and the soil might therefore be expected to impede root exploration less (if at all), than when the soil was drier. Water logging and lack of oxygen were also clearly evident with this poorly drained "Tokomaru" silt loam. Short periods of anaerobic conditions in soil seem to have caused irreparable damage to the root system of many plants. (130)

TABLE 23: The effects of soil and drill coulter designs on lupin and wheat root dry weights (g) in field conditions.

	Wheat	Lupin
<u>Coulter treatments</u>		
Chisel coulter	0.030	.124
Triple disc coulter	0.029	.133
Statistical significance of differences	NS	*
<u>Soil treatments</u>		
Rolled	0.030	.129
Unrolled	0.029	.128
Statistical significance of differences	NS	NS

* P = 0.05.

TABLE 24: The effects of soil x coulter interactions on lupin and wheat root dry weights (g) in field conditions. (experiment 5)

<u>Soil x Coulter Treatments</u>		WHEAT	LUPIN
		Chisel Coulter	Rolled
	Unrolled	0.029	.130
Triple Disc Coulter	Rolled	0.030	1.41
	Unrolled	0.029	1.26
Statistical significance of differences		NS	**

** P = 0.01

5.7 EXPERIMENT 6 (Field experiment)

5.7.1 Objectives.

Experiment 6 was conducted in Spring/Summer 1977/78 on the same area as experiment 5. The objectives of this experiment were identical to those described in experiment 5 except that in addition, counts of earthworm populations were made. Prior to drilling, wheat and lupin seeds were treated with a mixture of "Thiram" and "Benlate" to prevent fungus attacks. No irrigation or nutrients were applied during the whole experimental period. Samplings were taken at three intervals (viz. 3, 5 and 7 weeks). There were eight randomised experimental plots in each of four blocks. The plants were randomly sampled per plot for measurements of herbage dry matter and root dry weight.

Measurements of seedling emergence were taken at two intervals (10 and 14 days). Three separate meter lengths of rows of seedlings were randomly chosen and counted per plot.

Reported studies (149,152) on the effects of earthworms and other soil animals have indicated that they could create tunnels and burrows in the soil which might; (1) prevent undisturbed soil from becoming compacted and/or (2) modify any compaction effects after drilling. An attempt was therefore made to obtain a measure of the population of earthworms in each treatment in order to see if there were any interactions between earthworm populations and the drilling and compaction treatments. No attempt was made to closely study the actions of the earthworms and by what means they affected, or were themselves affected by the soil treatments. The populations were estimated by counting earthworms in extracted soil blocks (which measured 140mm x 120mm x 120mm). One soil

block was taken per plot. Terminal measurements of yields of wheat and lupin crops were taken in late Summer 1978.

Results. The sequential results of root and herbage dry weights for weeks 3, 5 and 7 are presented in Tables 25, 26; 27, 28; 29 and 30.

Seedling emergence counts on days 10 and 14 were given in Tables 31 and 32 respectively.

Earthworm counts at weeks 3 and 5 are shown in Tables 33 and 34 respectively, and terminal yields of both crops are given in Tables 35, 36 and 37.

TABLE 25: The effects of direct drilling coulter design and soil compaction on root and shoot growth of wheat and lupin crops at 3 weeks.
(main treatment effects)

Main Treatments	WHEAT		LUPIN	
	Root dry weight (g)	Herbage dry weight (g)	Root dry weight (g)	Herbage dry weight (g)
<u>Coulter Treatments</u>				
Chisel Coulter	0.300	0.354	0.665	1.355
Triple disc coulter	0.212	0.295	0.783	1.519
Statistical significance between coulters	N.S.	N.S.	N.S.	N.S.
<u>Soil Treatments</u>				
Rolled	0.251	0.317	0.654	1.357
Unrolled	0.261	0.323	0.745	1.517
Statistical significance between soil treatments	N.S.	N.S.	N.S.	N.S.

TABLE 26: The effects of direct drilling coulter designs and soil compaction on root and shoot growth of wheat and lupin crops at 3 weeks (interactions)

Interactions Soil X Coulter treatments			WHEAT		LUPIN	
			Root dry weight (g)	Herbage dry weight (g)	Root dry weight (g)	Herbage dry weight (g)
Chisel	Rolled	1	0.278	0.337	0.610	1.291
Coulter	Unrolled	2	0.323	0.372	0.720	1.419
Triple Disc	Rolled	3	0.224	0.317	0.697	1.423
Coulter	Unrolled	4	0.200	0.273	0.778	1.615
Statistical significance of the interaction			N.S.	N.S.	N.S.	N.S.

TABLE 27: The effects of direct drilling coulter design and soil compaction on root and shoot growth of wheat and lupin crops at 5 weeks (main treatment effects)

Main Treatments	WHEAT		LUPIN	
	Root dry weight (g)	Herbage dry weight (g)	Root dry weight (g)	Herbage dry weight (g)
<u>Coulter Treatments</u>				
Chisel Coulter	0.532	1.377	1.205	3.064
Triple Disc Coulter	0.491	1.545	0.896	2.691
Statistical significance between coulters	N.S.	N.S.	N.S.	N.S.
<u>Soil Treatments</u>				
Rolled	0.530	1.487	0.983	2.525
Unrolled	0.493	1.435	1.117	3.230
Statistical significance between soil treatments	N.S.	N.S.	N.S.	N.S.

TABLE 28: The effects of direct drilling coulter design and soil compaction on root and shoot growth of wheat and lupin crops at 5 weeks. (interactions)

Interactions Soil X Coulter Treatments			WHEAT		LUPIN	
			Root dry weight (g)	Herbage dry weight (g)	Root dry weight (g)	Herbage dry weight (g)
Chisel	Rolled	1	0.571	1.336	1.144	2.728
Coulter	Unrolled	2	0.493	1.419	1.266	1.401
Triple Disc	Rolled	3	0.489	1.640	0.822	2.322
Coulter	Unrolled	4	0.493	1.451	0.969	3.060
Statistical significance of the interactions			N.S.	N.S.	N.S.	N.S.

TABLE 29: The effects of direct drilling coulters design and soil compaction on root and shoot growth of wheat and lupin crops at 7 weeks (main treatment effects).

	WHEAT		LUPIN	
	Root dry weight (g)	Herbage dry weight (g)	Root dry weight (g)	Herbage dry weight (g)
<u>Coulter Treatments</u>				
Chisel Coulter	3.101	6.565	2.185	7.788
Triple Disc Coulter	2.657	5.550	1.805	7.112
Statistical significance between coulters	N.S.	N.S.	N.S.	N.S.
<u>Soil Treatments</u>				
Rolled	2.742	5.890	1.806	6.291
Unrolled	3.016	6.224	2.184	8.610
Statistical significance between soil treatments	N.S.	N.S.	N.S.	N.S.

TABLE 30: The effects of direct drilling coultter design and soil compaction on root and shoot growth of wheat and lupin crops at 7 weeks (interaction)

Interactions Soil X Coultter Treatments		WHEAT		LUPIN	
		Root dry weight (g)	Herbage dry weight (g)	Root dry weight (g)	Herbage dry weight (g)
Chisel Coultter	Rolled	2.908 NS	6.462 NS	1.898	6.202
	Unrolled	3.295 NS	6.668 NS	2.472	9.375 NS
Triple disc Coultter	Rolled	2.576 NS	5.318 NS	1.714	6.380
	Unrolled	2.738 NS	5.781 NS	1.896	7.845
Statistical significance of the interactions		N.S.	N.S.	N.S.	N.S.

TABLE 31: The effects of direct drilling coulter design and soil compaction on seedling emergence of wheat and lupin (main treatment effects)

	WHEAT SEEDLING COUNTS		LUPIN SEEDLING COUNTS	
	10 days after drilled	14 days after drilled	10 days after drilled	14 days after drilled
<u>Coulter Treatments</u>				
Chisel Coulter	22	21	17	21
Triple Disc Coulter	21	19	17	19
Statistical significance between coulters	N.S.	N.S.	N.S.	N.S.
<u>Soil Treatments</u>				
Rolled	23	21	17	19
Unrolled	19	20	18	21
Statistical significance between soil treatments	N.S.	N.S.	N.S.	N.S.

TABLE 32: The effects of direct drilling coulter design and soil compaction on seedling emergence of wheat and lupin (interactions)

Soil X Coulter Treatments			WHEAT SEEDLING COUNTS		LUPIN SEEDLING COUNTS	
			10 days after drilled	14 days after drilled	10 days after drilled	14 days after drilled
Chisel Coulter	Rolled	1	24	21	17	20
	Unrolled	2	20	21	17	22
Triple Disc Coulter	Rolled	3	23	20	16	18
	Unrolled	4	19	18	18	20
Statistical significance of the interactions			N.S.	N.S.	N.S.	N.S.

TABLE 33: The effects of direct drilling coulter design and soil compaction on earthworm populations (main treatment effects)

	WHEAT		LUPIN	
	Earthworm counts at 3 weeks	Earthworm counts at 5 weeks	Earthworm counts at 3 weeks	Earthworm counts at 5 weeks
<u>Coulter Treatments</u>				
Chisel Coulter	4.75	7.50	3.50	9.00
Triple Disc Coulter	4.25	7.37	4.12	7.62
Statistical significance between coulters	N.S.	N.S.	N.S.	*
<u>Soil Treatments</u>				
Rolled	4.12	6.75	3.62	7.37
Unrolled	4.87	8.12	4.00	9.25
Statistical significance between soil treatments	N.S.	N.S.	N.S.	*

TABLE 34: The effects of direct drilling coulter design and soil compaction on earthworm populations (interactions)

Soil X Coulter Treatments		WHEAT		LUPIN	
		Earthworm counts at 3 weeks	Earthworm counts at 5 weeks	Earthworm counts at 3 weeks	Earthworm counts at 5 weeks
Chisel	Rolled	4.25	7.25	3.25	7.75
Coulter	Unrolled	5.25	7.75	3.75	10.75
Triple	Rolled	4.00	6.25	4.00	7.00
Disc	Unrolled	4.50	8.50	4.25	8.25
Coulter					
Statistical significance of the interactions		N.S.	N.S.	N.S.	*

* P = 0.05.

TABLE 35: The effects of direct drilling coulter designs and soil compaction on wheat yield.

<u>Coulter treatments</u>	WHEAT YIELD number of heads/lm of drilled row	<u>Interactions</u>	WHEAT YIELD number of heads/lm of drilled row
Chisel	55.37		
Triple Disc	56.25	Chisel	
		Rolled	51.00
		Unrolled	59.75
Statistical signi- ficance between coulters	N.S.		
<u>Soil Treatments</u>			
Rolled	53.50		
Unrolled	58.12	Triple Disc Coulter	
		Rolled	56.0
		Unrolled	56.50
Statistical signi- ficance between soil treatments	N.S.	Significance	N.S.

TABLE 36: The effects of direct drilling coulter designs and soil compaction on lupin yield.

<u>Coulter treatments</u>	Seed dry weights grams	Total number of pods	Total number of seeds	Number of pods/ plants
Chisel Coulter	39.95	101	352	4.25
Triple Disc Coulter	43.16	110	391	4.47
Statistical signi- ficance between coulters	N.S.	N.S.	N.S.	N.S.
<hr/>				
<u>Soil treatments</u>				
Rolled	36.42	92	321	4.18
Unrolled	46.69	119	421	4.53
Statistical signi- ficance between soil treatments	N.S.	significance at 10%	N.S.	N.S.

TABLE 37: The effects of direct drilling coulter designs and soil compaction on lupin yield. (interactions)

Soil X Coulter Treatments			Seed dry weight (g)	Total number of pods	Total number of seeds	Number of pods per plant
Chisel	Rolled	1	33.62	88	302	3.95
Coulter	Unrolled	2	46.29	115	402	4.55
Triple Disc	Rolled	3	39.22	97	341	4.42
Coulter	Unrolled	4	47.09	124	441	4.52
Statistical significance of the interactions			N.S.	N.S.	N.S.	N.S.

N.S. = Non significant.

DISCUSSION(a) Root and herbage dry weights.

Results from Tables 25 to 30 inclusive indicated that root dry weights and herbage dry weights of both wheat and lupin crops were not significantly affected by coulter designs nor by the state of compaction of the soil prior to drilling, nor were there any significant interactions between soil compaction and coulter treatments. With some exceptions, there did appear however to be a slight but statistically insignificant trend towards lower weights of root and shoots with both coulters in the compacted plots and also with the triple disc coulter in both soils, compared to the chisel coulter. This was more noticeable with lupin than wheat.

Lupin had earlier (experiment 3) been shown to be more sensitive to the soil compaction than wheat. Lupin seedling development in this experiment appeared to be generally more rapid in the uncompacted plots especially in the triple disc coulter treatments. No clear and/or significant difference in development of roots compared with shoots could be seen in any of the treatments however.

(b) Seedling emergence.

Results of seedling counts at days 10 and 14 (Table 31 and 32) also failed to expose any significant differences between the two coulter treatments in both soil conditions.

There may have been a slight but statistically insignificant advantage with wheat at day 10 from compacting the soil prior to drilling with both coulters, but this was not confirmed at day 14. Again, no significant interactions could be found between coulter types and soil compaction.

(c) Earthworms.

In Table 33 the population of earthworms was not found to be significantly affected by soil density or coulter treatments under either crop at day 21. With wheat, there were still no significant differences in earthworm populations between coulters within either soil density nor between soil densities with either coulter at day 35 (Table 34). However with lupin at day 35, there was a significantly higher earthworm population in plots using the chisel coulter compared with the triple disc coulter (Table 33), and a similarly significant difference favouring uncompacted soil with lupin using both coulters compared to compacted soil at day 35 (Table 34).

It was also noted that the total number of earthworms had increased in all treatments between day 14 and 35 although this trend was not analysed statistically (Table 34).

It is difficult to ascertain whether or not the soil was compacted sufficiently to affect the life cycle and reproduction of the earthworms. Perhaps an earlier population count immediately after the soil was rolled might have yielded useful information in this regard. It is also possible that much of the structural differences of the soils, brought about as a result of rolling and non-rolling may have been reduced because of the rather extreme climatic conditions during the first two weeks of the experiment (heavy rainfall followed by a dry hot period). For this reason, the overall increase of earthworm population recorded at the 35th day may have simply reflected the improving climatic conditions. There was insufficient data collected on the earthworm activity in this experiment to draw strong conclusions as to the relative

effects of the two coulters per se on populations and life cycles and vice versa.

(d) Yields.

The terminal crop yield data of Table 35, 36 and 37 indicate that the terminal seed yields of both wheat and lupin appeared not to be significantly affected by coultter designs or compaction in this experiment.

This is in agreement with the previously discussed data obtained for root dry weight, herbage dry weight and seedling counts. The limited data obtained for wheat yields (number of heads/3 meter lengths of drilled row) was not considered adequate and therefore does not justify detailed discussion. However measurement of aspects of lupin yield involved determining seed dry weight, total number of pods, total number of seeds and numbers of pod per plant^{was taken,} No statistically significant differences were found in these parameters between coultter treatments although the trends seemed to suggest that lupin yield may have been marginally better in the triple disc plots than in the chisel coultter plots. Likewise, the uncompacted plots overall may have been marginally superior to the compacted plots, and in terms of total pods, this trend was significant at the lower order of probability of 10%. If this trend was indeed real, it probably reflected the marginally better (though not significant) seedling performance of lupin crop found in the uncompacted plots at earlier samplings.

6.

SUMMARY AND DISCUSSIONA. EQUIPMENT AND MEASURING TECHNIQUES

There has been little reported work on the development of equipment and techniques associated with the investigation of direct drilled groove characteristics. (68,103) The designing, modifying and testing of equipment and techniques used to detect changes in soil physical properties at seed level microenvironment have been an important part of this study.

There is no single measurement which adequately reflects the state of compaction of soils in relation to the tests which were envisaged in this study. In order, therefore, to gain as much information as possible from the various alternative measurements that were feasible a number of simultaneous studies were made. Individually all of these studies had limitations which are discussed below, but collectively they presented a good picture of the physical changes that were taking (or had taken) place in the soil as a result of the passage of the coulters. It is possible that in future studies of this type some of the less fruitful techniques might be eliminated but it is difficult to see any one technique in isolation providing all the answers required.

One of the major design difficulties has been the problem of locating measuring equipment in the soil without causing excessive disturbance to soils at the test site.

In the measurement of soil bulk density at the groove base a steel mini-core sample with sharpened leading edges was vertically driven

down into the soil. Samplings were taken with great care to minimize compaction at the edges of the core sampler. Nevertheless some compaction was inevitable because of the drag force which was developed through soil contact with the inside of the sampler tube. This force could be appreciable when the soil was wet and sticky.

In the measurement of soil strength the multi point penetrometer was developed for use with turf blocks that had been extracted from the field. One of the objectives of this multipoint penetrometer was to attempt to reduce some of the variability obtained with single point penetrometers by sampling each time with a cluster of four probes. It was found advantageous to locate a transducer across the proving ring of this device. In this manner, as the penetrometer advanced into the soil at a steady rate, a continuous record of penetration as a function of depth was obtained. A measure of soil strength could thus be obtained between given soil depths by averaging the penetrometer readings from the tracings within the appropriate ordinates. Where soil resistance at a specific depth was of interest, the penetrometer resistance at that depth could also be taken directly from the curve produced by the chart recorder. The penetrometer resistance readings were not only depended upon the combined influence of soil cohesive and frictional characteristic, but also the shape of the instrument. Some combination of cutting, separation, shear, friction and compression failure may have been responsible for the readings. Thus these readings were not regarded as being absolute, but instead were considered to be useful for comparison studies only.

In the measurement of soil pressure (instantaneous zone of influence) the pressure sensing tubes were designed to monitor only the normal component of stress developed by the passing coulters. They were not designed to study the complete state of stress in the soil at a given point.

It was recognised that the measurement of soil pressures alone could not be used to evaluate the soil compaction which resulted from these exerted pressures. The resulting compaction for a given pressure depends on the mineralogical and mechanical composition of the soil, its moisture content and the initial consolidation of the soil. The results reported were felt to be of value in supporting the data obtained from measurements of permanent deformation, and in attempting to locate the zones of influence of the passing coulters. The data could neither be expected to represent the major principal stress responsible for compaction (79), nor the mean stress (75). Furthermore only the normal component of the stress tension acting on the pressure membrane was measured, and this therefore assumed that all of other shear stresses were negligible. In fact it is probable that other shear stresses were created while the coulter was passing and that these should have been accounted for if a total stress analysis of the situation was to have been attempted.

The pressure on the rubber diaphragm was required to be transmitted by water. Thus its accuracy may have been influenced by ambient temperature variations. Specifically the main difficulties associated with this measuring technique were found to be:

- (a) The pressure sensing tube could not always be expected to

respond to the forces on it in exactly the same way as the cylinder of soil which it replaced;

- (b) The process of placing the sensing tubes in the soil inevitably caused some disturbance of soil around it;
- (c) The soil/rubber diaphragm surface contact could have been far from desirable because of the inability to examine them once they were in place;
- (d) Because of the potential temperature sensitivity of the device, it is possible that soil temperature gradients will have affected the sensing tubes while measuring was in process.

In the measurements of draft force while the actual results could be regarded as an accurate reflection of the draft requirements of the coulters in the bins, they could not be extrapolated directly to a field situation because of the extremely slow forward speed used in the bins.

The instrumentation used to monitor the disturbance on the surface of the soil on either sides of the coulter created grooves produced results of a qualitative nature because the device was not in anyway designed to measure the propagation stress as it may have affected soil changes. Neither were the probe characteristics (e.g. resilience, force pattern exerted on the probe, deformation pattern of soil around the probe) identified or studied.

Visual assessment of thin soil sections and the electron microscopic technique were two techniques which were found to be useful. More careful preparation and impregnation of samples may lead to eventual quantification of the characteristics (e.g. void and pore size)

of the soil sections obtained. X-ray examination of soil sections were attempted but was found unsatisfactory for the purposes of this study because the major interest was of changes in macrosoil structure, which is not adequately shown by X-ray.

B. SOIL PHYSICAL CHANGES AND ROOT RESPONSE DATA

The soil physical data obtained in these experiments were aimed at: (a) gaining an understanding of the permanent effects on a soil of the passage of two contrasting direct drilling coulters; (b) measuring simplistically the two major components of input energy required to operate each of the two coulters and (c) monitoring the instantaneous dissipation of soil stresses as the coulters passed.

a. Permanent soil deformation (bulk density and soil strength)

The summarised results of experiments 1, 2 and 3 are represented in Table 38.

Bulk density.

Compared with both the chisel coulters and the original soil, the common and highly significant trend of the triple disc coulters was to produce higher soil bulk densities at the groove base, irrespective of the initial soil bulk density.

The triple disc coulters increased soil strength at both the groove sidewalls and bases while the chisel coulters in most instances decreased the soil strength in these zones. In any case, the differences between the two coulters was highly significant.

The triple disc coulters also appeared to create narrow, smeared (if wet) and compacted grooves with little visible loose soil. The soil moisture content which appeared to sustain the most compaction by the triple disc coulters was 23% w/w. Soils wetter than this (28-30% w/w) and drier (20% w/w) appear to be less susceptible to compaction by this coulters. Similarly, the lower the initial soil bulk density, the greater appeared to be the increase in bulk density at the base of the triple disc

groove, although clearly there may have been an interaction in this respect with soil moisture content.

In all soil conditions, the chisel coulter appeared to have no effects on soil bulk density at the groove base. The soil bulk density data obtained in these experiments (and which are summarised in Table 38) can be rewritten as soil porosity (N%) data according to the expression $N\% = 100 - D/d$ where D and d are soil bulk density and particle density respectively. These data are also shown in the Table 38.

Soil strength.

Particles at both sidewalls and at the base of the triple disc grooves were seen to be smeared, which was considered to be an indirect indication that an increasing soil strength was likely to develop as they dried to form crusts where the smears had been.

Some smearing was also observed at the edges of the soil flaps generated by the chisel coulter. However, this smeared region was not at seed level and was eventually disturbed by the following harrowing operation. The smear created at the soil/metal interface of the triple disc coulter groove was, at first believed to have partly impeded seedling root elongation, particularly when the soil had been subjected to a dry period (2-3 days) after drilling. However data obtained from a subsequent experiment (4) suggested that the smear on both sidewalls of the triple disc created groove did not, in fact, mechanically impede the seedling roots. Rather the roots appeared to elongate axially and well beyond the smeared surfaces. Moreover, the smearing effect appeared to be more severe at a zone two thirds of the distance down from the top of the triple disc groove, and not in the areas immediately adjacent to the seeds.

TABLE 38: Summary of the effects of direct drilling coulter designs on bulk density, porosity and soil strength.

	Experiment No.	Moisture Content (w/w)	Soil before drilling	Chisel coulter treatment	Triple disc coulter treatment	Significance between coulter treatments	
Bulk density g/cm ³	1	23%	1.00	1.07	1.18	**	
	2	28%	1.04	1.03	1.15	**	
	3	20%	1.32	1.32	1.44	**	
Porosity %	1	23%		61	56		
	2	28%		61	57		
	3	20%					
Soil strength (penetrometer st)	Measured at the base of the grooves (N)	1	23%	.362	.279(decr)	.637(incr)	**
		2	28%	.343	.342(decr)	.427(incr)	**
		3	20%	2.83	.304(incr)	3.38 (incr)	*
	Measured at the sidewalls of the groove	1	23%	.362	.146(decr)	.409(incr)	**
		2	28%	.343	.249(decr)	.391(incr)	**
		3	20%	2.83	2.43 (decr)	3.11 (incr)	*

** P = 0.01

* P = 0.05

(b) Coulter operational forces.

Table 39 summarises the two major components of force required to operate the two coulter types in the experiments in which these were measured.

The penetration forces were those forces found necessary to create grooves with average depths of 35-40mm. It was observed that induced vertical cracking of the turf block was possible with the application of excessive penetration force, particularly in the case of the triple disc coulter, and in the drier soils. The data presented represents the gross weight applied above each coulter in the form of ballast. The net force required at any point in time was not known as the depth wheels carried the difference. Thus, statistical analysis of this data was felt to be meaningless.

It was apparent that the triple disc coulter produced a downward and wedging action which contrasted with the upward action of the chisel coulter. In as much as the latter action, (because of its proximity to the unrestricted soil surface) was able to be relieved by surface heaving, it is not surprising that the triple disc coulter required consistently, more vertical downward force to achieve penetration than did the chisel coulter. The order of magnitude of this difference averaged X4.0.

TABLE 39: Summary of forces required for penetration of two direct drilling coulters.

	Experiment No.	Moisture Content w/w	Chisel coulter treatment	Triple Disc Coulter treatment
Force required for coulter penetration (N)	1	23%	221	882
	2	28%	203	842
	3	20%	416	1210
Draft (N)	1	23%	2096	1684
	2	28%	1852	1210

The summarised results of draft measurements presented in Table 39 indicate that a significantly greater draft was required for the chisel coulter in both of the experiments in which this force component was measured. This was thought to be due to the greater energy needed by the chisel to shatter and pulverise the soil. The triple disc coulter in requiring less draft energy was seen to cut through and wedge the soil. It is also interesting to note that the draft requirements of the two coulters by comparison was of the reverse order (but not of the same magnitude) as the individual penetration forces. The mean order of draft difference in favour of the triple disc coulter was 1.25. Thus it might be concluded that if the input energy for both coulters can be resolved to these two simple components (draft and penetration) the total energy requirement for the chisel coulter was somewhat less than the triple disc coulter. Such a simplistic resolution would not be entirely realistic however as energy losses in the form of heat and wearing of components were not accounted for. The pure draft results however appear to support those of Koronka (1960) who was one of the few workers to measure this parameter.

The data for both coulters also showed an inverse relationship with soil moisture and soil strength data. As soil became drier, soil strength increased which resulted in higher draft forces.

(c) Instantaneous dissipation of soil stress.

Table 40 lists the summarized data for the two experiments in which the instantaneous dissipation of soil stress was recorded. This data suggests that pressures generated by the triple disc coulter were consistently greater than those generated by the chisel coulter. This

was especially so when measured directly under the base of the coulter path. The triple disc coulter produced, on average, three times the pressure in this position and 1.2 times the pressure at the sidewalls compared to the chisel coulter.

Again, the most reasonable explanation for these differences appears to lie in the comparative modes of action of the coulters. The chisel coulter in its loosening process produced an upward force and energy was expended in shattering and pulverising soils. The triple disc by contrast expended energy in packing soil particles at the base and to a lesser extent at the groove walls. Because the measurements of pressure at the base of the chisel coulter grooves were small, the recorded stress is likely to have been an hydrostatic stress rather than deviatoric. The same situation may have been occurring with the triple disc coulter but because of the greater magnitude of measured stress this could not be hypothesised with any confidence. Both must remain speculative however.

The recorded stress data were in strong agreement with the data obtained for measurements of soil strength and bulk density.

TABLE 40: Summarised effects of direct drilling coultter designs on soil pressure.

		EXPERIMENT I		EXPERIMENT II	
		Pressure measured at base position (kPa)			
Distance away from grooves		Triple Disc Coultter	Chisel Coultter	Triple Disc Coultter	Chisel Coultter
	3 cm		116 (2) ^t	35 (1)	167 (1)
5 cm		69 (4)	27 (4)	124 (1)	not measured
		Pressures measured at the sidewall position (kPa)			
3 cm		125 (2)	123 (3)	95 (3)	64 (3)
5 cm		not measured	73 (3)	49 (3)	30 (3)

^t figures in parenthesis represent the number of replicated readings found possible.

(d) Interactions

The data collected were of limited value in establishing broad interactions. For each coulter type, it was possible however to examine the relationship between soil moisture content and soil bulk density produced at the base of the drilled grooves in experiments 1 and 2, when initial soil bulk densities had been almost identical. Similar data from experiment 3 were not included because the initial soil bulk density differed markedly from those in experiments 1 and 2. The trends are shown in figure 65.

From this limited data it appears that as the soil moisture content increased, the difference between the two coulter types also increased, suggesting that the compaction associated with the triple disc coulter in this soil at initial bulk density approximating 1.00 g/cm^3 had increased with soil moisture content.

(e) The effects of coulter shapes on root growth

It is well known that roots cannot penetrate voids narrower in diameter than their root tips unless the void can be widened by pressure. Cemented or highly compacted pans present mechanical barriers to the elongation of roots. In soils with a deformable matrix, although root penetration is influenced by the heterogeneity of the soil, roots tend to have a geotropic response and create their own channels or elongate through cracks in the solid matrix. (126) The two contrasting drill coulter shapes tested in this investigation created different micro-environments at the seed level. This, in turn, brought about localized changes in the compactness of the soil and soil mechanical resistance.

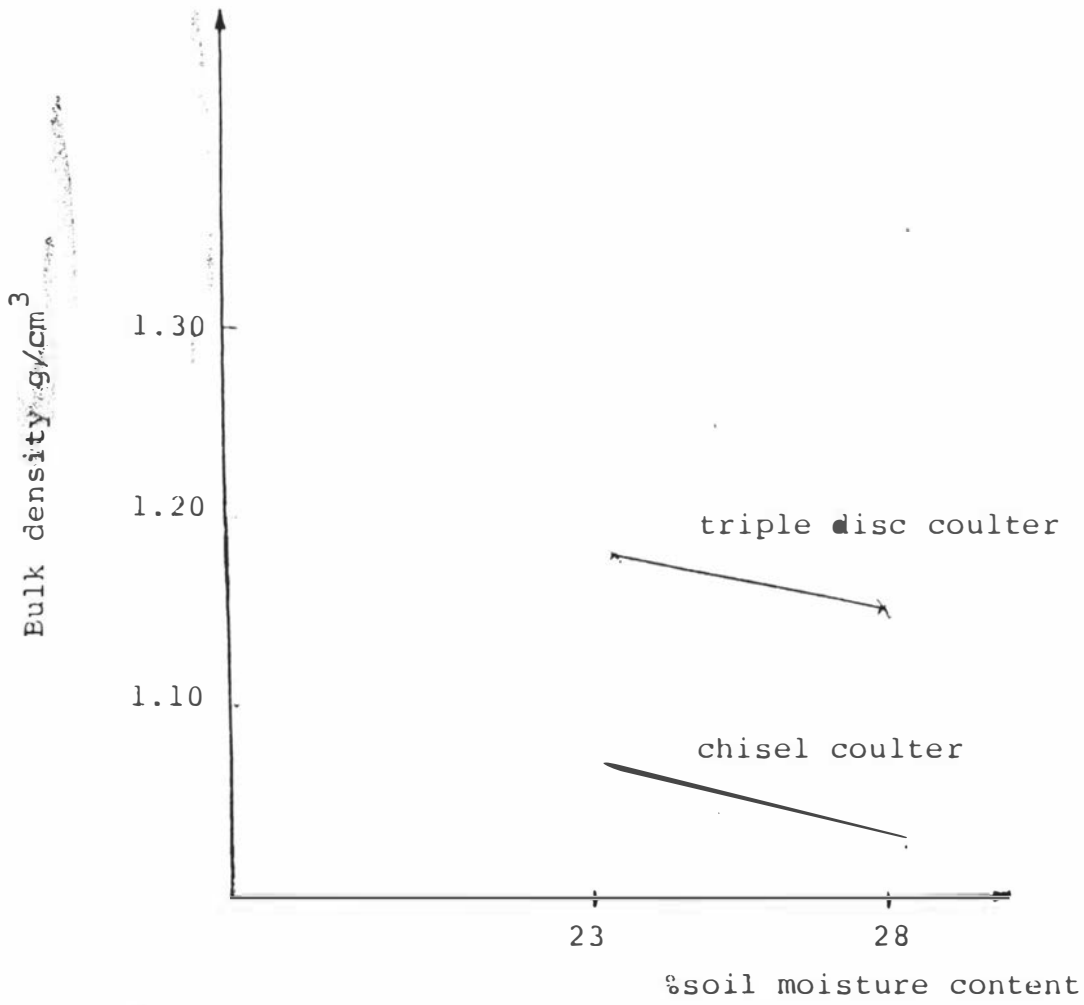


Fig.65. The inter-relationship between soil moisture content -soil bulk density and coulters type in indirect drilled silt loam.

It was however difficult to determine whether or not this mechanical resistance was important in isolation, as a change in one set of physical properties affects not only that property but also other factors such as soil, air, temperature and water supply. The results of the first two experiments reported herein, in which the soil moisture status was reasonably controlled and ambient conditions were not considered to be limiting, highlighted the effects of coulter designs in changing soil physical conditions in direct drilled grooves, but failed to show any indication of the effects of these soil physical changes on root growth. Although the groove created by the triple disc coulter appeared to be compacted in all experiments, clearly the desirability or otherwise of this compaction was subject to the initial soil conditions (i.e. loose or dense) and its moisture content (i.e. dry or wet). Thus, it is possible that in a moist, loose soil a triple disc coulter assembly could be more advantageous than a chisel coulter assembly. On the other hand, in a dry, dense soil condition, the chisel coulter was seen to be advantageous. The latter effect was shown in experiment 3 where a newly sown lupin crop was more sensitive to the soil compaction at the groove base created by the triple disc coulter than it was to the chisel grooves.

The most noticeable effects on the young lupin roots were reduced branching, flattening and distortion (fig. 57). Wheat root system were more difficult to separate from grass roots and other dead roots than were lupin. However, by volume they too appeared to be greater in the chisel coulter treatments than the triple disc coulter treatments in experiment 3. In any root study, some hydrotropic response of roots might be expected as a consequence of an uneven distribution of water

in the soil profile in the plants' environment. (166) It was therefore difficult in these experiments to differentiate between roots being impeded by the effects of the mechanical resistance of soil and from responding to any hydrotropic stimuli.

In all the dry soil regimes, the number of emerged wheat seedlings was low, possibly due to the drilled seeds either failing to germinate or germinating and failing to emerge.

In experiment 3, in which the soil was precompacted, its soil strength was probably further increased during the experiment as soil water evaporated (particularly from the "dry" ends of the bins). In this situation it is possible that the development of the radical end of the hypocotyl and the plumule end of hypogeal of the seedling may have been under some stress. These centres of growth may not have been in sufficient contact with the soil at that stage of growth, or were impeded by soil mechanical resistance (even though nutrient availability and the soil environment should have been favourable had the plants been able to utilise them to advantage).

By contrast, in experiments 1 and 2, it appeared that where the soil moisture contents were not limiting (23% w/w and 28% w/w respectively) and where soil bulk densities in the groove were not high (1.18g/cm³ and 1.15g/cm³ respectively) seeds probably had a suitable medium in which to initiate germination and proceeded to emergence.

Lupin seedlings also reflected differences between the coulter treatments. Emergence in the chisel coulter treatments was significantly greater than in the triple disc treatment and the tap root diameter was also significantly larger in the former treatment. The above ground stem

diameter of lupin in the triple disc coulter treatment was also smaller in experiment 3 than in the chisel treatment. This may simply be a direct reflection of the reduced root diameter but may also be an indirect effect resulting from the smaller triple disc roots being less able to explore nutrient reserves and respond to hydrotropic stimuli.

The field experiments were designed to investigate whether or not time permitted compensating effects to take place within the respective crops.

The results of the two field experiments were inconclusive. While it was expected that the soil bulk density would be modified by the two coulters in a similar manner to that recorded in the bins within a laboratory situation, insufficient plant response data could be collected to monitor any soil effects in terms of plant growth through its full cycle. In the second experiment while plant growth was relatively unrestricted by outside influences, no responses attributable to coulter treatments could be detected at any stage of growth. It is possible that in the active growth period of the latter experiment, root decomposition of the sprayed pasture, and earthworm activity may have been of sufficient importance to override any localised coulter influences. Certainly the greatest concentration of earthworms was found to be in the top 100mm of soil, and this population increased during the season. This explanation is not entirely satisfactory however because earthworm populations themselves differed significantly between coulter and compaction treatments under lupin, but not under wheat. Further explanations therefore can only remain speculative.

7.

CONCLUSIONS.

The study reported herein attempted to identify some of the soil physical properties which were affected by contrasting designs of direct drilling coulters and to relate these soil physical properties to root growth and plant development. The practical value of using any one of the physical measurements as a soil indicator may be argued but together with all of the other methods and techniques, consistent data was able to be collected, and these helped to define the in-groove microenvironments created by the two chosen coulters and relate these to plant root growth.

The data suggests that the designs of drill coulters and their consequent effects on soil physical properties are indeed important criteria in the technique of direct drilling.

An experimental chisel coulters developed by Baker (68), under varying moisture conditions pulverised a narrow band of subsurface soil and allowed seeds to drop into the base of the groove while the overlying turf flaps were held apart.

A commercially available triple disc coulters, by contrast, formed a V-shaped open groove with little shattering and left the seeds partly exposed at its base.

Smearing was found on the groove wall in moist soil with the triple disc coulters but experiments indicated that most roots elongated axially through the base of the groove and although the smeared surfaces may have had some effect on the movement of soil water vapour, they did not in anyway restrict root or plant development in these experiments. No smearing in the seed zone was observed with the chisel coulters and

some loose soil covered the seed in all soil conditions.

Neither coulter produced any detrimental compaction alongside the groove walls, although the triple disc displayed a greater compressive tendency in this area. The major zone of compaction was at the groove base where the triple disc coulter increased bulk density and soil strength consistently, particularly in the drier soil regimes. The chisel coulter produced no measurable compaction at any soil moisture content, and in fact may have had a slight tendency to decompact.

In the laboratory conditions, not surprisingly, seedling performance and root growth were better with the chisel coulter in almost all of the tested conditions except with moist, loose soil where it was equivalent to the triple disc. No root responses were observed with or without coulter compaction until the pre-drilling soil bulk density exceeded 1.32g/cm^3 , and then roots were restricted only with the triple disc coulter when sowing lupin and not at all with the chisel coulter treatments or with either treatment sowing wheat.

In the field conditions, any compaction of the soil by the triple disc coulter (particularly at and near the base of the groove) appeared to be compensated for by other factors during the plant's full growth cycle. The practical significance of the observed effects of the coulters on the soil is therefore questionable, although it must be recognised that the field trials described were by no means exhaustive.

The compaction and mechanical impedance produced by the triple disc coulter did not appear to be responsible for seed and/or seedling establishment failures per se. The soil moisture transport process and soil water vapour availability within the top 100mm are likely to have been more important factors than localised compaction (M.A. Choudhary,

pers.comm.).

The complex mechanism of root growth and its dependence on the soil microenvironment is not fully understood. It is therefore appropriate now, that physiological studies be directed towards exploring the links between seed and seedling performance in relation to the micro-soil environment at seed level produced by direct drilling coulters.

REFERENCES.

1. WEAVER, H.A.; JAMIESON, V.C. Effects of moisture on tractor tyre compaction of soil. *Soil Sci.*, 71, 15 - 23, 1951.
2. COOPER, A.W.; NICHOLS, M.L. Some observations on compaction test. *Agr.Engng.*, 40, 264 - 267, 1959.
3. VOMOCII, J.A.; FOUNTAINE, E.R., REGINATO, R.J. The influence of speed at drawbar load on the compacting effect of wheeled tractors. *Soil Sci. Soc.Am.Proc.* 40, 264 - 267, 1959.
4. PARKER, J.J.; TAYLOR, H.M. Soil strength and seedling emergence relations. *Agron. J.* 57, 289 - 291, 1965.
5. HANKS, R.J.; THORP, F.C. Seedling emergence of wheat as related to soil moisture content, bulk density, oxygen diffusion rate and crust strength. *Soil.Sci. Soc.Am.Proc.* 20, 307 - 310, 1956.
6. TAYLOR, H.M.; HUCK, M.G.; KLEPPER, B. in *Optimizing the soil physical environments towards greater crop yield* (D. Hillel ed). Acad. Press, New York, London, 1972.
7. ZIMMERMAN, R.P.; KARDOS, L.T. Effect of soil bulk density on root growth. *Soil.Sci.* 91, 281, 1961.
8. GOSS, M.J.; DREW, M.C. Effect of mechanical impedance on growth of seedlings. *A.R.C. Letcombe. Lab.Ann.Rep.* 1971, 35, 1972.
9. PHILLIPS, R.E.; KIRKHAM, D. Soil Compaction in the field and corn growth. *Agron.J.* 54, 29 - 32, 1962.
10. STOUT, B.A.; BUCHELE, W.F.; SNYDER, F.W. Effect of soil compaction on seedling emergence under simulated field conditions. *Agr.Engng.* 42, 68 - 72, 1961.
11. TRIPLETT, G.B.; TESAR, M.B. Effects of compaction, depth of planting and soil moisture tension on seedling emergence of alfalfa. *Agron.J.*, 52, 681 - 685, 1960.
12. LILLARD, J.H.; JONES, J.N. Planting and seed environment problems with corn in killed seed beds. *Trans. A.S.A.E.* 7 (3), 204 - 208. 1964.
13. TELISHI, B.; MCCOLLY, H.F.; ERICKSON, E. Draft measurement for tillage tools. *Agric.Engng.* 37, 605 - 617. 1956.
14. GREACEN, E.L.; BARLEY, K.P.; FARRELL, D.A. The mechanics of root growth in soil with particular reference to the implications for root distribution. In *root growth*, edited Whittington, Butterworths London. 1969.

15. GILL, W.R.; HOUSE, H.K.; HAGEN, R.M. Annotated Bibliography on Soil Compaction. Am.Soc. Agr.Eng., St. Joseph, Michigan. 1959.
16. GRABLE, A.R. Soil aeration and plant growth. Adv.Agron. 18, 57 - 106, 1966.
17. BLACK, C.A. Soil Plant Relationship pp. 70-201, 1968, Wiley, New York.
18. HILLEL, D. Soil and Water: Physical principles and processes, pp.163, Academic Press, New York, 1971.
19. CORNISH, P.S.; FETTELL, N.A. Root growth and phosphous nutrition of wheat seedlings in soil of high mechanical resistance. Proc.Int.Cong. on Energy conservation in crop production. August, 1977, Massey University.
20. WIERSUM, L.K. The relationship of the size and structural rigidity of pores to their penetration by root. Plant and Soil 9, 75 - 85, 1957.
21. BARLEY, K.P. The effect of mechanical stress on the growth of roots. J. Expt. Bot. 13, 95 - 110, 1962.
22. STOLZY, L.H.; BARLEY, K.P. Mechanical resistance encountered by root entering compact soil. Soil Sci. 105, 297 - 301, 1968.
23. EAVIS, B.W.; PAYNE, D. Soil physical conditions and root growth in Root Growth. Butterworths pp. 315 - 336, 1969 London.
24. SCOTT RUSSELL, R.; GROSS, M.J. Physical aspects of soil fertility - The response of roots to mechanical impedance. Neth.J.Agric. Sci. 22, 305 - 312, 1974. *
25. RUSSELL, E.W. The soil problem of minimum tillage. Pro. 8th. Bri.Weed.Control.Conf. 890 - 893, 1966.
26. HYDER, D.N.; SNEVA, F.A. Seed and plant relations as affected by seedbed firmness and a sandy loam range land soil. Soil.Sci.Soc.Am.Proc. 20, 416 - 417, 1956.
27. WILKINSON, B. Soil types and direct drilling: A provisional assessment. Outlk.Agric. 8, 233 - 235, 1975.
28. OUWERKERK, C.V.; BOONE, F.R. Soil physical aspects for zerotillage experiments. Neth.J.Agric.Sci. 18, 247 - 261, 1970.
29. CZEZATCHI, W.; RUHM, E. Adv.Agron. 26, 85, 1971.

30. BLEVINS, R.L.; THOMAS, G.W.; PHILLIPS, R.E. No-tillage Symposium. Ohio 140, 1972.
31. FINNEY, J.R.; KNIGHT, B.A.G. The effect of soil physical conditions produced by various cultivation systems on the root development of winter wheat. J.Agric.Sci. Camb. 80, 435 - 442, 1973.
32. LOGAN, I.C.; GOWMAN, M.A. Development in direct drilling machinery and some effects on soil conditions. Proc.Int.Conf. on Energy Conservation in crop production. August, 1977, Massey University.
33. BAEUMER, K.; BAKERMANS, W.A.P. Zerotillage. Adv.Agron. 25, 78 - 123, 1973.
34. KLUTE, A.; PETERS, D.B. Water uptake and root growth in Root Growth. (edited Whittington), Butterworths, London, 1969.
35. TAYLOR, H.M.; RATCLIFF, L.F. Root elongation rates of cotton and peanuts as a function of soil strength and soil water content. Soil.Sci. 108, 113 - 119, 1969.
36. TAYLOR, H.M.; HENDERSON, D.W. Some effects of organic additives on compressibility of soil. Soil Sci. 88, 101-106, 1959.
37. RICHARDS, L.A. Modulus of rupture of soils as an index of crusting. Soil.Sci.Soc.Am.Proc. 17, 321 - 323, 1953.
38. LAMBE, T.W. Soil stabilisation in Foundation Engineering. McGraw Hill, New York, pp. 351 - 457, 1962.
39. RUSSELL, M.B. Soil aeration and plant growth in Soil Physical conditions and plant growth. Shaw, B.T. ed. Academic Press, New York, pp. 253 - 301, 1952.
40. BAVER, L.D. Soil Physics. 3rd ed. John Wiley, New York, 1956.
41. WESSELLING, J. Some solutions of the steady-state diffusion of CO₂ through soils. Neth. J. Agric.Sci. 10, 109 - 117, 1962.
42. FARRELL, D.A.; GREACEN, E.L.; GURR, C.G. Vapor transfer in soil due to air turbulence. Soil.Sci. 102, 305 - 313, 1966.
43. SCOTTER, D.R.; THURTELL, G.W.; TANNER, C.B. Measuring Oxygen uptake by the roots of intact plants under controlled condition. Soil.Sci. 104, 374, 1967.
44. WOOLEY, J.T. Drainage requirement of plants in Drainage for efficient crop production conference proceedings. A.S.A.E. pp.78, Dec. 1967, Chicago, Ill.

45. SCOTT-RUSSELL, R.; CANNELL, R.Q.; GOSS, M.T. Effects of direct drilling on soil conditions and root growth. *Outlk.Agric.* 8, 227 - 232, 1975.
46. CANNELL, R.Q.; DOWDELL, R.J.; HALL, K.C.; CREES, R. Effect of cultivation on soil nitrogen and the soil atmosphere. A.R.C. Letcombe, Lab. Ann. Rep. 1974, 57 - 59, 1975.
47. SMITH, K.A.; DOWDELL, K.J.; HALL, K.C.; CREES, R. Effect of cultivation on the content of oxygen and ethylene in soil. A.R.C. Letcombe, Lab. Ann. Rep. 1973, 35, 1974.
48. WILLIS, W.O.; RANEY, W.A. Effects of compaction on content and transmission of heat in soil. Monograph A.S.A.E. *Compaction of Agricultural Soil*. St. Joseph, Michigan, 1971.
49. KOHNKE, H.; BARBER, S.A. *Proc. Indiana. Acad.Sci.* 78, 418, 1908.
50. TROUSE, A.C. Jr. Soil conditions as they affect plant establishment, root development and yield: Effects of soil moisture on plant activities in *Compaction of Agricultural Soils*. A.S.A.E. Monograph 1971.
51. JACKSON, R.D. Diurnal changes in soil water content during drying. *Soil.Sci.Soc. Am. Sp. Pub. No.5*, pp.45 - 51, 1973.
52. CANNELL, R.Q.; FINNEY, J.R. Effects of direct drilling and reduced cultivation on soil conditions for root growth. *Outlk.Agric.* 7, (4), 184 - 189, 1973.
53. RICHARD, S.J.; HAGAN, R.M.; McCALLA, J.M. Soil temperature and plant growth in *Soil Physical conditions and plant growth* (ed. B.T. Shaw) Academic Press, New York, 1952.
54. MOODY, J.E.; JONES, J.N.; LILLARD, J.H. Influence of Straw Mulch on soil moisture, soil temperature and the growth of corn. *Soil.Sci.Soc.Am.Proc.* 27, 700, 1963.
55. BLEVINS, R.L.; COOK, D.; PHILLIPS, S.H.; PHILLIPS, R.E. Influence of no tillage on soil moisture. *Agron. J.* 63, 593 - 595, 1971.
56. BAKER, C.J. Experiments relating to techniques for direct drilling of seeds into untilled dead turf. *J.Agric.Engng Res.* 21, 133 - 144, 1976.
57. YOUNG, H.M. No tillage farming in the U.S.A.: Its profit and potential. *Outlk.Agric.* 7 (4), 143 - 148, 1973.

58. FLOCKER, W.J.; VOCOMIL, J.A.; HOWARD, F.D. Some growth responses of tomatoes to soil compaction. *Soil.Sci.Soc.Am.Proc.* 23, 188 - 192, 1959.
59. BODMAN, G.B.; CONSTANTIN, G.K. Influence of particle size distribution in soil compaction. *Hilgardia.* 36, 567 - 591, 1965.
60. BRUCE, R.R. An instrument for the determination of soil compactability. *Soil.Sci.Soc.Am.Proc.* 19, 253 - 257, 1955.
61. VOCOMIL, J.A.; FLOCKER, W.J. Effects of soil compaction on storage and movement of soil air and water. *Trans. A.S.A.E.* 4, 242 - 246, 1961.
62. CANNELL, R.Q.; FINNEY, J.R. Effects of direct drilling and reduced cultivations for root growth. *Outlk, Agric.* 7, 184 - 191, 1973.
63. BULFIN, M.; GLEESON, T. Soil condition under non cultivation. *Irish.J.Agric.Res.* 6, 177 - 187, 1967.
64. SOANE, B.D. The effects of traffic and implements on soil compaction. *Inst.Agric.Engineers* 25 (3), 115 - 125, 1970.
65. EAVIS, B.W.; RATCLIFF, L.F.; TAYLOR, H.M. Use of a dead load technique to determine axial root pressure. *Agron.J.* 61, 640 - 643, 1969.
66. SOANE, B.D.; BUTSON, M.J.; PIDGEON, D. Soil machine interactions in zerotillage for cereals and raspberries in Scotland. *Outlk.Agric.* 8, 221, 1975.
67. HUGHES, K.A. A study of tillage mechanics in relation to soil properties and crop growth. Unpublished thesis, Massey University Library, 1975.
68. BAKER, C.J. An investigation into the techniques of direct drilling seeds into undisturbed, sprayed pasture. Unpublished thesis, Massey University Library, 1977.
69. BEAUMER, K. First experiences with direct drilling in Germany. *Neth.J.Agric.Sci.* 18, 282, 1970.
70. BOONE, F.R.; SLAGER, S.; MIEDEMA, R.; ELEVELD, R. Some influences of zerotillage on the structure and stability of a fine textured river levee soil. *Neth.J.Agric.Sci.* 24, 105 - 119.
71. GILL, R.W.; VANDENBERG, G.E. Soil dynamics in tillage and traction. *Agriculture Handbook 316*, U.S. Government Printing Office, 1967.

72. LYLES, L.; WOODRUFF, N.P.; 1963. Effects of moisture and packers on consolidation and cloddiness of soil. Trans. A.S.A.E. 6, 273.
73. MARSHALL, T.J.; QUIRK, J.P. Stability of structural aggregates of dry soil. Aust.J.Agric.Res. 1, 266, 1950.
74. GILL, W.R.; McCREERY, W.F. Relation of size of cut to tillage tool efficiency. Agric.Engng. 41, (6), 372 - 374, 381, 1960.
75. CHANCELLOR, W.J. Effect of soil compaction on soil strength in Compaction of Agricultural Soils. A.S.A.E. Monograph. 1971.
76. GUPTA, C.P.; PANDYA, A.C. Behaviour of soil dynamic loading: Its implication to tillage implements. Trans. A.S.A.E. 10, 352, 1967.
77. DE ROOCK, B.; COOPER, A.W. Relation between propagation velocity of mechanical waves through soil and soil strength. Trans. A.S.A.E. 10, 471, 1967.
78. STONEBRIDGE, W.C.; FLETCHER, I.C. Spray seed: the Western Australia direct sowing system. Outlk.Agric. 7 (4) 155 - 161, 1973.
79. VANDENBERG, G.E.; BUCHELE, W.F.; MALVERNY, L.E. Application of continuum mechanics to soil compaction. Trans. A.S.A.E. 1, 24 - 27, 1958.
80. SOEHN, W. Fundamentals of pressure distribution and soil compaction under tractor tires. Agr.Engng. 39, 276 - 286, 290, 1958.
81. COOPER, A.W.; VANDENBERG, G.E.; McCOLLY, H.F.; ERICKSON, A.E. Strain gage all measures soil pressure. Agr.Engng. 38, 232 - 235, 1957.
82. FREITAG, D.R. Methods of measuring soil compaction in Compaction of Agricultural Soil. A.S.A.E. Monograph. 1971.
83. STRANAK, A. Soil compaction and direct drilling of cereals. Outlk.Agric. 5 (6), 241 - 6, 1968.
84. VANDENBERG, G.E.; COOPER, A.W.; ERICKSON, A.E.; CARLETON, W.M. Soil pressure distribution under tractor and implement traffic. Agr.Engng. 38, 854 - 855, 859, 1957.
85. COOPER, A.W.; REAVES, C.W. Stress distribution in the soil under tractor loads. Agr.Engng. 41, 20 - 21, 31, 1960.
86. COHRON, G.T. Forces causing soil compaction in Compaction of Agricultural Soils. A.S.A.E. Monograph.pp. 106 - 119, 1971.

87. BLEVINS, R.L.; HOLLOWAYCHUK, N.; WILDING, L.P.
Micromorphology of soil fabric at tree-root soil interface.
Soil.Sci.Soc.Am .Proc. 34, 460, 1970.
88. LUND, Z.F. A technique for making thin sections of soil with roots in place.
Soil.Sci.Soc.Am.Proc. 29, 633 - 635, 1965.
89. BOURBEAU, G.A.; KERGER, K.C. Thin sections of soils and friable materials prepared by Impregnation with the plastic "Castolite".
Soil.Sci.Soc.Am.Proc. 12, 409 - 412, 1947.
90. BOUL, S.W.; FADNESS, D.M. New method of impregnating fragile material for thin sectioning.
Soil.Sci.Soc.Am.Proc. 25, 253, 1961.
91. INNES, R.P.; PLUTH, D.J. Thin section preparation using Epoxy Impregnation for petrographic and electron microscopic analysis. Soil.Sci.Soc.Am.Proc. 34, 483 - 485, 1970.
92. McKENZIE, A.F.; DAWSON, J.E. The preparation and study of thin sections of wet organic soil materials.
J.SoilSci. 12, 142 - 144, 1961.
93. LANGTON, J.E.; LEE, G.B. Preparation of thin sections from moist organic soil materials.
Soil.Sci.Soc.Am.Proc. 29, 221 - 223, 1965.
94. MAI, T.V.; BAKER, C.J. The interaction of soil compaction, root growth and drill coulter design in direct drilling.
Proc.Int.Conf. on Energy Cons. in Crop.Prodn., Massey University, August, 1977.
95. CHOUDHARY, M.A.; BAKER, C.J. The inter-relationship of direct drilled seeds and dry soils as a function of sowing techniques under controlled climatic conditions.
Proc.Int.Conf. on Energy Cons. in Crop Prodn., Massey University, August, 1977.
96. LYNN, W.C.; GROSSMAN, R.B. Observations of certain soil fabrics with the S.E.M.
Soil.Sci.Soc.Am.Proc. 34, 645 - 648, 1970.
97. CESCAS, M.P.; TYNER, E.H.; HARMER, R.S. III
Ferromanganiferous soil concretions. A scanning electron microscopic study of their micro,pore structures.
Soil.Sci.Soc.Am.Proc. 34, 641, 1970.
98. COX, T.L.; HULETT, L.D. Application of S.E.M. to root soil relationship in Yellow poplar.
Soil Science 120, 195 - 199, 1975.

99. GILL, W.R.; MILLER, R.D. A method for study of the influence of mechanical impedance and aeration on the growth of seedling roots.
Soil Sci.Soc.Am.Proc. 20 (2), 154, 1956.
100. KORONKA, P. Machinery development for direct drilling.
Outlk. Agric. 7, 190 - 195, 1974.
101. PHILLIPS, S.H.; YOUNG, H.M. Jr. No tillage farming. Reiman Associates, Milwaukee, Wisconsin, 141 - 148, 1973.
102. RUSSELL, E.W. Reduced cultivation and direct drilling, the present position and the research needs of these techniques.
Outlk.Agric. 8, 257 - 259, 1975.
103. DIXON, H.N. The effects of coulter design on soil compaction and root development of a cereal following direct drilling.
Unpublished Project, Massey University Library, 1972.
104. ALLEN, H.P. I.C.I. Plant protection division experience with direct drilling system 1961 - 1974.
Outlk.Agric. 8, 213 - 215, 1975.
105. SOANE, B.D.; PIDGEON, J.D. Tillage requirement in relation to soil physical properties.
Soil.Sci. 119, 376 - 384, 1975.
106. POLLOCK, J.A. Personal communication, Soil Science Department, Massey University, 1977.
107. GRADWELL, M.W. Changes in the pore-space of a pasture top soil under animal treading. N.Z. Agr. Res. 8, 663 - 674, 1960.
108. GRADWELL, M.W. The available-water capacities of some southern and central zonal soils of New Zealand.
N.Z. Agr. Res. 17, 469, 1974.
109. BLACK, G.R. "Bulk Density". Methods of Soil Analysis.
(Ed. Black) 1, 374, 1965.
110. STACES, H.C.T.; PALM, A.W. A thin walled tube for core samplings of soil. Aust.J. exp.agric.An.Husb. 2 (7), 238 - 241, 1962.
111. FREITAG, D.R. Methods of measuring soil compaction in Compaction of Agricultural Soils A.S.A.E. Monograph pp. 49 - 53, 1971.
112. WILLARDSON, L.S.; TAYLOR, S.A. Soil sampler for direct moisture determination. Ag.Engng 43, 33 1962.
113. PHILLIPS, R.E.; KIRKHAM, D. Soil compaction in the field and corn growth. Agron. J. 54, 29 - 34, 1962.

114. TAYLOR, H.M.; GARDNER, H.R. Penetration of cotton seed tap roots as influenced by bulk density, water content and soil strength. *Soil Sci.* 96, 153 - 156, 1963.
115. BARLEY, K.P.
Soil Fertility 27, 267, 1964.
116. TAYLOR, H.M.; BURNETT, E. Influence of soil strength on the root growth habits of plants.
Soil Sci. 98, 174 - 180. 1964.
117. HENRY, J.E.; McKIBBEN, J.S. Effect of soil strength on corn root penetration. *Trans. A.S.A.E.* 48, 281, 1967.
118. CAMP, C.R. Jr.; LUND, Z.F. Effect of mechanical impedance on cotton root growth. *Trans. A.S.A.E.* 49, 188 - 190, 1968.
119. YONG, R.N.; WARKENTIN, B.P. Soil properties and behaviour.
Elsevier Scientific Pub.Co., New York, 1975.
120. PAYNE, P.C.J. The relationship between the mechanical properties of soil and the performance of simple cultivation implements.
J.Agr.Engng Res. 1, 23 - 50, 1956.
121. PAYNE, P.C.J.; TANNER, D.W. The relationship between rake angle and the performance of simple cultivation implements.
J.Agric.Engng Res. 4, 312 - 325, 1959.
122. BOWDITCH, H.G. Engineering aspects of seedbed tillage machinery for arable and semi arable land. *Pro.Nat.Agric.Mach. Wkshop (Sydney)* 47 - 59, 1969.
123. BARLEY, K.P.; GREACEN, E.L. Mechanical resistance of roots.
Adv.Agron. 19, 1 - 43, 1967.
124. TAYLOR, H.M.; ROBERTSON, G.M.; PARKER, J.J. Cotton seedling tap root elongation as affected by soil strength changes induced by slurying and water extraction.
Soil Sci.Soc.Am.Proc. 31, 700 - 704, 1967.
125. CARNS, A. Soil Crusts. *Ag.Engng* 15, 167 - 169, 1934.
126. FORRESTALL, F.F.; GESSEL, S.P. Soil properties related to forest cover type and productivity on the lee forest, Snohomish County, Washington. *Soil Sci.Soc.Am.Proc.* 19, 384 - 389, 1955.
127. BARBER, S.A. Effects of tillage practice on corn (*Zea Mays*. L.) root distribution and morphology.
Agron.J. 63, 724 - 726, 1971.

128. TAYLOR, H.M.; GARDNER, H.R. Use of wax substrates in root penetration study. *Soil Sci.Soc.Am.Proc.* 24, 79 - 81, 1960.
129. TAYLOR, H.M.; ROBERTSON, G.M.; PARKER, J.J. Soil strength root penetration relations for medium to coarse textured soil materials. *Soil Sci.* 102, 18 - 22, 1966.
130. LETEY, J.; STOLZY, L.H.; BLACKER, G.P. Effect of duration and timing of low soil oxygen content on shoot and root growth. *Agron.J.* 54, 34 - 37, 1962.
131. VEIHMEYER, F.J.; HENDRICKSON, A.H. Soil density and root penetration. *Soil Sci.* 65, 487 - 493, 1948.
132. BERTRAND, A.R.; KOHNKE, H. Subsoil conditions and their effects on oxygen supply and the growth of corn roots. *Soil Sci.Soc.Am.Proc.* 21, 135 - 140, 1957.
133. TROUSE, A.C. Jr. Soil conditions as they affect plant establishment, root development and yield. *In* *Compaction of Agricultural Soil*. A.S.A.E. Monograph.1971.
134. FLOCKER, W.J.; MENARY, E.J. Some physiological responses in two tomato varieties associated with levels of soil bulk density. *Hilgardia*, 30, 101 - 121, 1960.
135. KAR, S.; VARADE, S.B. Influence of mechanical impedance on rice seedling root growth. *Agron.J.* 64, 80 - 81, 1972.
136. DANIELSON, R.E. *In*: *Irrigation of agricultural lands* (Ed. by R.M. Hagen et al) Madison, Wis, Am.Soc.Agronomy, pp. 390 - 423, 1967.
137. DE ROO, H.C. Root growth in Connecticut Tobacco Soils. *Bull./Conn.Agric.Exp.Stn.* 608, 36, 1957.
138. TAYLOR, H.M.; MATHERS, A.C.; LOTSPEICH, F.B. Pans in the Southern Great Plains soils: I. Why root restricting pans occur *Agron. J.* 56, 328, 1964.
139. GOSS, M.J.; DREW, M.C. Effect of mechanical impedance on growth of seedlings. A.R.C. Letcombe. *Lab.Ann.Rep.* 1971, 35 - 42, 1972.
140. BARLEY, K.P.; FARRELL, D.A.; GREACEN, E.L. The influence of soil strength on the penetration of a loam by plant roots. *Aust. J. Soil. Res.* 3, 69 - 79, 1965.
141. EAVIS, B.W. Soil physical conditions affecting seedling root growth. *Plant and Soil*, 36: 613 - 622, 1972.

142. BARLEY, K.P. Influence of soil strength on the growth of roots. Soil Sci. 96, 175 - 180, 1963.
143. MAZURAK, A.P.; POHLMA, K. 9th Int.Cong.Soil.Sci. Adelaide, 1, 769 - 813, 1968.
144. TAYLOR, H.M.; RATLIFF, L.F. Root elongation rates of cotton and peanuts as a function of soil strength and soil water content. Soil Sci. 107, 108 - 113, 119, 1969.
145. SMITH, K.A.; RUSSELL, R.S. Occurrence of ethylene and its significance in anaerobic soil. Nature. 222, 769 - 771, 1969.
146. GREACEN, E.L.; OH, J.S. Physics of root growth. Nature, New Biology. 235, 24 - 25, 1972.
147. BAKERMANS, W.A.P.; de WIT, C.T. Crop husbandry on naturally compacted soils. Neth.J.Agric.Sci. 18, 225 - 246, 1970.
148. ARNOLD, R.A.; CLEMENT, C.K. The use of herbicides in alternate husbandry as a substitute for ploughing. Weed Research 6, 142 - 157, 1966.
149. EDWARD, C.A.; LOFTY, J.R. Biology of earthworms. Chapman and Hall London, 282 pp. 1972.
150. CANNELL, R.Q.; DREW, M.C. Plant root systems and crop growth. S.P.A.N. 16 (1), 39, 1973.
151. LOGAN, I. Minimum cultivation and direct drilling techniques in other major agricultural systems. Proc. Minimum Cultivation Convention, Perth, Western Australia, 1977.
152. SPRINGETT, J.A. The effects of direct drilling on soil animals. Proc. Minimum Cultivation Convention, Perth, Western Australia, 181 - 183, 1977.
153. SPRINGETT, J.A. Effects of direct drilling on soil fauna. Outlk.Agric. 8, 243 - 244, 1975.
154. VAN DOREN, D.M.; TRIPLETT, G.B. Nitrogen, Phosphorus and Potassium fertilization of non-tilled Maize. Agron.J. 61, 637 - 639, 1969.
155. TRIPLETT, G.B.; OSMOND, C.A.; SUTTON, P. Ohio Rep. 57, 39 - 41, 1972.
156. PHILLIPS, W.M. Dryland Sorghum production and Weed Control with minimum tillage. Weed Science 17, 451 - 454, 1969.

157. BARLEY, K.P. Effects of root growth and decay on the permeability of a synthetic sandy loam. *Soil Science* 78, 205 - 210, 1954.
158. DAVIS, D.B.; CANNELL, R.Q. Review of experiments on reduced cultivation and direct-drilling in the U.K. 1954 - 1974. *Outlk Agric.* 8, 216, 1975.
159. HAMLY, D.H. Softening of the seeds of Melilotus alba. *Bot.Gaz.* 93, 345 - 75, 1932.
160. MULTHORPE, F.L.; MOORBY, J. An introduction to Crop Physiology: Germination and Seedling emergence. Cambridge University Press, page 110 - 123, 1974.
161. HOPKINS, R.M.; PATRICK, W.H. Combined effect of oxygen content and soil compaction on root penetration. *Soil Sci.* 108, 408 - 413, 1969.
162. DASBERG, S. Soil water movement to germinating seeds. *J. Exp. Bot.* 22, 999 - 1008, 1971.
163. HYDE, E.O. The function of the hilum in some Papilionaceae in relation to the ripening of the seed and the permeability of the testa. *Annals of Bot. N.S.* 28, 241 - 256, 1954.
164. CROSSET, R.N.; CAMPBELL, D.J.; JOHN, A. The effect of ethylene on the development of barley root system. A.R.C. Lescombe. *Lab. Ann. Rep.* 1971, 11 - 13, 1972.
165. AUBERTIN, G.M.; KARDOS, L.T. Root growth through porous media under controlled condition: Effect of aeration level and Rigidity. *Soil Sci.Soc.Am.Pro.* 29, 363, 1965.
166. RUFELT, H. Ges and hydrotropic responses of root in Root growth (edited Whittington) Butterworths, London, pp 54-63, 1969.

ACKNOWLEDGEMENTS

The author is grateful to Dr C.J. Baker of Massey University for his guidance, encouragement, understanding and valuable help during the study and presentation of this thesis.

The author also wishes to thank the following:

Professor B.R. Watkin of Massey University for guidance and assistance.

Dr R. Northey of Soil Bureau, D.S.I.R., Lower Hutt for his guidance and suggestions.

Mr G.C. Arnold of Mathematics and Statistics department, Massey University for his advice and assistance in Biometrics.

Messrs E.M. Badger and J.H. McDonald are thanked for their technical help.

The assistance of other members of the Agronomy Department and Photographic Unit of Massey University, and the Electron Microscopy group of D.S.I.R. is gratefully acknowledged.

I wish to express my utmost appreciation and special thanks to my wife Phuong for her profound understanding. Without her resolute support and encouragement, the task may never have been completed.

Thanks are also due to the External Aid Division, New Zealand Ministry of Foreign Affairs and the McMillan Brown Agricultural Research Scholarship for financial help.

Finally thanks are also due to Mrs M. McAusland for typing the thesis.

APPENDIX 1.

TABLE A.1 SOIL BULK DENSITY MEASUREMENT (Expt.1)

REPLICATE No.	TRIPLE DISC COULTER							CHISEL COULTER						
	1	2	3	4	5	6	Average	1	2	3	4	5	6	Average
Soil moisture content at drilling w/w %	21	29	28	27	24	25	25	23	24	20	27	27	16	23 NS
Soil bulk density before drilling g/cc	0.99	1.04	0.99	0.92	0.94	1.00	1.00	0.93	1.06	1.88	0.95	1.07	0.99	1.00 NS
Soil bulk density after drilling g/cc	1.20	1.16	1.20	1.17	1.18	1.20	1.18	1.12	1.03	1.11	1.01	1.02	1.13	1.07 **

NS = non-significant

TABLE A.2 SOIL BULK DENSITY MEASUREMENTS (Expt,2)

REPLICATE No.	Triple Disc Coulter							Chisel Coulter						
	1	2	3	4	5	6	Average	1	2	3	4	5	6	Average
Soil moisture content														
at drilling														
% w/w	27	31	28	26	29	27	28	30	27	29	24	30	27	28
Soil bulk density														
before drilling														
g/cm ³	1.03	0.98	1.07	1.08	1.06	1.04	1.04	1.04	1.05	1.00	1.06	1.06	1.07	1.04
Soil bulk density														
after drilling														
g/cm ³	1.20	1.09	1.15	1.17	1.18	1.17	1.15	1.04	1.05	1.03	1.03	1.02	1.04	1.03 **

** Significant level P = 0.01

TABLE A.3 SOIL BULK DENSITY MEASUREMENTS AT SOIL MOISTURE 20w/w (Expt.3)

Triple Disc Coulter

Chisel Coulter

REPLICATE No.	1	2	3	4	5	6	Average	1	2	3	4	5	6	Average
Soil bulk density before drilling g/cm ³	1.36	1.38	1.23	1.36	1.32	1.32	1.33	1.36	1.38	1.23	1.36	1.32	1.32	1.32
Soil bulk density after drilling g/cm ³	1.45	1.46	1.40	1.46	1.41	1.44	1.44	1.30	1.32	1.32	1.30	1.29	1.39	1.32**

** = Significant level P = 0.01

APPENDIX 2

TABLE A.4 SOIL STRENGTH MEASUREMENTS (EXPERIMENTS 1,2,3) (In N)

Upper figures = Expt.1.
Centre figures = Expt.2.
Lower figures = Expt.3.

REPLICATE	Triple Disc Coulter					Measured at the Bottom	Measured at the Sidewall	Soil Strength Before Drilling	Chisel Coulter					Measured at the Bottom	Measured at the Sidewall	Soil Strength Before Drilling
	DISTANCE AWAY FROM THE GROOVE								DISTANCE AWAY FROM THE GROOVE							
	15	25	35	45	55				15	25	35	45	55			
1	.238	.287	.513	.431	.333	.762	.333	.325	.050	.132	.174	.259	.313	.232	.119	.294
	.465	.482	.418	.360	.330	.389	.480	.284	.218	.257	.282	.259	.259	.242	.186	.286
						3.15	3.04	2.50					2.80	2.48	2.61	
2	.396	.580	.458	.485	.649	.683	.392	.384	.180	.260	.380	.308	.181	.259	.186	.374
	.426	.448	.376	.460	.365	.379	.377	.311	.174	.252	.367	.309	.338	.355	.320	.409
						3.39	3.11	2.90					3.30	2.28	2.50	
3	.218	.284	.311	.210	.208	.311	.169	.308	.198	.218	.411	.289	.284	.306	.156	.384
	.311	.382	.384	.377	.328	.418	.311	.330	.255	.350	.323	.277	.311	.289	.276	.301
						3.00	3.11	2.47					3.08	1.93	3.11	
4	.654	.815	.695	.801	.913	.673	.666	.463	.147	.127	.174	.208	.213	.223	.162	.325
	.483	.551	.497	.350	.429	.507	.362	.350	.196	.230	.328	.240	.409	.318	.232	.426
						3.47	2.46	2.90					2.97	2.52	2.81	
5	.142	.161	.237	.394	.316	.340	.235	.318	.152	.184	.179	.206	.265	.120	.112	.262
	.483	.527	.431	.382	.429	.406	.411	.340	.144	.208	.370	.382	.345	.303	.208	.320
						3.85	3.23	2.15					2.97	2.52	2.81	
6	.588	.612	.605	.592	.673	1.063	.546	.502	.180	.220	.309	.272	.318	.529	.127	.480
	.397	.448	.519	.316	.365	.455	.406	.367	.206	.284	.331	.284	.304	.274	.299	.284
						3.73	3.73	3.43					3.00	2.96	3.24	

APPENDIX 3.

Typical draft curves are given in Figs. A.1 and A.2 for experiments 1 and 2 respectively. The mean drafts for each coulter are given in Table A.5.

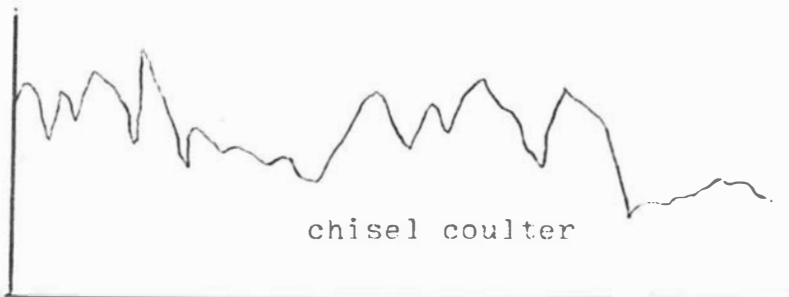
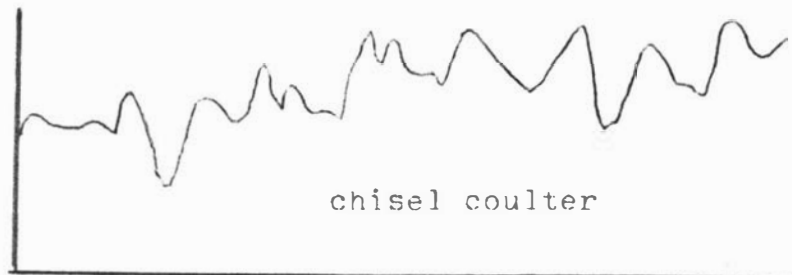
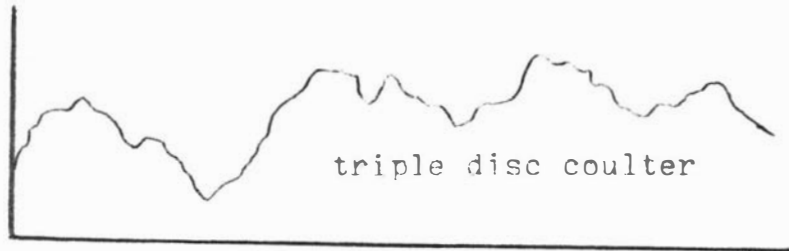
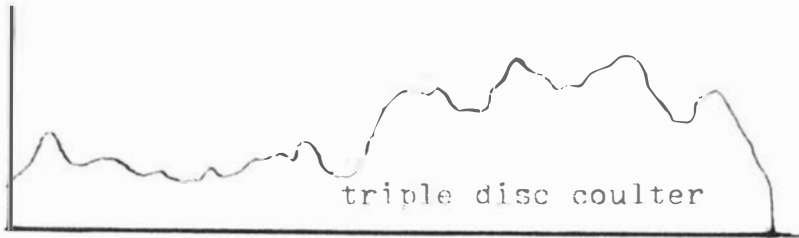
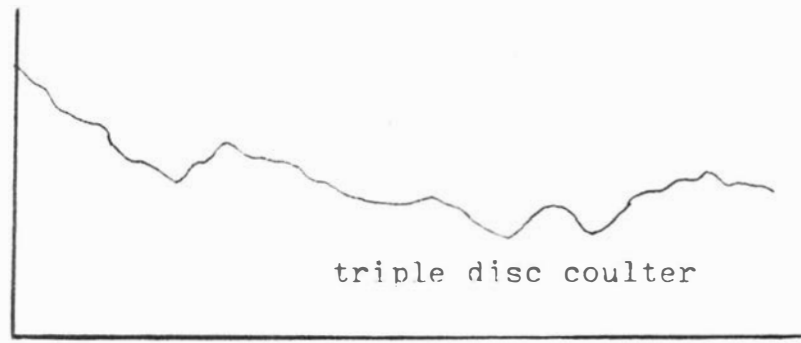
TABLE A.5 DRAFT FORCES REQUIRED BY TWO DRILLING COULTER TYPES IN A SILT LOAM

		TREATMENTS	
Replicate		Chisel Coulter	Triple Disc Coulter
Draft Forces (N)	1	1545	1320
		1879	1384
	2	1988	1101
		1966	1677
	3	2026	1210
		2415	1922
MEAN	1853 2094	1210 1684 **	

Upper figures: Measurements with soil at 28-30% m.c
Lower figures: Measurements with soil at 22-24% m.c

** P = 0 .01

UNIT OF CHART PAPER (mm)



Distance in mm
Fig.A1 Draft curves (Expt 1)

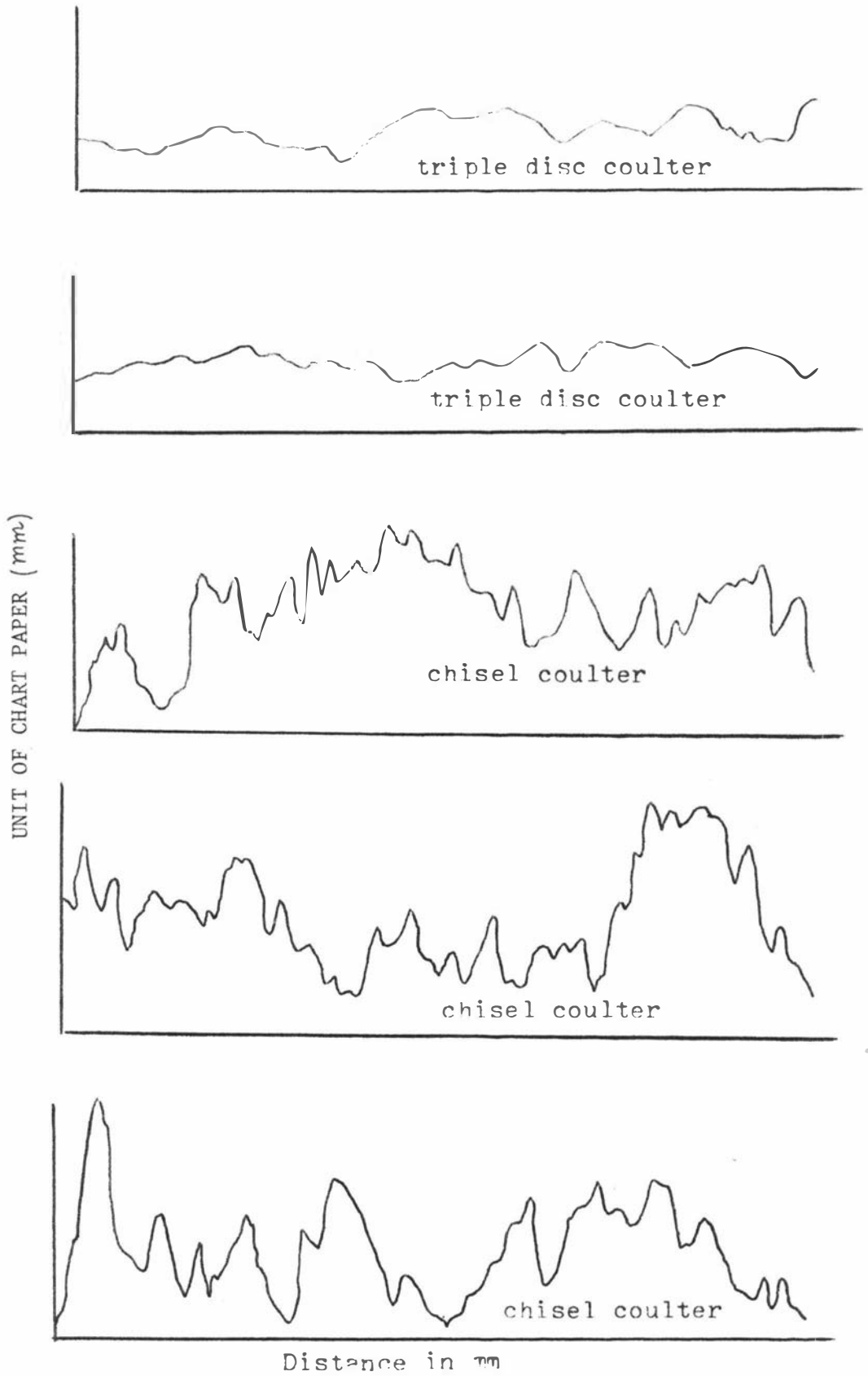


Fig.A2 Draft curves(Expt 2)

TABLE A.7

THE EFFECTS OF DIRECT DRILLED GROOVE SHAPE, SMEAR, COMPACTION AND COVER
ON LUPIN SEEDLINGS

	REPLICATE	1	2	3	4
Chisel	RDW	0.018	0.018	0.021	0.019
	PL	57	48	43	58
	RL	90	87	93	90
Knife-cut V shaped groove, well covered	RDW	0.020	0.012	0.020	0.046
	PL	48	38	38	55
	RL	70	85	73	146
Knife-cut V shaped smearred groove wall	RDW	0.043	0.016	0.033	0.025
	PL	38	42	43	38
	RL	120	75	120	115
Knife-cut V shaped non-smearred groove wall	RDW	0.018	0.043	0.018	0.013
	PL	35	38	48	40
	RL	113	105	70	70

*RDW = root dry weight in grammes

*PL = plant height (mm)

*RL = root length (mm)

TABLE A.8 THE EFFECTS OF DIRECT DRILLED GROOVE SHAPE, SMEAR, COMPACTION AND COVER ON WHEAT SEEDLINGS

	REPLICATE	1	2	3	4
Chisel	RDW	0,013	0.017	0,017	0.011
	PL	88	105	80	75
	RL	115	135	93	75
Knife-cut V shape groove, well covered	RDW	0.007	0.025	0.015	0.011
	PL	80	100	80	100
	RL	65	118	97	130
Knife-cut V shape smeared groove wall thin cover	RDW	0.011	0.026	0.011	0.016
	PL	100	106	80	105
	RL	130	158	100	105
Knife-cut V shape non-smeared groove wall thin cover	RDW	0.018	0.011	0.021	0.018
	PL	65	70	90	85
	RL	70	70	100	100

RDW = root dry weight (grammes)
 PL = plant height (mm)
 RL = root length (mm)

APPENDIX 5.

ESTIMATION OF WATER FROM TURF BLOCKS UNDER RAIN CANOPIES

Daily evaporation from turf blocks deposited under clear P.V.C. rain protection canopies was estimated by the 'bucket' method. The method was described as follows:

Soil cores taken from the tested soil block (having had the exposed surface area measured) were snugly fitted into beakers slightly larger than the cores in such a way that disturbance of soil and lateral evaporation of soil cores were avoided.

The beakers were placed into predrilled holes with the soil surface in the beakers levelled with the surface of soil of the turf block outside.

Evaporation was taken as the difference between the two water contents measured on two consecutive days

ESTIMATION OF WATER EVAPORATION IN THE SPRING-SUMMER 1976

Evaporation ml/58cm²(surface area of a soil core)

SAMPLE No.	REPLICATE			
	1	2	3	
1	5.53	5.43	5.50	
2	5.15	4.51	4.20	
3	5.50	5.20	5.10	
4	5.09	4.91	4.00	
5	5.97	4.05	6.40	Mean 5.10
Average	5.45	4.82	5.04	

Total surface area of the turf block

$$= 14,000\text{cm}^2$$

Daily evaporation

$$= \frac{5.10\text{ml} \times 14000}{58}$$

#1200ml/block

Evaporation of $\frac{1}{2}$ of the soil block was therefore estimated at 600ml of water per day.

ESTIMATION OF EVAPORATION IN THE AUTUMN-WINTER 1976

Evaporation ml/soil core (58cm²)/day

SAMPLE No.	REPLICATE		
	1	2	3
1	0.76	0.83	0.92
2	0.85	0.94	0.82
3	1.31	1.35	0.96
4	0.86	1.08	1.14
5	1.06	1.00	1.06
Average	0.97	1.04	0.98 Mean 1.00

Daily evaporation per soil block

$$= \frac{1 \text{ ml} \times 1400}{58}$$

$$= 241 \text{ ml /day}$$

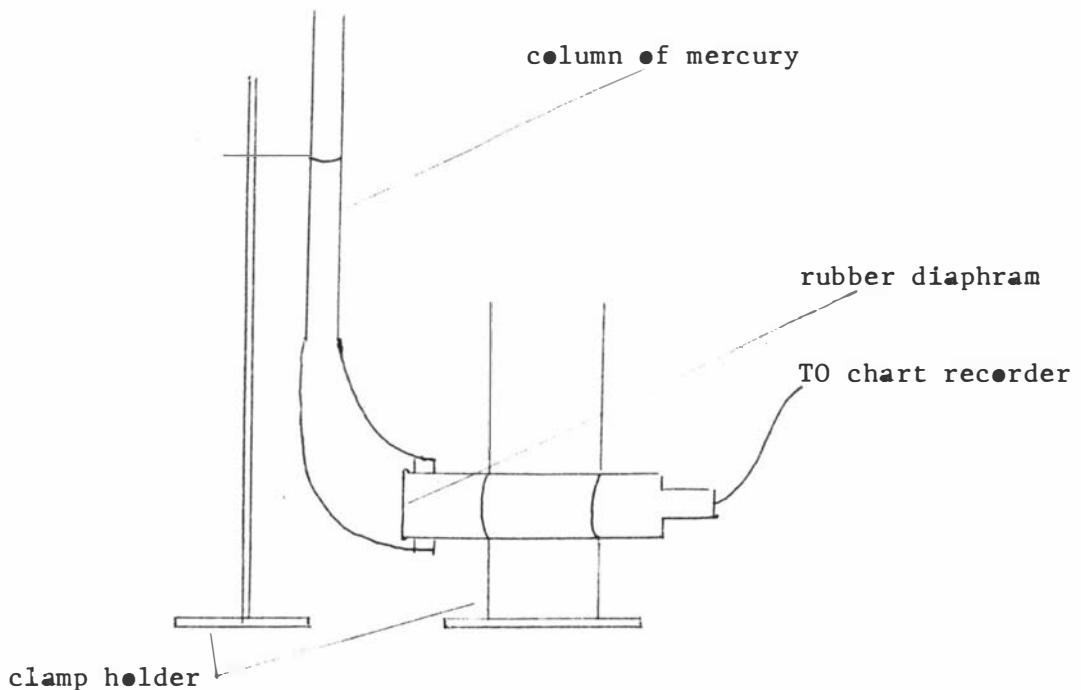
APPENDIX 6.

CALIBRATIONS

1. THE PRESSURE SENSING TUBE

A mercury column was used to obtain calibrated curves (Fig A.3) for the pressure sensing apparatus. Mercury was poured into a glass tube, the end of which was in contact with the rubber diaphragm of the pressure tube while the other end of the sensing apparatus was connected to a chart recorder.

To avoid errors incurred due to the effects of changing temperature and humidity on the pressure sensing assemblies, each was calibrated prior to each drilling experiment.



2. THE DISPLACEMENT TRANSDUCER AND THE LOAD CELL

Weights were used to obtain calibrated curves for the measurements of penetrometer resistance in the soils (displacement transducer) and the draft force (load-cell). Speed of the Chart paper was set at 1/10 the speed of the testing rig (1m/min) in all calibrations.

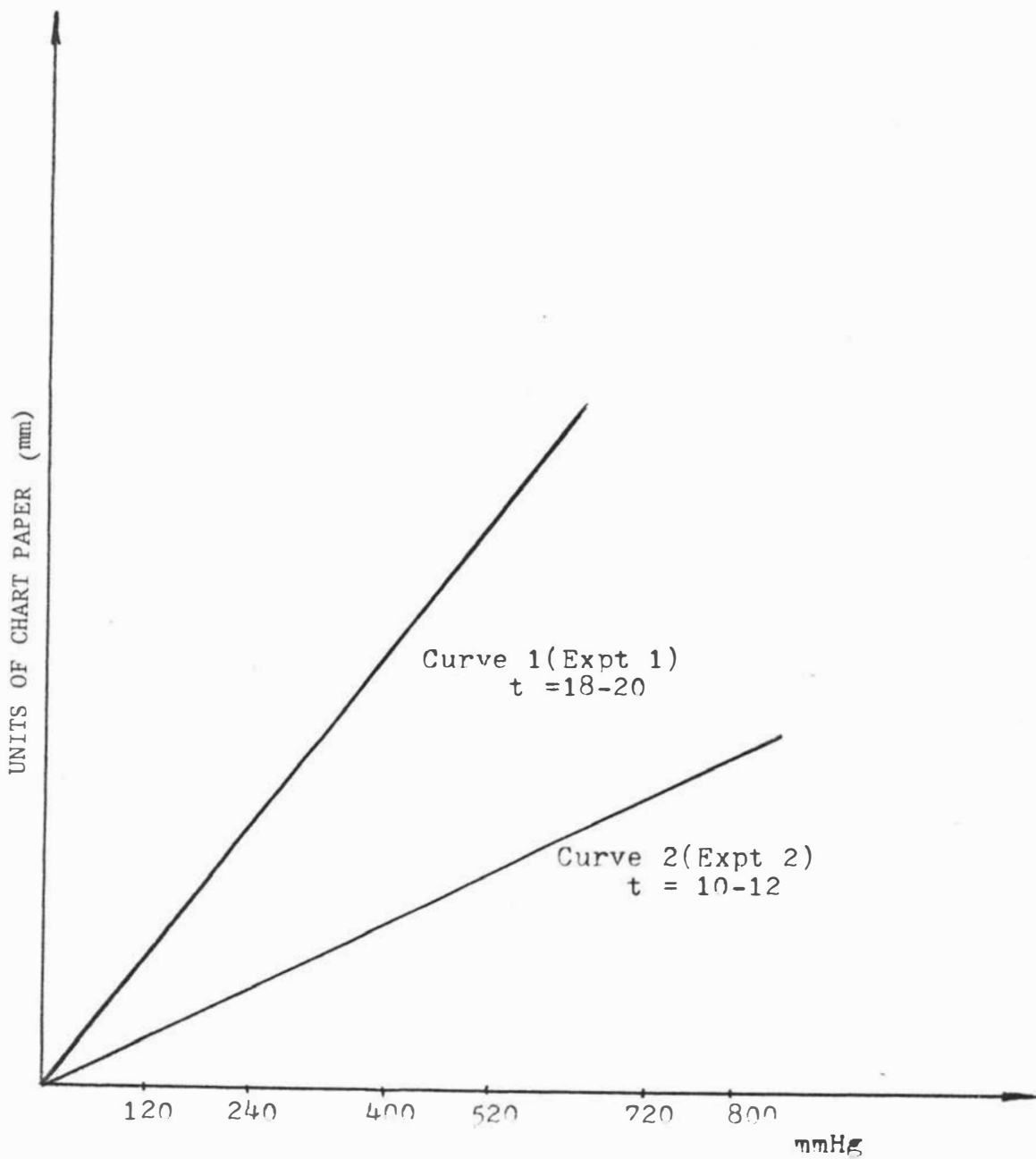


Fig.A3 Calibration curves for pressure measurement with Kyowa transducer PS-5KB.

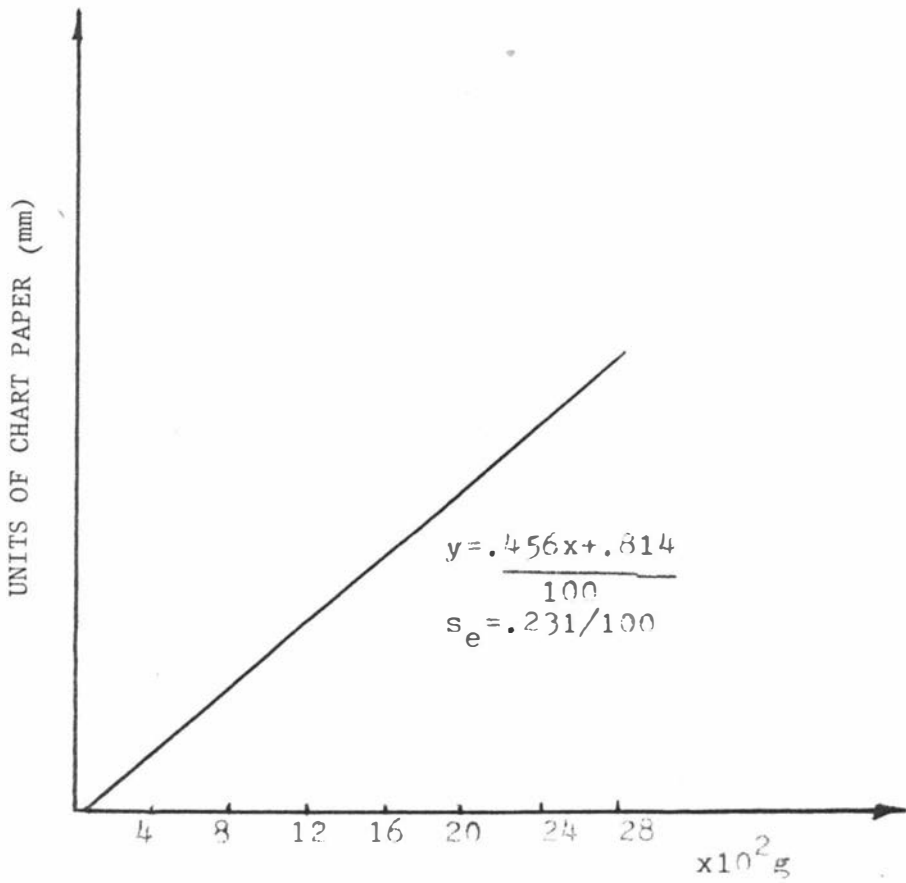


Fig.A4 The calibration curve for measurement
 with the multipoint penetrometer.

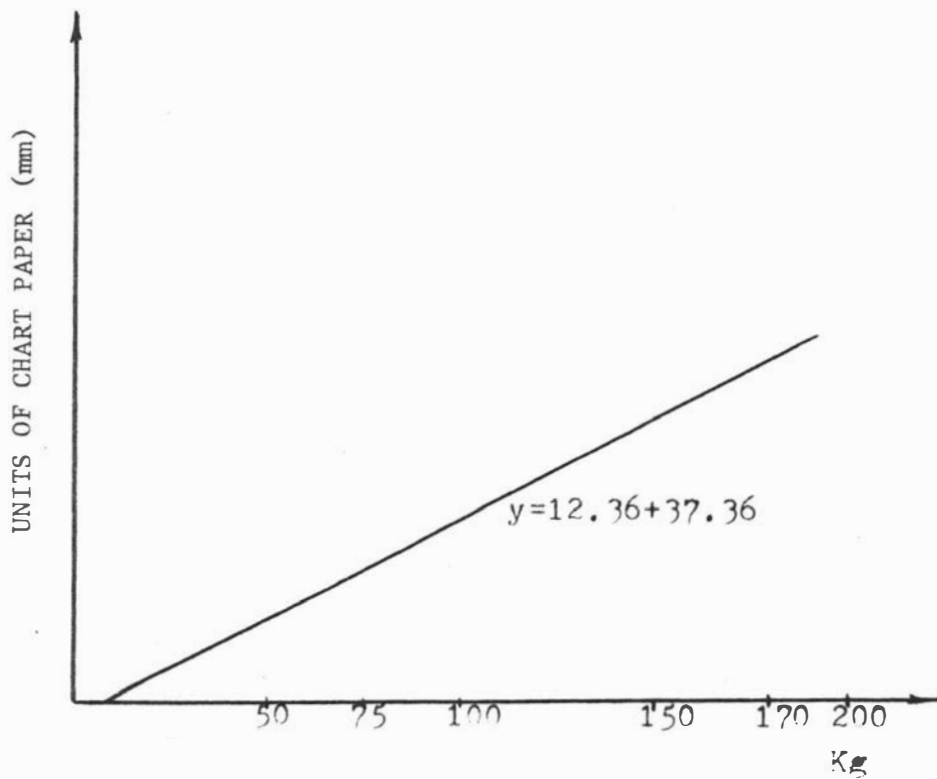


Fig.A5.The calibration curve for draft measurement with Kyowa 1.T load cell.

APPENDIX 7.

DETERMINATION OF ROOT PERCENTAGE IN SOIL CORES

Core samples (dia 34mm, 50mm long) were soaked in a dispersing solution to facilitate root washing for 24 hrs. The soil was displaced out of the root systems by gently washing, mostly under water, with a low pressure water hose. Roots and organic matter remained on the screen mesh of .125mm, were oven-dried and weighted. Detailed results are given in table A.9.

TABLE A.9. THE ORGANIC ROOT PERCENTAGE IN SOIL

SAMPLE												
NUMBER	1	2	3	4	5	6	7	8	9	10	11	Average
1ST SAMPLING	1.9	1.0	1.2	1.0	1.5	1.2	2.0	1.0	2.1	1.9	1.5	1.45
2ND SAMPLING	2.1	1.2	1.6	1.3	1.2	1.0	1.2	1.3	1.2	1.5	1.2	1.47
											MEAN	1.46

APPENDIX 8.

METEOROLOGICAL DATA

The data was recorded at the Massey University sub-station E05464 during the experimental period.

They are shown in Fig A.6. - Fig A.12 inclusively.

EXPERIMENT	PERIOD
1	27/ 1/76 - 15/ 3/76
2	28/ 6/76 - 15/ 8/76
3	12/11/76 - 16/12/77
4	18/12/77 - 31/12/77
5	6/ 5/77 - 9/ 6/77
6	21/10/77 - 15/ 02/78

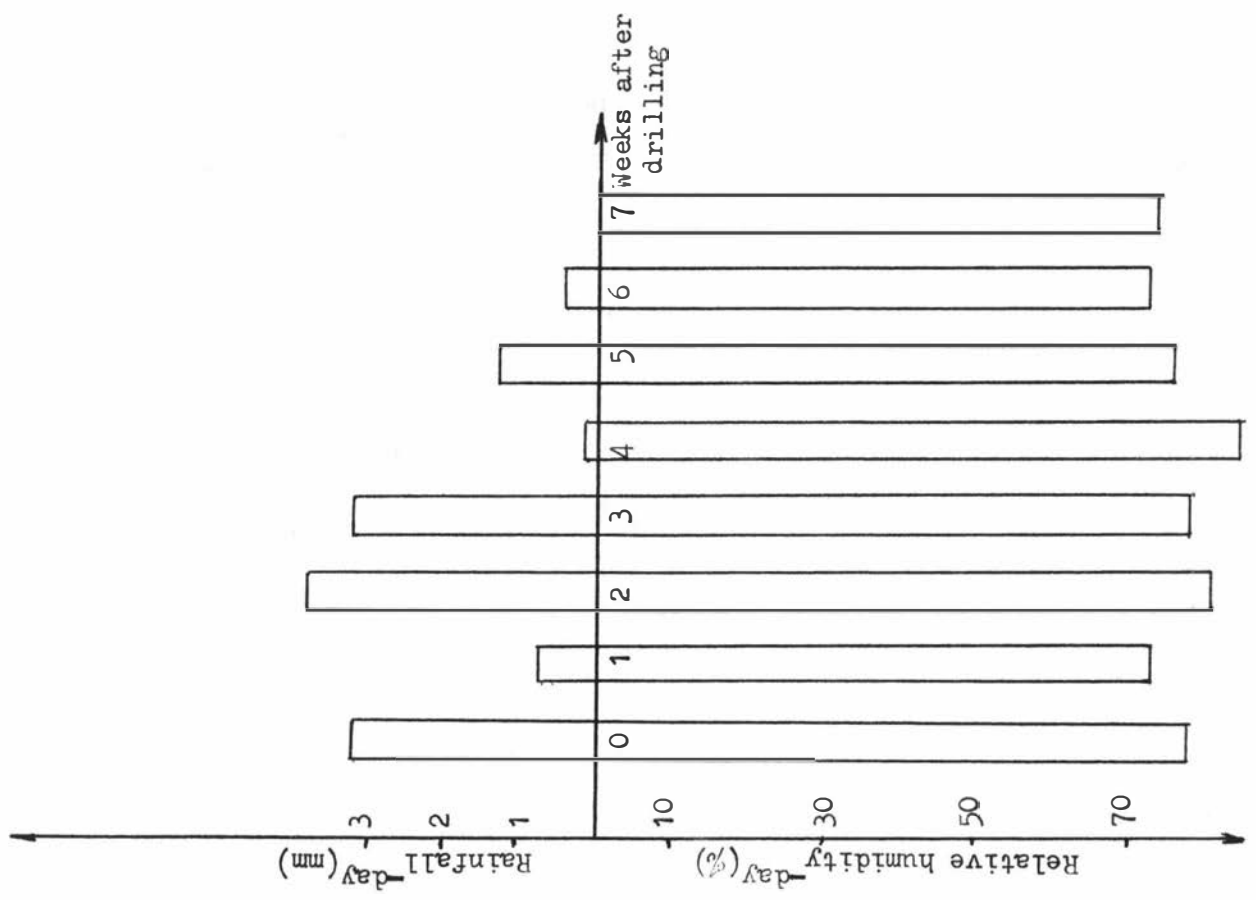
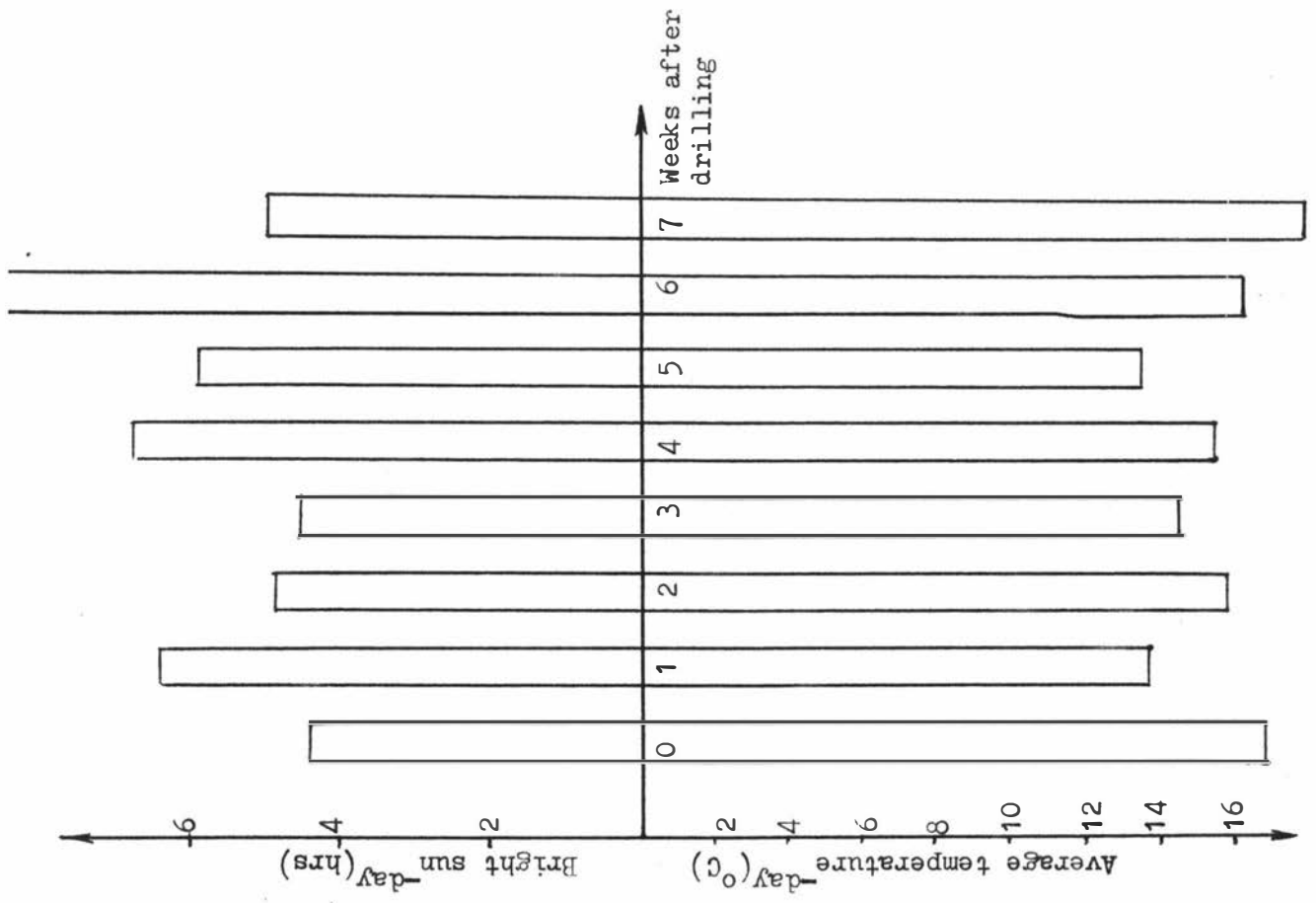


Fig. A 6. Weather data (expt 1).

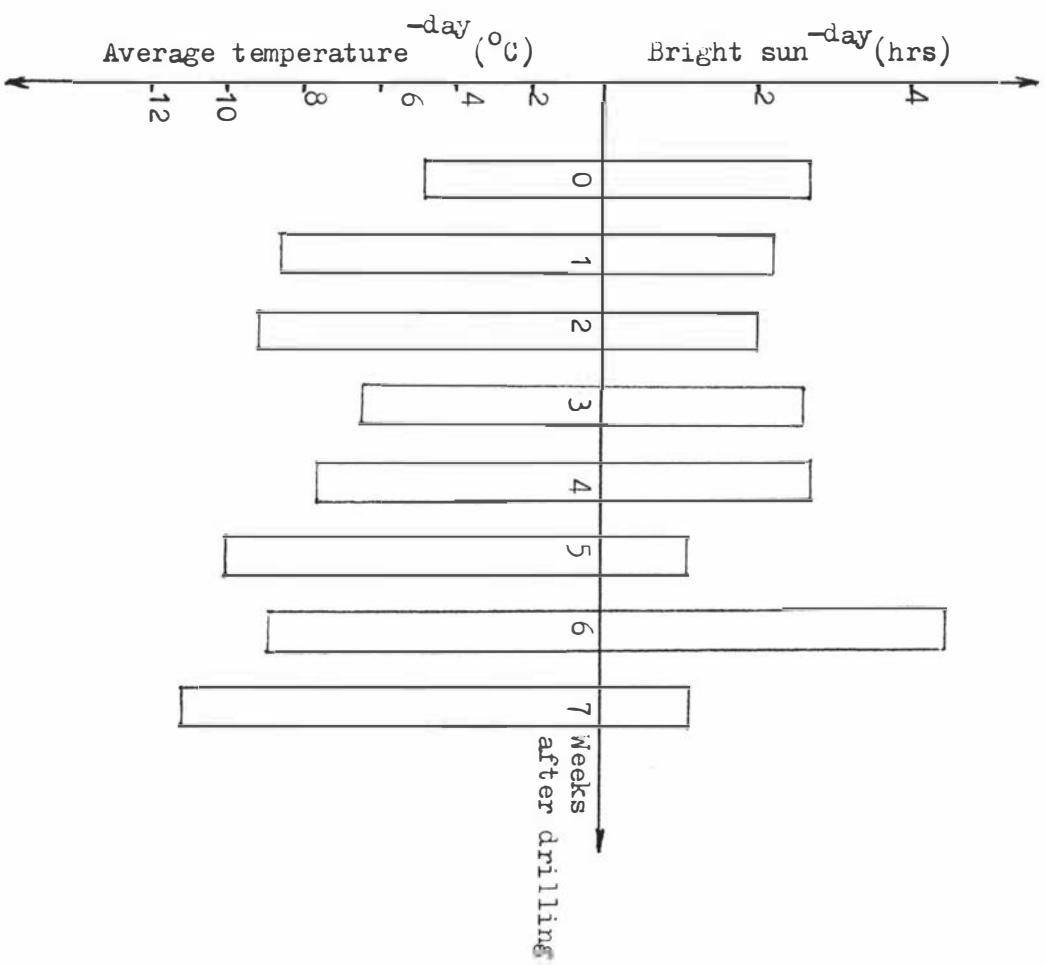
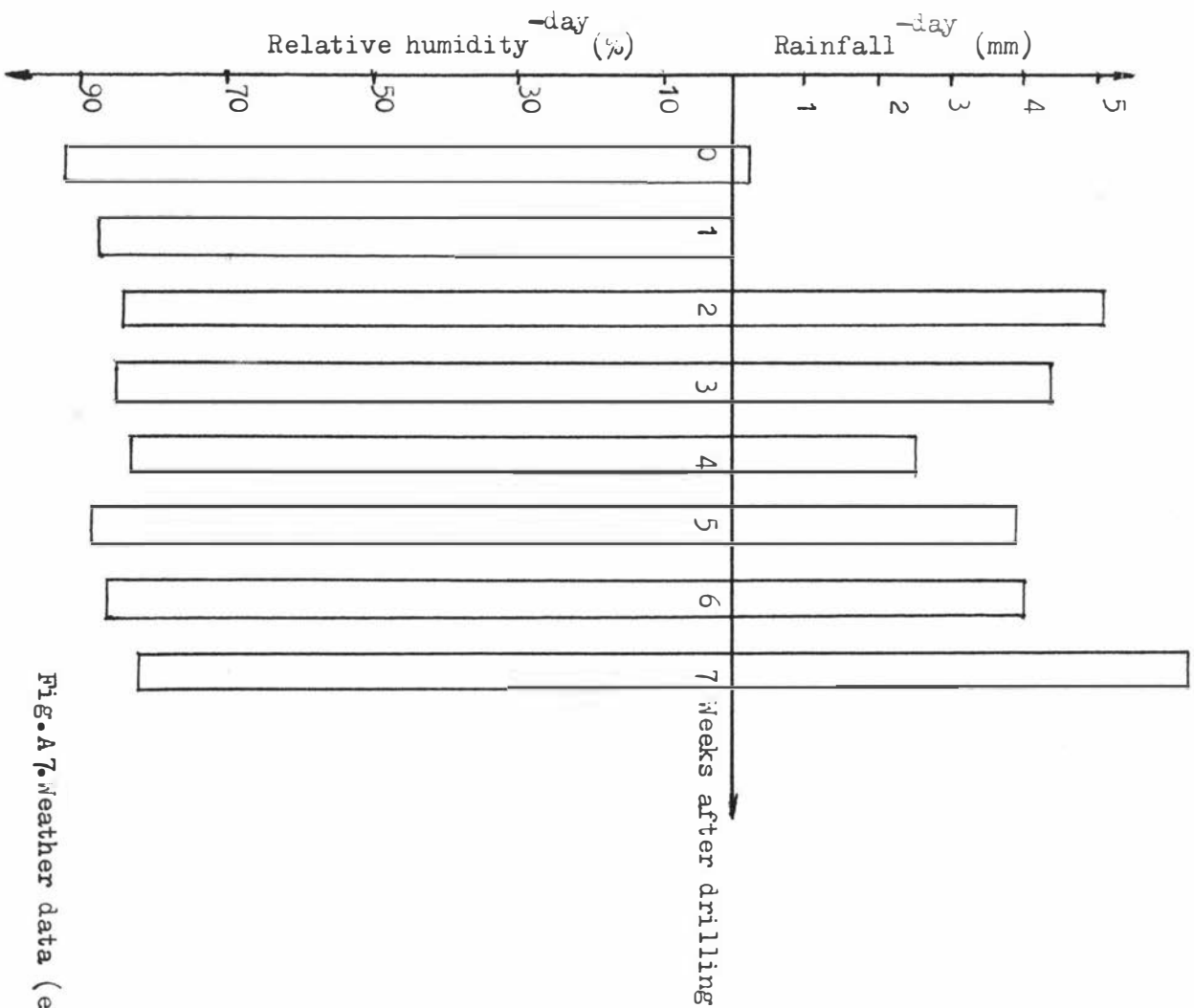


Fig. A 7. Weather data (expt 2)

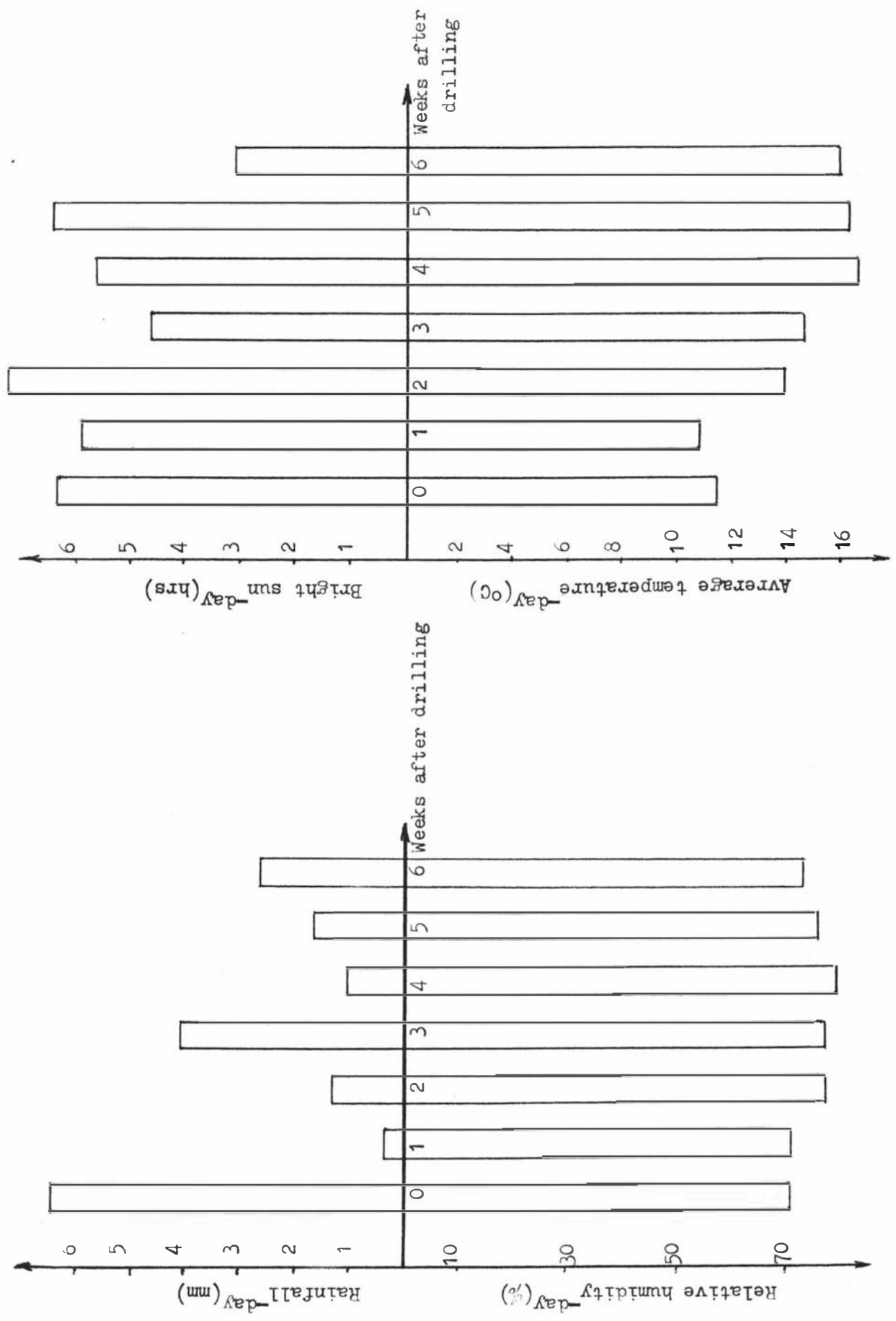


Fig. A8 Weather data(expt 3).

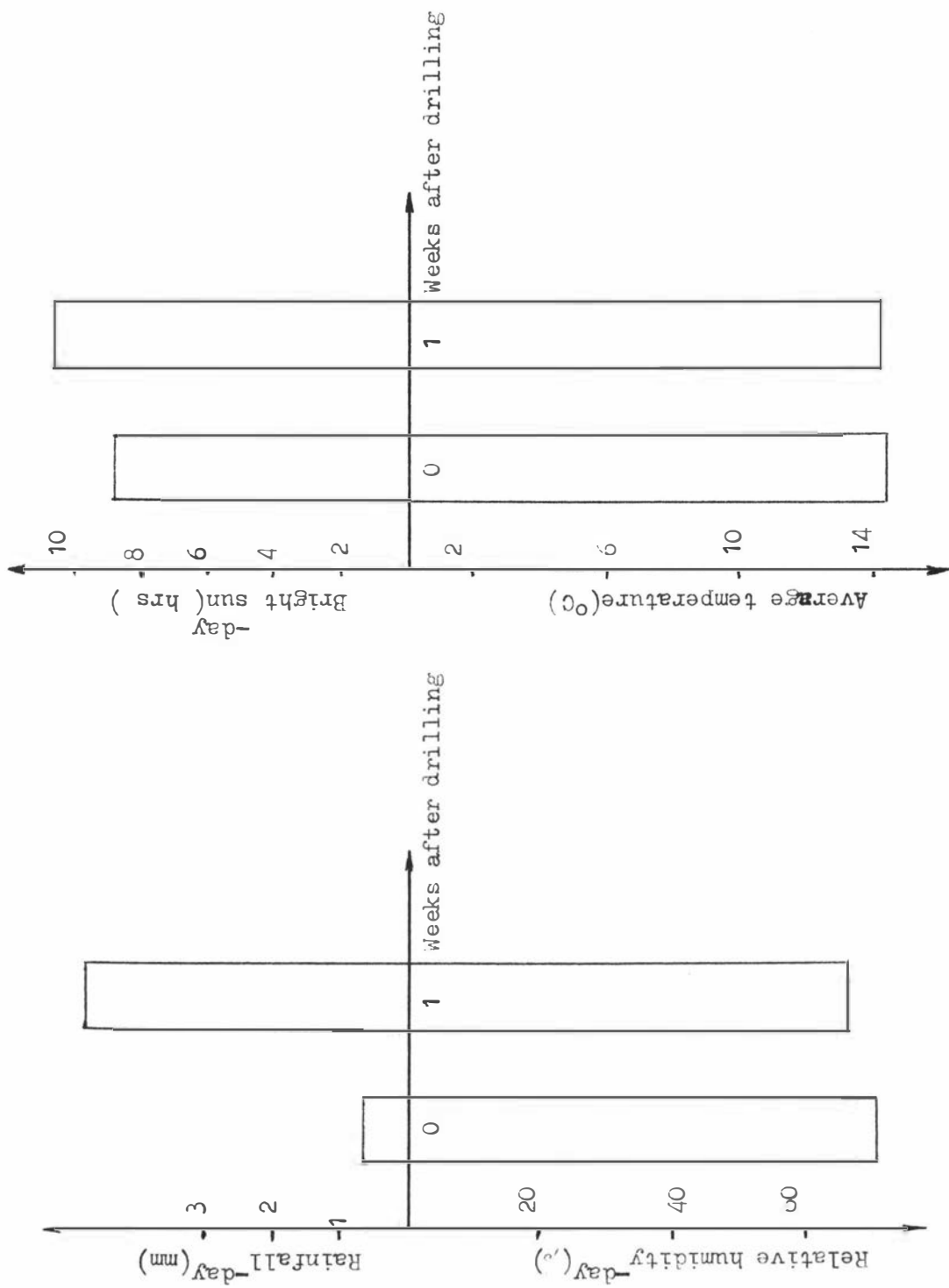


Fig. A9. Weather data (expt 4).

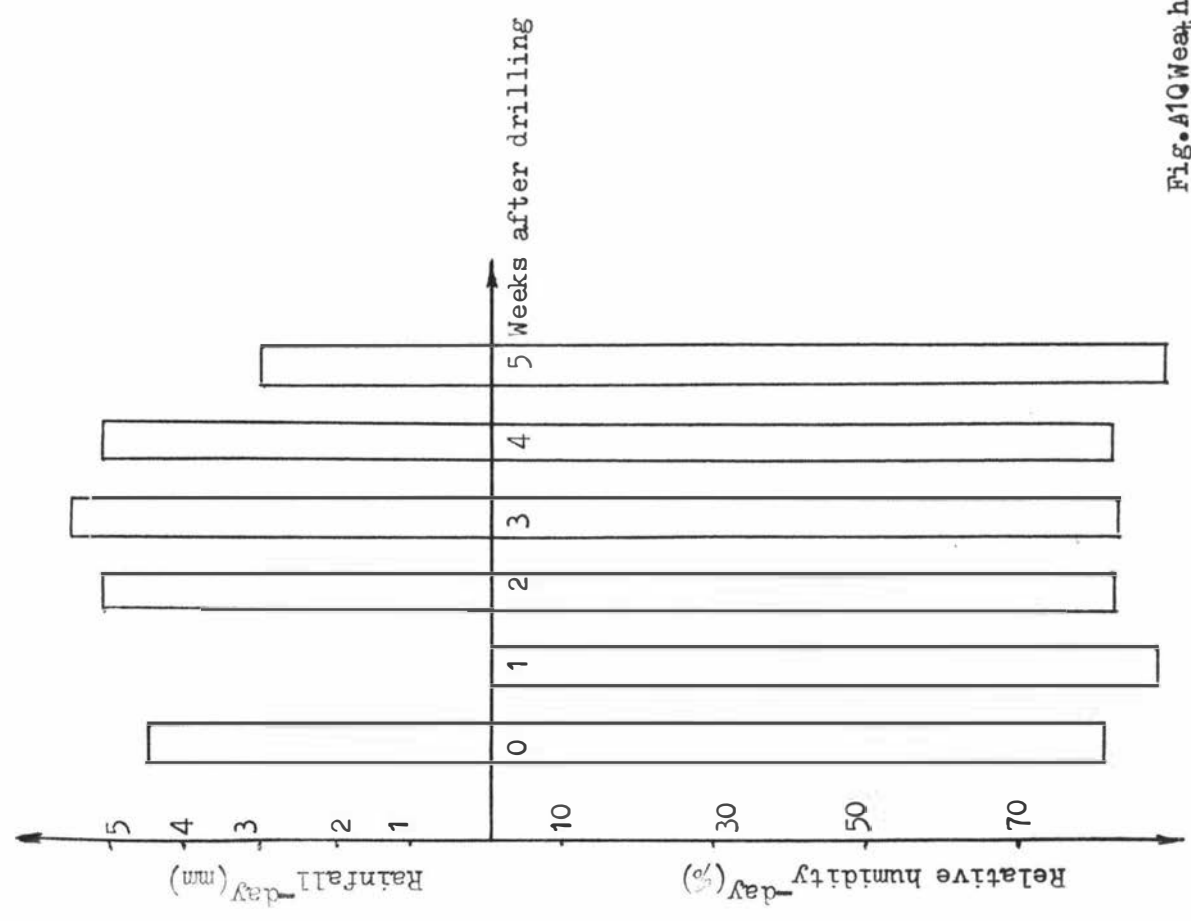
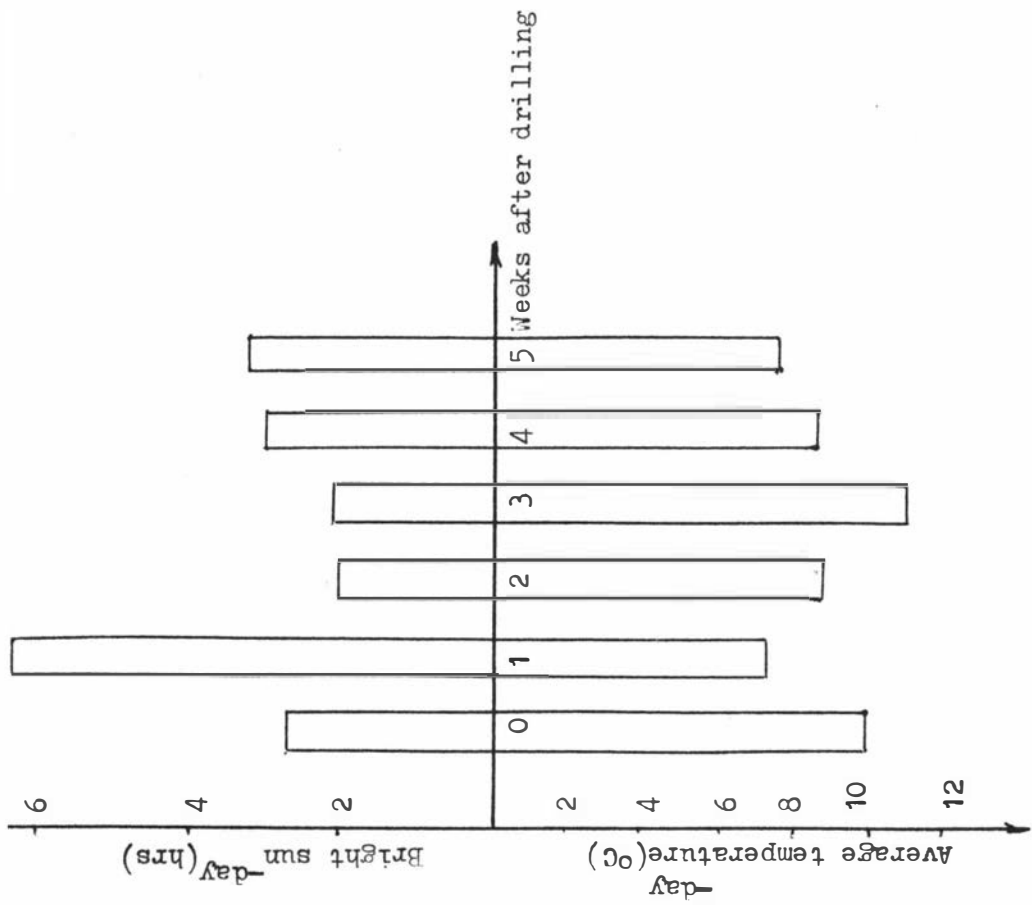


Fig. A10 Weather data (expt 5).

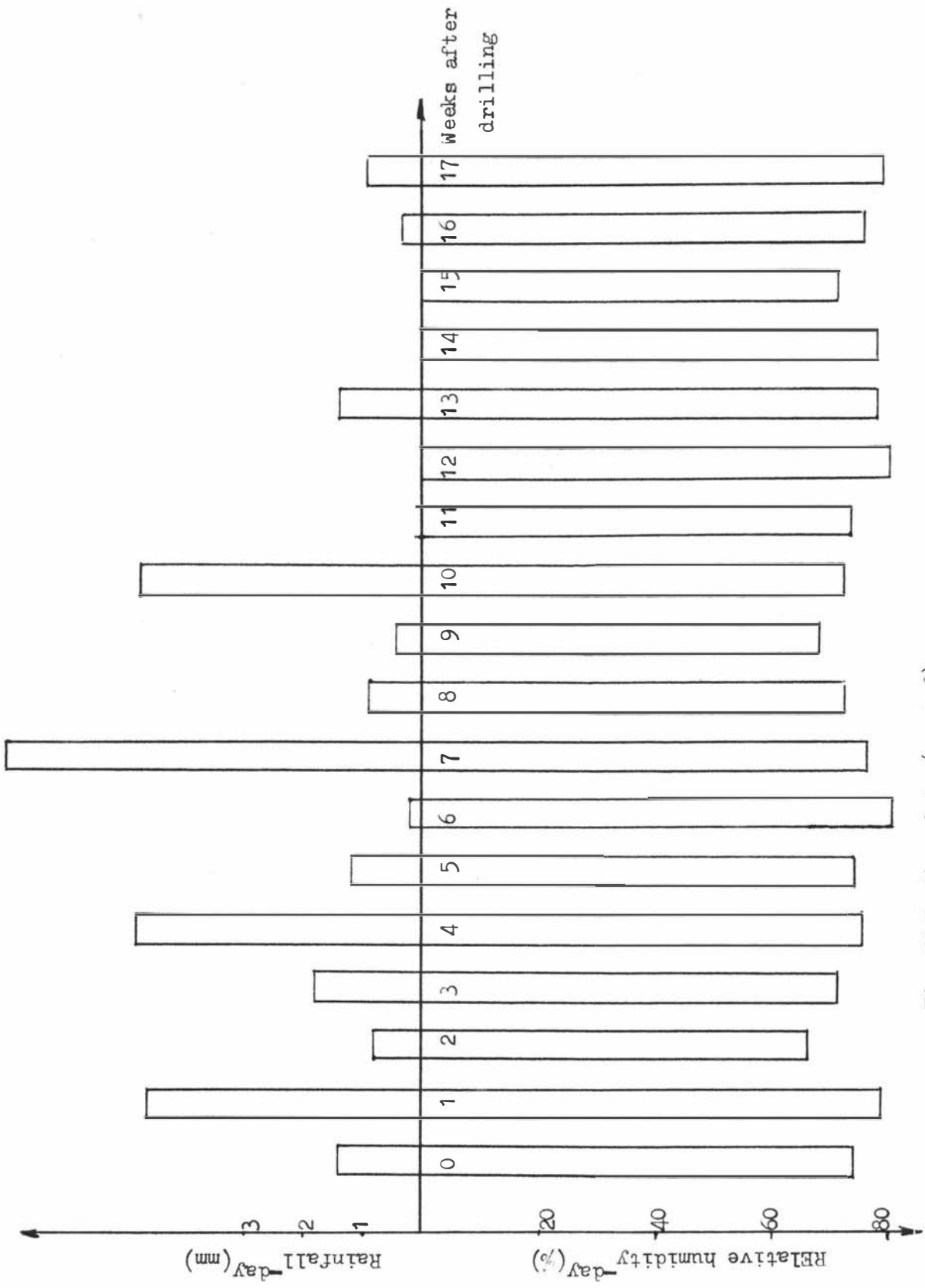


Fig. A11 Weather data (expt 6).

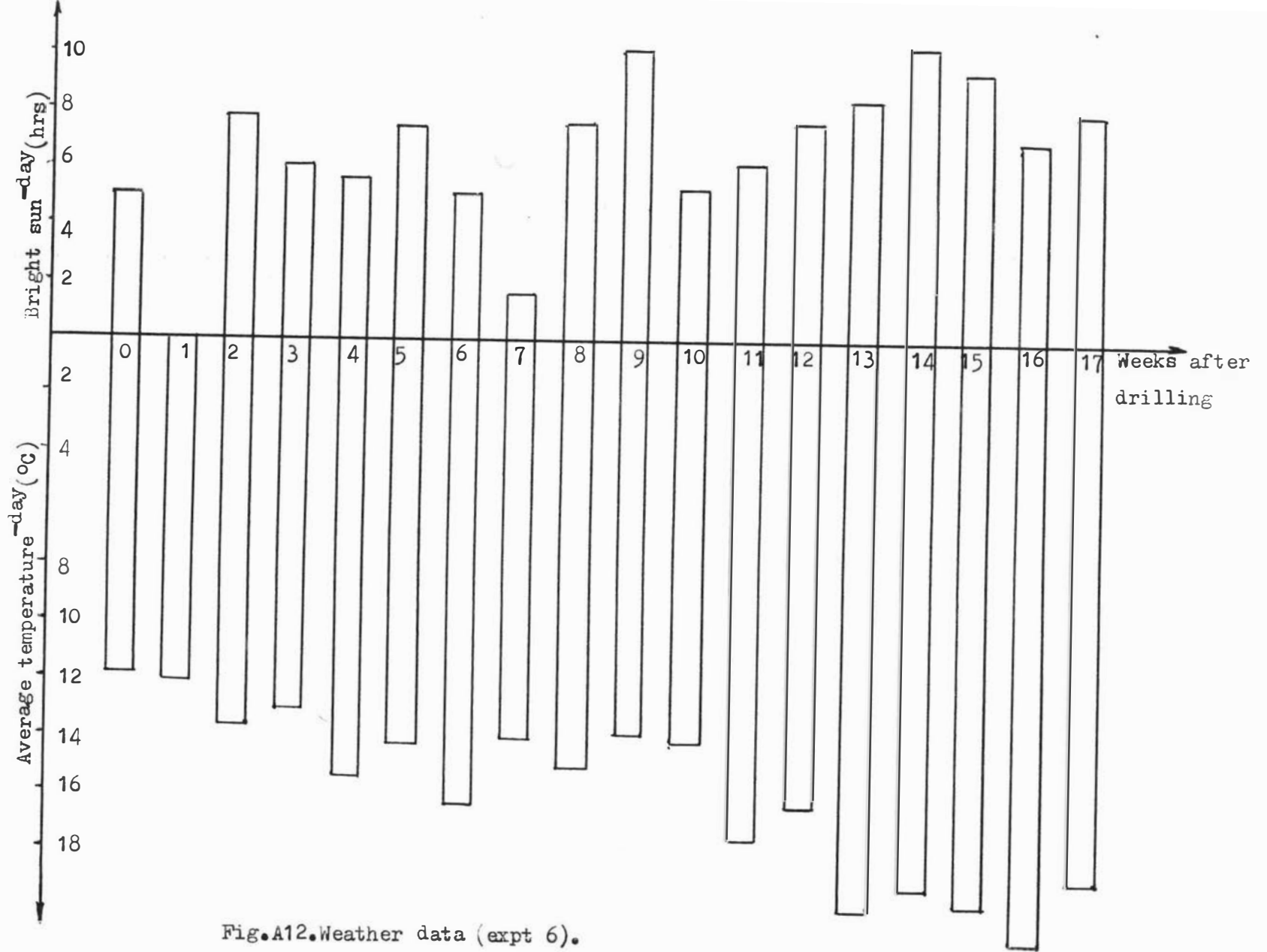


Fig.A12.Weather data (expt 6).

APPENDIX 9.

SOIL BINS AND TESTING APPARATUS

Detailed description of this equipment and instrumentation was given by Baker (68). Only brief description was given here for reference purposes.

Tillage bins: rectangular, portable and constructed of 6.4mm steel plate, the base lined with 1mm gauge stainless steel. Turf samples were extracted from any suitable site by a special turf cutter moving ahead of/and attached to a collection tillage bin.

Tool Carrier and track: An elevated supporting bed is constructed of rolled steel joists. Two parallel 150mm x 75mm joists form the bed on to which maximum of 5 tillage bins could be placed. Attached alongside each of the 10m bed joists, but supporting only the weight of tool carrier are two 120mm x 75mm joists which form the carriage track.

Tool Carrier: An inverted stirrup-shaped tool carrier of 200mm x 75mm welded channel iron travels a course parallel to the tillage bins and is supported on each side by four cast iron wheels running above and below outer track.

Drive: Motivation of the tool carrier is by a 7½Hp. electric motor driving through a mechanical clutch and variable speed hydraulic drive.

DESCRIPTIONS OF THE COULTERS Baker (68).

a. The commercially available type disc coulters.

This coulters consists of two flat discs (305mm) vertically inclined to each other and approximately 15° included angles, forming a V slightly ahead of the base where they touch. Preceding this is a vertical flat pre disc. All discs have no breast (or disc) angle. Thus the drill coulters is more aptly termed a double disc coulters, but common usage has tended to include the flat pre-disc as part of the drill coulters itself with the result that the drill coulters assembly has become known as a triple disc coulters (Fig. 7).

b. The experimental chisel coulters.

A drill coulters featuring a rigid upright member as the soil engaging component and which has a narrow partly hollow vertical shank, to the base of which is attached at right angles a wider, slightly inclined, chisel shaped flat plate (Fig. 6).

APPENDIX 10.

EQUIPMENT

MEASUREMENT OF PENETRATION FORCE

- displacement transducer
Phillips model PR9314/10
- converter
- power supply 12v
- chart recorder (Rikidenki F.S.=2v)

MEASUREMENT OF DRAFT FORCE

- load cell Kyowa LU 1 TE
- power supply 12v
- microvoltmeter F.S. set at 0.5v (Kikidenki)

MEASUREMENT OF INSTANTANEOUS ZONE OF INFLUENCE

- pressure transducer Kyowa model P.S 5KB
- power supply 12v
- microvoltmeter (used as an amplifier) F.S.=10mv
- chart recorder F.S.= 0.2v

MEASUREMENT OF THE DISTURBANCE ZONE ON THE SOIL SURFACE

- displacement transducer Phillips model PR9314/10
- power supply 12v
- converter
- chart recorder F.S, set at 10mv

PHYSICAL PROPERTIES OF EPOFIX RESIN (manufactured by Struers, Denmark)

Epofix resin is soluble in alcohol and in acetone. Epofix hardening liquid is also soluble in alcohol, acetone and in water. The liquid resin hardener mixture as used in the study has the following properties:

TEMPERATURE	VISCOSITY (cp)	VAPOUR PRESSURE mm Hg	POT LIFE (minutes)
25°C	550	0.5	30
50°C	150	2.0	15

Degree of hardness when completely hardened : 18-24Kg/mm Vickers.

00700 F O R T R A N C O M P I L E R I T E M A R K 2.9.170

F A I
= = =

FINDWAY ANALYSIS OF VARIANCE

MATAI PHUONG 1970 AGRU

```

DIMENSION TRIAL(15), TITLE(50,20), V(50,20,20), X(50,20,20), GX(50), GXX
(50), SSXR(50), SSXA(50), SXR(50,20), SXA(50,20), GXS(50), CTX(50), TX(5
20), RXX(50), RXX(50), LXX(50), RMS(50), RIS(50), RMS(50), SLA(50), DA1(50)
3 READ 100, (TRIAL(LI), LI=1,13)

```

```

READ 101, LMAX, IMAX, JMAX, IR, IA, IN, M
READ 102, (TITLE(L,LL), LL=1,2), L=1, LMAX)
READ 103, TA1, IA5, FR1, FR5, FA1, FA5
DEGREES OF FREEDOM

```

```

R=IR
A=IA
DFR=R-1.
DFA=A-1.
DFT=(R+A)-1.
DFE=DFT-(DFR+DFA)
DO 50 J=1, JMAX
DO 50 I=1, IMAX
READ 104, IH, (V(L,I,J), L=1, LMAX)
DO 51 L=1, LMAX
DO 51 J=1, JMAX
DO 51 I=1, IMAX
X(L,I,J)=V(L,I,J)

```

CONTINUE
INITIALISATION STATEMENTS

```

DO 52 L=1, LMAX
GX(L)=0
GXX(L)=0
SSXR(L)=0
SSXA(L)=0

```

```

CONTINUE
DO 53 L=1, LMAX
DO 53 I=1, IMAX
SXR(L,I)=0

```

```

CONTINUE
DO 54 L=1, LMAX
DO 54 J=1, JMAX
SXA(L,J)=0

```

CONTINUE
CALCULATIONS

```

DO 1 L=1, LMAX
DO 1 I=1, IMAX
DO 1 J=1, JMAX
GX(L)=GX(L)+X(L,I,J)
GXX(L)=GXX(L)+(X(L,I,J)**2)
DO 2 L=1, LMAX
GXS(L)=GX(L)*GX(L)
CTX(L)=GXS(L)/(R*A)
DO 3 L=1, LMAX
DO 3 I=1, IMAX
DO 3 J=1, JMAX
SXR(L,I)=SXR(L,I)+X(L,I,J)
DO 4 L=1, LMAX
DO 4 I=1, IMAX

```

```

4 SSXA(L)=SSXA(L)+(C(XA(L,I))*SA(L,I))
  UU 5 L=1,LMAX
  UU 5 J=1,JMAX
  UU 5 I=1,IMAX
5 SXA(L,J)=SXA(L,J)+X(L,I,J)
  UU 6 L=1,LMAX
  UU 6 J=1,JMAX
6 SSXA(L)=SSXA(L)+(SXA(L,J))*SA(L,J)
  UU 7 L=1,LMAX
  TXX(L)=UXX(L)-CIX(L)
  RXX(L)=(SSXA(L)/A)-CIX(L)
  AXX(L)=(SSXA(L)/R)-CIX(L)
  LXX(L)=TXX(L)-(RAX(L)+AXX(L))
  RMS(L)=RXX(L)/DFR
  AMS(L)=AXX(L)/DFR
  EMS(L)=LXX(L)/LFE
  FR(L)=RMS(L)/EMS(L)
  FA(L)=AMS(L)/EMS(L)
  SEA(L)=SQRT(ABS((2.*EMS(L))/R))
  DA1(L)=SEA(L)*TA1
  DA5(L)=SEA(L)*TA5
  AV(L)=UA(L)/(R*A)
  CV(L)=(SQRT(ABS(EMS(L))))/AV(L)*100.
7 CONTINUE
  UU 8 L=1,LMAX
  UU 8 J=1,JMAX
8 AMEAN(L,J)=SXA(L,J)/R
  UU 9 L=1,LMAX
  UU 9 I=1,IMAX
9 RMEAN(L,I)=SXA(L,I)/A
  PRINTING STATEMENTS
  UU 10 L=1,LMAX
  PRINT 105,(TRIAL(L),L,I-1,IS)

  PRINT 106
  PRINT 107,(TITLE(L,LL),LL=1,2),IH
  PRINT 108
  PRINT 109
  PRINT 108
  PRINT 110,DFR,RXX(L),RMS(L),FR(L),FR1,FR5
  PRINT 111,DFR,AXX(L),AMS(L),FA(L),FA1,FA5
  PRINT 112,DFR,LXX(L),EMS(L)
  PRINT 108
  PRINT 113,CV(L)
  PRINT 108
  PRINT 106
  UU 14 J=1,JMAX
14 PRINT 116,(CX(L,I,J),I=1,IMAX),AMEAN(L,J)
  PRINT 106
  PRINT 115,(RMEAN(L,I),I=1,IMAX)
  PRINT 106
  PRINT 106
  PRINT 117,SEA(L),DA1(L),DA5(L)
  PRINT 106
  PRINT 106
10 CONTINUE
  UU 35 L=1,LMAX
  UU 35 I=1,IMAX
  UU 35 J=1,JMAX
  X(L,I,J)=0
  IF(IH-IN)11,99,99
  FORMAT STATEMENTS
100 FORMAT(16A5)
101 FORMAT(GI2)
102 FORMAT(7(2A5),/,(X#(2#))
103 FORMAT(6F6.3)
104 FORMAT(13,3A,F4.2,3A,F4.2,3A,F5.3,3A,F5.2)
105 FORMAT(1H,16A5)
106 FORMAT(1H,/)
107 FORMAT(1H,2UNANALYSIS OF VARIANCE,DX,2A5,1UX,7H HARVEST,2X,12)
108 FORMAT(1H,110H)
-----
109 FORMAT(1H,2H SOURCE,11X,2HDF,11X,2HSS,14X,2HMS,10X,2HF CAL,7X,5H
REQ)
110 FORMAT(1H,2H BLOCK,11X,F4.0,F10.4,F11.0,2(1X,F0.2))
111 FORMAT(1H,2H TREAT,11X,F4.0,F10.4,F11.0,2(1X,F0.2))
112 FORMAT(1H,2H ERROR,11X,F4.0,F10.4)
113 FORMAT(1H,2H COEFF VAR =,F10.2)
114 FORMAT(1H,2H BLOCK MEANS,10F12.4)
115 FORMAT(1H,2H TUF12.4)
116 FORMAT(1H,2H STD ERROR,5X,F12.4,5X,7H LSD,10X,F12.4,5X,7H LSD,5PC,F1
2.4)
99 CALL EXIT
END

```

H A I
= = =

THREE WAY ANALYSIS OF VARIANCE

MAR 1970

```

DIMENSION TRIAL(10), TITLE(20,20), V(20,9,9,9), X(20,9,9,9), GX(20), GXX
L(20), SSXR(20), SSXA(20), SSXB(20), SSXAB(20), SXAB(20,9,9), SXR(20,9), S
ZAA(20,9), SAB(20,9), GAS(20), GTX(20), TXX(20), HAX(20), BAX(20), ABXX(20
), LAX(20), LHS(20), SLA(20), SLB(20), SLAB(20), UA1(20), UAS(20), UB1(20
), UBS(20), UAB1(20), UAB5(20), UV(20), AV(20)
DIMENSION RAX(20), AHS(20), BHS(20), ABHS(20), RMS(20), FA(20), FB(20), F
AB(20), FR(20), AMEAN(20,9), BMEAN(20,9), ABMEAN(20,9,9)
DIMENSION CODE(10)
READ(5,100) (TRIAL(L), L=1,10)

```

```

17 READ(5,100) (CODE(L), L=1,10)
READ(5,101) LMAX, LBMAX, JMAX, KMAX, L1, L2, L3, L4
READ(5,119) I1, I2, FR1, FR5, F1, F5, FB1, F5, FAB1, FAB5
READ(5,102) (TITLE(L,LL), LL=1,2), L=1, LMAX)

```

```

18 DO 57 J=1, JMAX
DO 57 K=1, KMAX
DO 57 I=1, IMAX
57 READ(5,103) IM, (V(L, I, J, K), L=1, LMAX)
210 DO 51 L=1, LMAX
DO 51 I=1, IMAX
DO 51 J=1, JMAX
DO 51 K=1, KMAX
X(L, I, J, K) = V(L, I, J, K)

```

```

51 CONTINUE
DEGREES OF FREEDOM
R=IR
A=IA
B=IB
DFR=K-1.
DFA=A-1.
DFB=B-1.
DFAB=(A*B)-1.
DFE=((A*B)-1.)*DFR
DFI=(R*A*B)-1.
INITIALISATION STATEMENTS

```

```

50 DO 52 L=1, LMAX
GX(L)=0
GXX(L)=0
SSXR(L)=0
SSXA(L)=0
SSXB(L)=0
SSXAB(L)=0

```

```

52 CONTINUE
DO 53 L=1, LMAX
DO 53 J=1, JMAX
DO 53 K=1, KMAX
SXAB(L, J, K)=0

```

```

53 CONTINUE
DO 54 L=1, LMAX
DO 54 I=1, IMAX
SXR(L, I)=0

```

```

54 CONTINUE
DO 55 L=1, LMAX

```

```

UU 55 J=1, JMAX
SXA(L, J)=0
55 CONTINUE
UU 56 L=1, LMAX
UU 56 K=1, KMAX
SXB(L, K)=0
56 CONTINUE
CALCULATIONS
UU 1 L=1, LMAX
UU 1 I=1, IMAX
UU 1 J=1, JMAX
UU 1 K=1, KMAX
UX(L)=UX(L)+X(L, I, J, K)
GXX(L)=GXX(L)+(X(L, I, J, K)*X(L, I, J, K))
1 CONTINUE
UU 2 L=1, LMAX
GXS(L)=UX(L)*UX(L)
CTX(L)=GXS(L)/(N*A*U)
2 CONTINUE
UU 3 L=1, LMAX
UU 3 I=1, IMAX
UU 3 J=1, JMAX
UU 3 K=1, KMAX
SXR(L, I)=SXR(L, I)+X(L, I, J, K)
3 CONTINUE
UU 4 L=1, LMAX
UU 4 I=1, IMAX
SSXR(L)=SSXR(L)+(SXR(L, I)*SXR(L, I))
4 CONTINUE
UU 5 L=1, LMAX
UU 5 J=1, JMAX
UU 5 I=1, IMAX
UU 5 K=1, KMAX
SXA(L, J)=SXA(L, J)+X(L, I, J, K)
5 CONTINUE
UU 6 L=1, LMAX
UU 6 J=1, JMAX
SSXA(L)=SSXA(L)+(SXA(L, J)*SXA(L, J))
6 CONTINUE
UU 7 L=1, LMAX
UU 7 K=1, KMAX
UU 7 I=1, IMAX
UU 7 J=1, JMAX
SXB(L, K)=SXB(L, K)+X(L, I, J, K)
7 CONTINUE
UU 8 L=1, LMAX
UU 8 K=1, KMAX
SSXB(L)=SSXB(L)+(SXB(L, K)*SXB(L, K))
8 CONTINUE
UU 9 L=1, LMAX
UU 9 J=1, JMAX
UU 9 K=1, KMAX
UU 9 I=1, IMAX
SXB(L, J, K)=SXB(L, J, K)+X(L, I, J, K)
9 CONTINUE
UU 10 L=1, LMAX
UU 10 J=1, JMAX
UU 10 K=1, KMAX
SSXB(L)=SSXB(L)+(SXB(L, J, K)*SXB(L, J, K))
10 CONTINUE
UU 11 L=1, LMAX

```

```

TAA(L)=CXX(L)-CIA(L)
RAA(L)=(SSXA(L)/(A*U))-CIA(L)
AXX(L)=(SSXA(L)/(K*U))-CIA(L)
BAA(L)=(SSAB(L)/(A*K))-CIA(L)
ABXX(L)=(SSXAB(L)/K)-CIA(L)-AXX(L)-BXX(L)
EXX(L)=IXX(L)-(RAA(L)+AXX(L)+BAA(L)+ABAA(L))
AMS(L)=AXX(L)/UFA
UMS(L)=BXX(L)/UFB
ABMS(L)=ABAA(L)/UFAU
EMS(L)=EXX(L)/UFE
RMS(L)=RXX(L)/UFR
FA(L)=AMS(L)/EMS(L)
FB(L)=BMS(L)/RMS(L)
FAB(L)=ABMS(L)/EMS(L)
FR(L)=RMS(L)/RMS(L)
SEA(L)=SQRT(ABS((2.*LMS(L))/(K*U)))
SEB(L)=SQRT(ABS((2.*LMS(L))/(K*U)))
SEAB(L)=SQRT(ABS((2.*LMS(L))/(K*U)))
DA1(L)=SEA(L)*TA1
DAB(L)=SEA(L)*TAB
UB1(L)=SEB(L)*TA1
UB5(L)=SEB(L)*TAB
JAB1(L)=SEAB(L)*TA1
DAB5(L)=SEAB(L)*TAB
AV(L)=UA(L)/(K*A*U)
CV(L)=(SQRT(ABS(LMS(L))/AV(L))*100.)
11 CONTINUE
UU 12 L=1,LMAX
UU 12 J=1,JHAX
12 AMEAN(L,J)=SXA(L,J)/(K*U)
UU 13 L=1,LMAX
UU 13 K=1,KHAX
13 BMEAN(L,K)=SXB(L,K)/(K*A)
UU 14 L=1,LMAX
UU 14 J=1,JHAX
UU 14 K=1,KHAX
14 ABMEAN(L,J,K)=SXAB(L,J,K)/K
PRINTING STATEMENTS
UU 15 L=1,LMAX
WRITE(6,105)(TRIAL(L),LTF=1,10)

WRITE(6,120)
WRITE(6,100)(TITLE(L,LL),LL=1,2,11)
WRITE(6,108)
WRITE(6,107)
WRITE(6,100)
WRITE(6,121) UFA,RAA(L),RMS(L),FR(L),FAS,FRK
WRITE(6,109) UFA,AXX(L),AMS(L),FA(L),FAL,FAU,SLA(L),DA1(L),DAB(L)
WRITE(6,111) UFB,BXX(L),BMS(L),FB(L),FBL,FBU,SLB(L),UB1(L),UB5(L)
WRITE(6,110) UFAU,ABAA(L),ABMS(L),FAB(L),FAB1,FAU5,SEAB(L),DAB1(L)
1 DAB5(L)
WRITE(6,112) UFE,EXX(L),EMS(L)
WRITE(6,108)
WRITE(6,114) CV(L)
WRITE(6,108)
WRITE(6,120)
WRITE(6,113)
WRITE(6,120)
UU 16 K=1,KHAX
10 WRITE(6,122) (ABMEAN(L,J,K),J=1,JHAX),BMEAN(L,K)
WRITE(6,120)

```

```

WRITE(6,113) (NAME(I),J=1,JMAX)
WRITE(6,120)
WRITE(6,104) (CODE(I),LT=1,16)
WRITE(6,120)
15 CONTINUE
IF(1H=1N)10,99,99
FORMAT STATEMENTS
00 FORMAT(16A5)
01 FORMAT(6I2)
02 FORMAT(6(2A5))
03 FORMAT(14X,F0.3,5X,12,4X,F0.3,5X,12)
04 FORMAT(1H,16A5)
05 FORMAT(1H1,16A5)
06 FORMAT(1H,20H ANALYSIS OF VARIANCE,5X,2A5,10X,6HNUMBER,2X,I/)
07 FORMAT(1H,8H SOURCE,11X,2HDF,11X,2HSS,14X,2HMS,10X,5HFCAL,7X,5HFK
      1X,4X,9HSTDEV,7X,7HLSDF,10X,5HFCAL,7X,5HFK
08 FORMAT(1H,110H-----)
09 FORMAT(1H,16HTREATMENT A      F 4.0,2F10.4,F 11.3,2(1X,F0.2),3(1X,F
      11.4))
10 FORMAT(1H,17H A*B INTERACTION  F 3.0,2F10.4,F 11.3,2(1X,F0.2),3(1X,F
      11.4))
11 FORMAT(1H,16HTREATMENT B      F 4.0,2F10.4,F 11.3,2(1X,F0.2),3(1X,F
      11.4))
12 FORMAT(1H,5H MEANS,11X,14.0,2F10.4)
13 FORMAT(1H,15X,25H MEANS FOR A*B INTERACTION)
14 FORMAT(1H,12H COEFF VAR = F10.2)
15 FORMAT(1H,11H MEANS FOR A,1X,12F10.3)
19 FORMAT(10F0.3)
0  FORMAT(1H,/)
1  FORMAT(1H,16H REPLICATE      F 4.0,2F10.4,F 11.3,2(1X,F0.2))
22 FORMAT(1H,12X,12F10.3)
99 CALL EXIT
END

```

NOTE: INPUT

LMAX : NUMBER OF EXPERIMENTS (ie WHEAT, LUPIN)

IMAX : NUMBER OF BLOCKS

JMAX : FACTOR LEVEL (FOR FACTOR A ie Density X2)

KMAX : FACTOR LEVEL (FOR FACTOR B ie Coulters X2)

IR : BLOCK NO ; IA : TREATMENT NO (ie Factors)

IN : NUMBER OF TREATMENT COMBINATIONS (ie 4)