INTERRELATIONSHIPS BETWEEN PERFORMANCE OF DIRECT DRILLED SEEDS, SOIL MICRO-ENVIRONMENT AND DRILLING EQUIPMENT

A thesis presented in partial fulfilment of the
requirements for the degree
of
Doctor of Philosophy at

Massey University
Palmerston North

by

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1979

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ABSTRACT

Stand establishment of crops by direct drilling is a function of seed germination and seedling emergence efficacy and their interactions with the soil physical micro-environment created by direct drill coulters.

Experiments conducted in two contrasting controlled climates using 0.5 tonne undisturbed turf blocks suggested that the three coulter types compared (viz. an experimental chisel coulter, a hoe and a triple disc coulter) performed significantly differently, in terms of wheat seedling emergence, when the seed was direct drilled into a fine sandy loam soil. Overall the chisel coulter promoted highest seedling emergence (63.5%) followed by the hoe coulter (50.6%) and the triple disc coulter (27.0%). When the initial soil moisture potential was close to permanent wilting point, seedling emergence counts between these three coulters were highly significant with the difference between the chisel and triple disc coulters being almost six-fold. When the initial soil moisture level was adequate, seedling emergence counts from the triple disc grooves, were still significantly lower than from the chisel and hoe coulters which themselves performed equally.

When the controlled relative humidity was increased from 60% to 90%, seedling emergence increased but this difference was significant only at a lower level of probability of P = 0.10.

Application of pressures (using press wheels) up to 70 kPa over the covered seeds after bar harrowing had no significant effect on seedling emergence at either the low or adequate initial soil moisture levels. When similar pressures were applied directly over the uncovered seeds, seedling emergence significantly increased to 60% in the hoe coulter grooves and to 28% in the triple disc coulter grooves compared to the unpressed seeds. No significant increase was observed from the chisel coulter groove as a result of these pressures because it had already promoted a high seedling emergence count of 58%.

Further experiments, using small undisturbed turf blocks, to examine more closely the poor performance of the triple disc coulter, indicated that smearing had not been the main cause of seedling emergence failure. When the triple disc coulter grooves were modified

using combinations of pressure applications and seed covering techniques, seedling emergence was significantly improved. It appeared that this improvement in seedling emergence was a function of a modified soil physical micro-environment at the seed-soil interface. Based on these results two hypotheses were evolved. The first hypothesis suggested that the transfer of liquid soil moisture to the seed for germination (and perhaps away from the unprotected seedling after germination but prior to emergence) could be altered by the shape of the seed groove and placement and covering of the seed. This was described as "soil moisture diffusion"

The second hypothesis suggested that after the germination, subterranean seedling survival depended on the availability of vapour phase moisture which was also a function of the groove shape and covering medium. This was described as "soil moisture captivity".

A thermo-electric dew point hygrometer was used to measure the in-groove vapour moisture potential within the drilled grooves in the larger turf blocks, in a controlled environment. Significant and repeatable differences in the drying rates of the grooves created by the three coulter types were measured and promised to at least partly explain the underlying causes of their abilities (or lack of abilities in some cases) to promote seedling emergence. Combined counts of seedling emergence and sub-surface seedling survival were moderately correlated ($r = 0.71$) with the corresponding rates of loss of in-groove soil vapour moisture.

It appeared from the data that the important design characteristics for direct drilling coulters were that they must have the ability to both exploit the limited supply of sub-surface liquid moisture for germination and also to retain soil moisture in the vapour form for seedling emergence and/or survival. The latter function appeared to be aided by the creation of minimum surface shattering and maintenance of a high incidence of surface mulch in the form of sod or organic matter.

Field experiments suggested that when the only measured soil moisture data available was at or prior to drilling, the present state of knowledge would not permit accurate seedling emergence data to be predicted for any given coulter and covering technique. If however, soil moisture data was available for the period between drilling and seedling emergence, reasonable predictions of seedling emergence could be made, given the characteristics of the coulter types and covering techniques used. Examples of mathematical models were constructed for each of the three coulter types used, to predict seedling emergence as a function of these soil moisture data.

The field experiments also confirmed that higher seedling emergence counts could be expected when the chisel coulter was used in dry soils compared with the hoe or triple disc coulters. During a typical spring-summer-autumn period in the Manawatu, when wheat seed was direct-drilled at fortnightly intervals into a "Tokomaru silt loam soil"; from 16% of the drillings the chisel coulter promoted significantly higher seedling emergence counts than either the hoe or triple disc coulters.

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL INTRODUCTION

Stand establishment of crops is markedly influenced by the efficacy of seed germination and seedling emergence. An understanding of soil physical factors and their interrelationships with seed germination and seedling emergence is therefore fundamental to the design function of seed drills and especially furrow openers.

The total environment influencing the germinating seed may be classified as tri-part, composed of chemical, biological and physical parameters. Within the broad range of non-limiting seed-soil biological and chemical conditions, the stresses imposed by the physical factors may become the dominant forces which might then limit seed germination and/or seedling emergence in the field.

For field crops, seeds have been traditionally sown into conventionally cultivated clean seed-beds. A considerable amount of data are now available concerning the characteristics of soil-tillage profiles in conventional seed-beds which aim to encourage consistently optimum responses from seeds and seedlings during germination and emergence. In direct drilling (or zero-tillage), because the technique is based on the avoidance of general seed-bed tillage, with or without herbicides, to eradicate the competing weeds, the seed is sown directly into the untilled soil. Little comparable data exist for untilled seedbeds, and extrapolation from the tilled seedbeds conditions seems to be justified only in limited situations.

The development in the 1950's of the desiccants diquat and paraquat, which displayed wide spectra of activities against green tissues and virtual inactivity in soil, lead to the modern concept of direct drilling, and an accompanying upsurge in research activity. Cannell and Ellis(1) compiled a summary of comparative yields from direct drilling and ploughing experiments and their data reported that in 61% of the experiments (24 comparisons) on spring barley direct drilling gave equal to, or greater yields than conventional tillage. For winter wheat the corresponding figure was 45%. Some depressions in yields with direct drilling have been attributed to modified soil physical parameters and to design inadequacies of the drills used for this purpose. For example, Baeumer[2] suggested that inadequate penetration of drill coulters in dry soils, and consolidation and smearing of the drill slit were the main causes of reduced plant population in his experiments. Soane[3] *et al.* also made similar observations but emphasized the need to quantify the interactions of drilling machinery and the soil physical parameters. There does not appear to be much data available, however, to show the effects of the modified soil physical parameters on the crop establishment. In one of the more recent studies Baker[4] found higher seedling emergence percentage with an experimental chisel coulter compared to that with a commercially available triple disc coulter. He suggested that the experimental chisel coulter was, apparently, creating more favourable soil physical conditions for seed germination and seedling emergence.

More recently it has become necessary to extend the need for understanding to embrace the probable interactions between soil, seed, drilling machine and the atmosphere and to formulate useful correlations for optimum seed responses to planting.

One of the objectives of this study has been to identify and investigate the salient soil physical parameters which might be altered by the action of direct drilling coulter designs, and in turn to study the effects that these might have on the germination and seedling emergence of wheat seeds and seedlings.

1.2 INTERACTIONS BETWEEN SOIL, SEED AND AMBIENT CONDITIONS IN TILLED SOILS

In order to understand some of the relationships between the parameters in untilled seedbeds, reference to the more plentiful data obtained from conventionally cultivated seedbeds was considered to be a logical background.

1.2.1 Soil and Seed Moisture Requirements for Seed Germination

The need for moisture during seed imbibition, seed germination and seedling emergence has long been recognised, and specific requirements of many species have been determined. Hunter and Ericson[5] found that for five soils, the average minimum values of matric potential necessary for emergence of corn, rice soyabeans and sugarbeet seeds respectively, were -12.7, -8.0, -6.7 and -3.5 bars. Collis-George and Melville[6] showed that in the process of liquid water absorption at 20 ± 1.5^{o}C, wheat seeds germinated when their moisture contents were approximately 0.68g/g (d.b). According to Hillel[7] soil moisture potential affected seed germination and seedling emergence, either directly through its effects on conductivity or indirectly through its effects on temperature, which in turn affected physiological processes during embrionic development and seedling growth. This author also reported that because imbibition was a dynamic process, it became clear that the potential energy of the soil was not the only factor to affect seed germination. Rate of movement of water in the soil across the seed-soil interface and in the seed should also be taken into account, especially during early imbibition, when the rate of water uptake was higest. Phillips[8] and Hadas[9] and Hadas & Stibbe[11] suggested that water taken up from the soil adjacent to the imbibing seeds made the matric potential at the seed surface lower than that of the soil bulk. Also it appeared that for good germination and emergence a relative uptake of water of approximately 100% of the initial seed weight was necessary[9]. Feedes[12] quoted Dasberg as claiming that soil water at distances exceeding 10mm from the seed was not taken up by seeds of average diameter of 2mm. He apparently claimed further that outside that range the hydraulic conductivity of the soil was of no importance.

From the results of Collis-George and Hector[13], Hadas[9] and Feedes[12] it appears that the combined effects of matric potential, hydraulic conductivity and seed-soil contact were not fully separated, interpreted and specified in a way that would have been useful as an aid to the design of drill coulters aimed at promoting maximum seedling emergence performance. The information is even less adequate in this respect when applied to the design of direct drilling coulters because of a parallel dearth of data on fundamental soil moisture interactions in uncultivated soils.

1.2.2 The mechanism of Soil Moisture Availability to Seeds

The process of seed germination starts when the seed is exposed to favourable conditions. The supply of soil moisture to the seed is generally considered to take place either by direct seed-soil contact or through vapour diffusion in a humid environment. Scotter[63] noted that soil moisture movement was considered to take place in wet soil through liquid flow while in very dry soils vapour diffusion was the dominant transport mechanism. The same author reported that the relative vapour pressures in equilibrium with soils at intermediate water contents ranged from approximately 0.60 to 0.99. These two limits closely corresponded to air dry and permanent wilting point conditions respectively. Such water contents occured frequently in the field, particularly near the surface of bare soil.

1.2.3 The Importance of Seed-soil Contact

Trouse[14] considered that good contact between seed and moist soil aided moisture transfer to the seed. Compressing a seed into the soil improved this contact, but it did not assure a better supply of moisture to the seed. When compression was excessive there was a serious reduction in the larger, more easily drained macropores, and frequently an increase in the number of smaller macropores which were poor moisture conductors. He further considered that evaporation from the exposed seed-soil interface may in time have reduced the moisture about the seed and generated a desorption process in the initially imbibed seed, which might have desiccated before seedling emergence took place.

As previously reported[9], when the water content adjacent to the imbibing seed decreased, an impairment of the seed-soil water contact resulted. Hadas and Russo[15] suggested that the wetted seed area was hard to determine. They attempted to characterize a combination of the relative seed contact area and the hydraulic conductivity of the soil bulk. They observed that the limiting factor for the availability of soil moisture lay in the seed's hydraulic properties and the seed-soil contact impedence. They recommended that improving the seed properties in relation to soil water, by increasing the seed-soil contact area, should lead to improved seedling emergence performance.

Hillel & Hadas[16] suggested that seedbeds be prepared so as to insure a mean soil aggregate diameter of at least one-fifth that of the seed. They felt that this should increase the water uptake by increasing the seed-soil contact area and decreasing the imbibition period during which the top soil would keep the moisture potential.

1.2.4 The Soil-root Interface

The establishment of plants is closely related to the development and establishment of the radicle in the moist soil, for the uptake of moisture and nutrients. In dry soil and ambient conditions this phenomenon is of more significance. From the viewpoint of the transfer of water to the germinating seed, one of the most important physical characteristics of the soil-root interface is the degree of physical contact of the radicle with the soil.

In conventional cultivation systems and in the laboratory, these phenomena have been researched by a number of authors.[14,17,18,19,20,21]. The resistance of the soil adjacent to the radicle "rhizosphere resistance" changed under various soil moisture and ambient conditions[21]. The same author observed that when this interface resistance was sufficiently high, the rapidly growing root tips had reduced the water potential of the adjacent soil to near the wilting point, even though the water potential a short distance away was close to field capacity. It has also been recognized that plant roots were incapable of development into soil at moisture contents much below the permanent wilting percentage[14]. The effects of various environmental factors on the relation between root entry and the resistance of the media have also been determined for various species. Barley *et al.*[22], and Taylor & Gardner[23] found little or no effect of soil water suction on root entry until the suction values exceeded 0.7 bar. Above that value the percentage of roots that entered the soil mass seemed to reduce. Gardner and Danielson[24] found, however, that the proportion of cotton roots that penetrated a wax layer increased as soil water potential increased to 0.50 bar. These authors concluded that any departure from optimum conditions for plant growth by any of several soil physical factors reduced the ability of plant roots to enter impeding layers.

According to Trouse[14] it could be concluded that moisture stresses were likely to limit root penetration and elongation at soil moisture contents near the permanent wilting percentage. In adequate plant growth conditions an increase in soil strength under the seed would reduce the rate of root penetration and elongation[23].

1.2.5 The Interaction Between Soil and Ambient Environment

Soil physical conditions may be altered by ambient conditions. The air temperature and relative humidity affected the soil drying rates which might determine the extent of soil crust and root zone soil strength, which in turn might affect seed germination and plant establishment.[25]

Effect on Soil Moisture Evaporation

"The actual rate of evaporation from the soil is determined either by the evaporative capacity of the atmospheric environment, or by the ability of the bulk soil to deliver the surface evaporative sites whichever is the lesser".[87] Jackson[26] quoted Buckingham as stating that, if a moist soil was exposed to initially high evaporative conditions, the dry layer that rapidly formed would reduce subsequent evaporation and the cumulative evaporation might in the long term be less than that for a soil initially exposed to low evaporative conditions. This hypothesis, which was first forwarded in 1907 was later confirmed by laboratory data[27]. Jackson (loc. cit.) in his field experiments noticed that the "dry layer" formation occured much sooner in warmer conditions but concluded that cumulative evaporation might not necessarily be lower when an early dry surface layer formed compared with that when the surface was moist over a long time. However, he suggested that this might hold in cases where the soil had been artificially mulched or cultivated to create a loose dry surface layer.

It appears, therefore, that the initial soil moisture content and the subsequent rate and pattern of drying are important factors, particularly in relation to seed germination and seedling emergence. More particularly, it is felt that because direct drilling coulters create the only physical disturbance of the soil at or near the seed zone, their design criteria might have to take into account the ambient conditions and their effects on soil and seed performance.

1.2.6 Soil Mechanical Impedence to Seedling

Soil mechanical impedence is a phenomenon which affects seed and seedling emergence in two distinct ways; impedence to root systems and impedence to seedling emergence. The major emphasis of the study reported herein was at first to consider seedling emergence and its interrelationships with soil compaction, crust formation and ambient conditions. Later emphasis, however, included some consideration also of early root impedence, as this appeared to be linked to the early survival of the seedling.

In conventional cultivation there have been many reports on this subject[28, 29, 30, 31, 32]. The mechanism of seedling emergence through crusts, with and without compaction, and the vertical thrust and total energy expended by a range of species has been studied. For example Taylor *et al.*[25] with a range of soil and ambient conditions, found that penetration resistance for most cereals was approximately 7 bars, but thought that this was a first approximation and valid only for a certain range of environmental conditions. Hacks and Thorpe[32] showed that some wheat seedlings would emerge through crusts of 0.8 bar strength, and that about 20 percent of grain sorghum seedlings could emerge through crusts of 1.4 bars strength.

Lateral anchorage was considered to be extremely important as it enabled the shoot to exert its potentially available thrust. If the zone immediately below the seed was not firm, the shoot tended to grow horizontally rather than vertically[29, 30, 33]. These authors reported also that if the area immediately around the seed was firm enough, this might help hard-testa germination, by applying a counter pressure and bursting the seed coat when the hydrostatic pressure (turgor) inside the seed started building up. If the hydrostatic pressure (which was considered to be a function of moisture stresses or ambient conditions) was not sufficient to overcome the wall restraints and soil impedence, elongation of that root ceased[25].

Johnson and Henry[34] noticed that by compacting a soil layer 25 mm above the seed a diffusion barrier was created which reduced the overall drying rate yet allowed adequate corn emergence, because the drying of the compacted layer was delayed. They also noted a higher plant establishment response at lower initial moisture contents and a reduced overall soil drying rate, when pressure was applied over the seed. French[35], Fischer[36] and Hudspeth[37] used rubber tyred press wheels to press the seed into the soil and then covered them with loose soil and obtained results similar to Johnson & Henry[34].

1.2.7 Soil Aeration

"Seed germination is a process related to living cells and requires an expenditure of energy by these cells. Energy requiring processes in living cells are usually sustained by processes of oxidation, in the presence or absence of oxygen. These processes, respiration and fermentation, involve an exchange of gases, an output of carbon dioxide in both cases and also the uptake of oxygen in the case of respiration"[38].

From the above statement it is apparent that it is important to have soil aeration conditions, conducive to optimum seed performance. Aeration effects on the seed, seedling and root system could regulate plant growth, according to several authors[39,40,41,42,43]. Apparently considerable controversy has existed about the aeration parameters that were most useful to measure, and about the levels of aeration that limited root development[44]. Trouse[14] stated that poor aeration could be partially responsible for a slower rate of hypocotyl expansion in compressed soil because it was the oxygen that was required for rapid growth and cell elongation which gave the hypocotyl its forward thrust. He further suggested that direct effects of reduced aeration on roots seemed to be those of reduced functioning and elongation. It is important, therefore, in field conditions, to meet these oxygen requirements for rapid growth of roots and penetration into the moist soil interface.

Morinaga[45], as early as 1926, found that beans, corn, and many other seed would not germinate under water, although they germinated well on moist blotting paper. He attributed the germination failure under water to a lack of oxygen. In his experiments, however celery and lettuce germinated satisfactorily under water. Tacket and Pearson[44] found that root penetration through low density soil was not affected until oxygen concentration was reduced to below 10%. Considering aeration, Hack[39], who worked with tomato seed in compost with high matric potential, found good emergence at -0.027 bar matric potential which was equivalent to an air filled pore space of 20% (v/v) of air. He found poor emergence at -0.013 bar matric potential which corresponded with 8% (v/v) of air. Hank and Thorpe[40] observed a reduction in wheat seedling emergence at oxygen diffusion rates below 1.24 to 1.65. 10^{-7}kg.m^{-2}. $sec.^{-1}$ This rate corresponded to a pore space of approximately 16% in a silty clay loam and 25% in a fine sandy loam. Feedes[12] quoted Dasberg as stating in 1968 that there was a decrease in total emergence of wheat seedling and of a range grass *(Oryzopsis)* when the oxygen diffusion rate to platinum electrodes was below 0.33. 10^{-7}kg. m^{-2}. sec^{-1}. He further observed that the bulk of the oxygen was taken up by the seed by means of diffusion. Stout *et al.* [28] cited Farnsworth as having found that soils with an air capacity of less than 12% suppressed germination of sugar beet seeds due to the poor aeration.

Apart from mechanical means, the soil dynamic atmospheric process might have been altered by the ambient temperature variations, the ambient vapour pressure gradient, soil bio-chemical amendments and soil moisture content changes[14]. It appears to be important, when designing a seed-bed preparation system, to maintain an oxygen diffusion rate into the soil by controlling the size and continuity of the pore system.

1.3 INTERACTIONS BETWEEN SOIL, AMBIENT CONDITIONS, SEED AND DIRECT DRILLING COULTER DESIGNS IN UNTILLED SOILS

Studies from the last decade suggest that considerable experience has now been gained with no-tillage or direct drilling practices. A number of studies have been reported[11, 46, 47, 48, 49, 50, 51], comparing conventional and direct drilling techniques with varying degrees of success claimed for the latter. From these studies it seems that there has been little attention given to research into the fundamental relationships of the soil, seed and coulter design interactions of direct drilling. Successful adoption of direct drilling systems for crop production is likely to depend on an understanding of the interactions between the soil and coulters used, as well as of the plant responses obtained. Soane *et al.*[3] observed that no quantitative measurements of slit characteristics following direct drilling using triple disc coulters had been made. These authors recognized the problems with smearing, incomplete groove closure, seed-soil contact and "ponding" within the slit, particularly in silty clay loam soils. It was suggested[52, 53, 54, 55] that when direct drilling was introduced it resulted in consolidation or compaction. This was a problem particularly in the root zone, when the triple disc coulter was used[56]. Bulk density readings and the resistance to penetration were usually greater in direct drilled soils than in ploughed soil.[3]. In other experiments this did not occur where the soils were of light texture or of high organic matter[57, 58, 59].

Slow establishment of plants was considered by Russell *et al.* [60] to be associated with mechanical impedence due to compaction and/or smearing of grooves which apparently resulted in more profound and squashed roots. Mai[56], comparing two direct drilling coulters observed high penetrometer resistance and bulk density (relative to the untilled soil) in the root zone when using a triple disc on silt loam soil. However, he reported no significant difference in bulk density and resistance to penetration relative to untilled soil when he used an experimental chisel coulter designed earlier by Baker[4]. Stibbe and Ariel[47] reported the results of Hillel *et al.* who apparently had found that the moisture contents of the 100 mm planting layer were higher for a zero-tillage treatment than for ploughed land. Lal[61,62] noted increased soil moisture in mulched and undisturbed soils in humid tropics. In limited rainfall years, he claimed that yields were frequently greater with direct drilling than after ploughing.

Baeumer[2] cited results of Kahnt who in 1969 and 1970 had examined the performance of wheat, barley, oats and field beans on a silt loam, a clay loam and a shallow calcareous soil. He compared seedling emergence of two direct drilling methods with conventional methods. He reported means of seedling emergence for all species of 86%, 51% and 67% after using a "rotaseeder" and 78%, 79% and 49% seedling emergence after using a "semavator" in silt loam soil, clay loam soil and calcareous soil respectively. He concluded that plant density was strongly depressed especially on soils with high clay contents. Baeumer[2] also quoted Debruck, who in his two year experiments with triple disc drills in 1969 apparently observed a 20% reduction in seedling emergence on a clay loam compared with conventional cultivation. However, on sandy and loam soils seedling emergence with the triple disc coulter varied only slightly when compared with conventional cultivation. Results from another study[49] which compared seedling emergence in direct drilling and conventional cultivation showed 65% and 82% emergence in a silt loam and a silt clay loam respectively using direct drilling compared with 84% and 87% emergence using conventionally tilled seedbeds. This author did not attempt to isolate the effects of ambient conditions and soil physical factors in relation to the reported emergence results. In another recent laboratory study on undisturbed soil blocks[4], emergence counts were taken using three different coulter assemblies followed by bar harrowing. The results reported maximum wheat seedling emergence of 77% with an experimental chisel coulter, compared to 27% and 26% with commercially available hoe and a triple disc coulter assemblies respectively. This author, however, cautioned against interpreting these results as being wholly applicable to field practices at this stage. Even though he recorded the large seedling emergence differences quoted above he was not able to explain the detailed processes of soil groove drying rates and the amount and mode of availability of moisture to the imbibing seed and emerging seedlings which probably had accounted for the differences. In fact this author noted that measurement of the seed-soil microenvironment remained one of the more difficult aspects of such a study. He explained indirectly (by irrigation) the effects that the soil moisture status had had on seedling emergence performance.

There appears not to have been any more recently reported data which might further explain the reasons underlying the differences in seedling performance between drill coulters. For this reason it appeared to be important to attempt to isolate and study those processes of soil water transfer to the seed which might be influenced by drill coulter design.

1.4 SPECIFIC RESEARCH OBJECTIVES

It is clear that the eventual scope and usefulness of the direct drilling technique depends largely on how well the soil and climatic conditions can be defined and on the ability of scientists to specify the requirements of coulter designs for more reliable seed germination and crop establishment. The study reported herein therefore was to attempt to measure the micro-environment at the seed-soil interface in direct drilled grooves created by a range of selected coulters. It was hoped that significant interactions which were attributable to designs of coulters and covering methods in both controlled climatic conditions and field conditions might be identified. It was also felt to be important to attempt to formulate possible quantitative relationships which might be used in identifying coulter design criteria, and therefore the possible application of any given direct drilling machinery and/or technique in given soil and ambient conditions.

The specific aims of this study were as listed below:

(a) To re-examine in closely controlled climatic conditions, wheat seedling emergence data previously obtained under partially controlled conditions[(4)] using three different direct drilling coulter designs and covering techniques.

(b) To identify and measure the important soil physical parameters most likely to affect seedling emergence from untilled soils and which were able to be modified by mechanical means.

(c) To attempt to improve the seedling emergence performance of the least successful coulter design[(4)] and in so doing to identify the critical coulter design parameters which had been limiting its performance.

(d) To repeatedly test selected drilling and covering methods over a range of ambient and field conditions in order to ascertain the frequency of expected seedling emergence differences in field situations.

(e) To investigate the feasibility of creating simple models to explain or predict seedling performance in terms of measurable soil, ambient and drill coulter parameters.

1.5 THE EXPERIMENT PROGRAMME

The project was initiated in 1976 and was executed in the following stages.

(i) Measurement of the effects of soil-machine interactions in undisturbed soil blocks.

(ii) Study of limiting factors causing seedling emergence in small undisturbed turf blocks.

(iii) Study of the in-groove micro-environment at the seed-soil interface.

(iv) Field experiments: Comparisons of coulter types and their performance under a range of climatic and soil conditions.

CHAPTER II

MEASUREMENT OF THE EFFECTS OF SOIL-MACHINE INTERACTIONS IN UNDISTURBED SOIL BLOCKS

2.1 GENERAL OBJECTIVES

The performance of three coulter designs and covering techniques were tested in terms of their ability to promote wheat seedling emergence. This technique utilized large (0.5 tonne) undisturbed turf blocks which were placed in controlled climate rooms for 2 to 3 weeks after drilling. Measurements included seed germination and seedling emergence counts, soil moisture contents, temperature in the direct drilling grooves and the mechanical impedence to seedling emergence.

Specific objectives

The main aims of these experiments were four fold:

(a) To compare the performance of three coulter assemblies in their abilities to form suitable seed beds for seed germination and seedling emergence.

(b) To assess the effects of initial general matrix soil moisture level at the time of drilling, on seed germination and seedling emergence.

(c) To study the interactions of initial in-groove soil moisture contents with soil physical factors.

(d) To determine the effects of ambient relative humidity on soil moisture status, which might in turn affect the seed performance.

(e) To examine the role of different methods of covering and pressing the seed after drilling, in an attempt to isolate the effects of seed-soil contact on soil moisture diffusion and absorption by the imbibing and germinating seed.

2.2 DISCUSSION OF MATERIALS AND EXPERIMENTAL TECHNIQUES USED

2.2.1 Tillage Bin Technique

The use of soil bins is not new in the sceintific studies of soil-plant-machine relations. Scientists and engineers have used disturbed soil samples and/or artificially packed bins to study soil physical behaviour, soil machine mechanics and soil-plant interactions (63,64,65). Variable ambient conditions have made it necessary to use such techniques mainly indoors, and even in controlled climatic conditions, in order to accurately formulate qualitative and quantitative interactions.

By definition, it is clearly necessary to use undisturbed soil samples, representative of field conditions, in direct drilling studies using such techniques. The importance of using a tillage bin technique in direct drilling studies is supported by the fact that fundamental soil physical paramters and their interactions with coulter designs and ambient conditions have not been well understood and interpreted using field studies.

Baker[66] explained a mechanized technique for extracting "undisturbed" turf blocks from the field and outlined the merits of their use in laboratory tillage studies. In the present study, use was made of these soil bins to investigate critically the interactions of soil physical factors, ambient conditions and direct drilling techniques. Undisturbed turf blocks (measuring 1.8 m long, 660 mm wide and 200 mm deep) were extracted from a "Manawatu fine sandy loam" soil, and a tool testing apparatus (loc. cit) was employed to operate the chosen direct drilling tools in these soil blocks. The method of pre-drilling treatment and storage of these bins under rain canopies and drilling (Baker)[67] was followed with only minor variations. The method of extracting these soil blocks is shown and summarised in plates (1. a,b,c).

2.2.2 Coulter Types: Selection

There are a variety of effective direct drilling coulters available commercially and experimentally[67]. These include coulter assemblies with chisels, discs, sweeps and rotary strip tillers. In order to compare coulter designs, which provided contrasting actions in the soils, the following performance criteria were adopted with respect to the grooves created.

Plate 1(a) Turf block extraction procedure; connection of tillage bin to turf cutter.

Plate 1(b) Turf block extraction procedure; initiation of turf cutter and bin travel into soil.

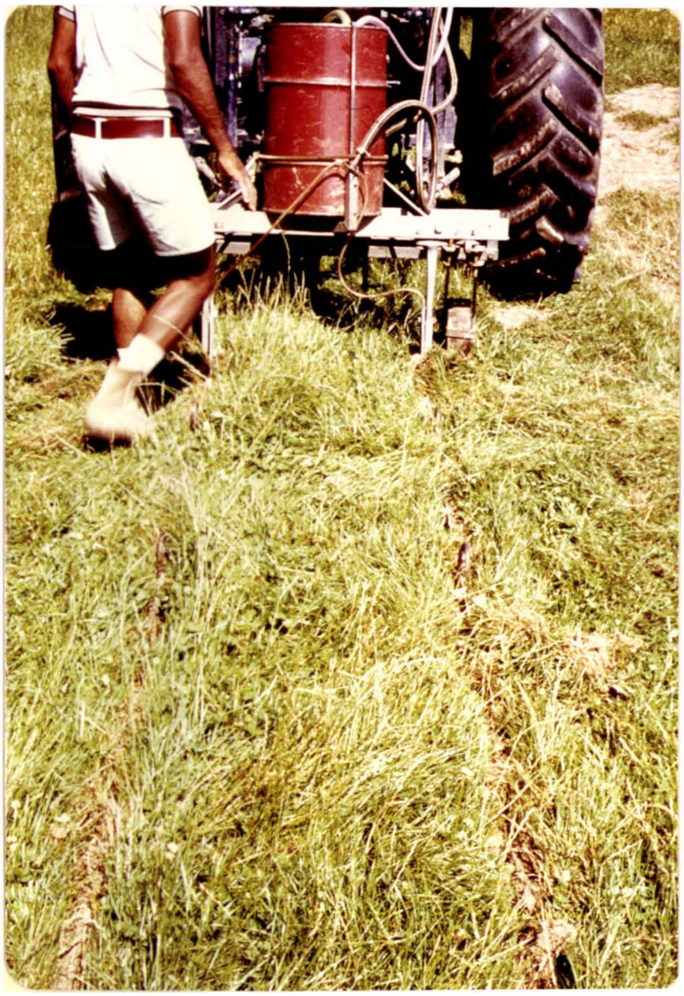


Plate.1(c) Turf block extraction procedure; tillage bin at full depth.

(a) Minimum shattering and a "V" or "U" shaped groove.

(b) A shattered "V" or "U" shaped groove with considerable loose soil available.

(c) Subsurface shattering of soil with minimum surface disturbance.

With these broad criteria in mind it was considered that the following three coulter types provided suitable examples of the types of grooves to be compared.

1. Triple Disc Coulter

The triple disc coulter was a commercially available coulter assembly*. It consisted of a flat vertical pre-disc of 250 mm diameter followed by two flat discs angled towards each other at approximately 10 degrees included angle and touching near the bottom(68). The groove was created with a compressive action and usually there was little loose soil available in the seed environment(69). An example of this coulter is shown in plate (2d).

2. Hoe Coulter

The hoe coulter used was a commercially available coulter assembly*. It consisted of a flat vertical pre-disc followed by a narrow "V" shaped hoe coulter. This gave some shattering effect, particularly in drier and firm soils, but tended to pull up lumps of soil and turf, creating soil cracks near the row. An example of this coulter is shown in plate (2b).

3. Chisel Coulter

The chisel coulter was an experimental coulter assembly developed at Massey University(67). This coulter assembly featured a flat vertical pre-disc of 250 mm diameter which was followed by a hollow chisel coulter with small slightly inclined sub-surface wings. The wings produced a sub-surface shattering effect especially in friable and drier soils. At the surface level, however, the groove slit remained mainly closed with undisturbed dead turf. An example of this coulter is shown in plate (2c).

* P & D Duncan Ltd.

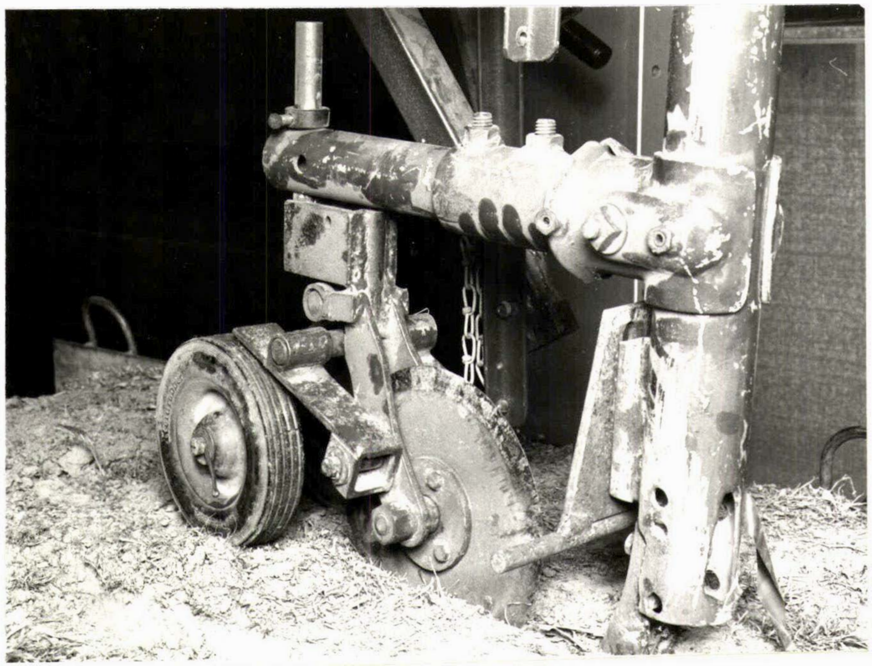


Plate 2(a) The original position of depth control wheels in relation to the coulter assembly (note the distance ahead of hoe coulter)

Plate.2(b) The modified position of the depth control wheels (note the closeness to the hoe coulter). This plate also illustrates the hoe coulter assembly.

Plate 2(c) Rear view of the chisel coulter assembly with the modified position of the depth control wh

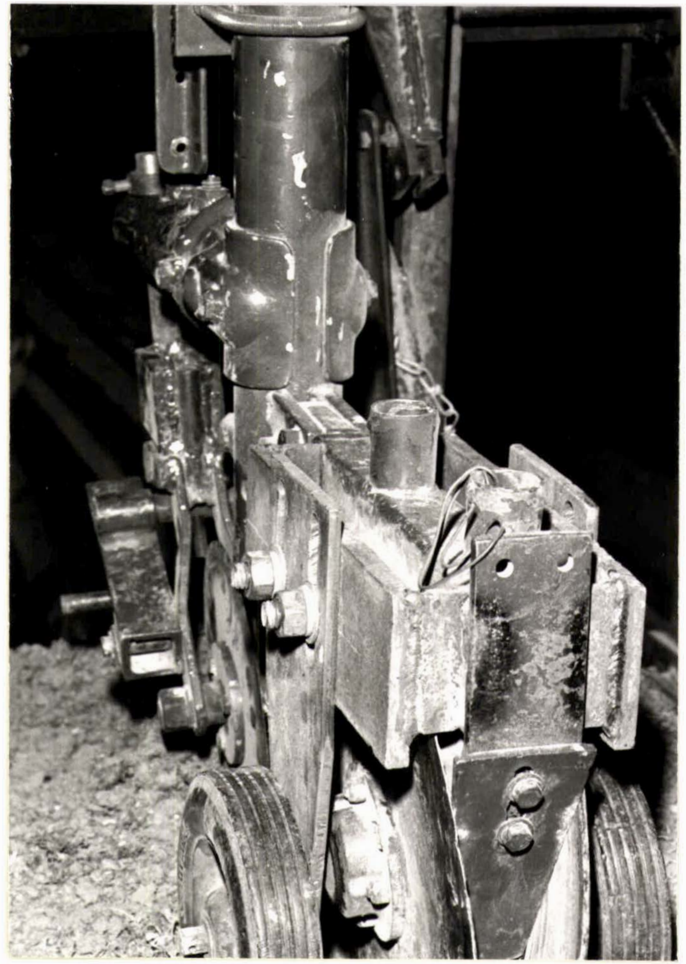


Plate 2(d) Rear view of the triple disc assembly with the modified position of the depth control wheels

2.2.3 Initial Soil Moisture Content

Initial soil moisture conditions may be expected to affect the success or failure of the establishment phase of crops. Baker[67] found that a direct drill incorporating a chisel coulter gave significantly superior seedling emergence performance compared to a triple disc drill in dry soils. He concluded that a comparative increase of 22.3% of initial soil moisture was necessary to improve seedling emergence when using a triple disc coulter to the equivalent of that when using a chisel coulter.

Baeumer[2] cited Kahnt (1970) also observing that direct drilling with triple disc coulters failed when used in dry soils. Stibbe and Ariel [47] on the other hand, used a triple disc drill in their experiments and observed a decrease in yield on zero-tillage fields compared with conventional cultivation, when the annual rainfall was 500 mm or higher. They thought that the use of the triple disc coulter resulted in higher compaction in the root zone when drilled on soils at higher moisture contents. This compaction resulted in shallow rooting of the plants and therefore limited the availability of soil moisture and nutrients to the plants. Soane *et al.* [3] frequently observed the smearing effect on grooves in silty clay loam soils when triple disc coulters were used.

Apart from the results of Baker[67] which were conducted in partially controlled ambient conditions, there appears to have been few, if any, experiments conducted to compare coulter designs in extreme soil moisture conditions.

The purpose of this study was to compare a selected range of coulter designs in two extreme moisture conditions under controlled ambient environments. The two moisture regimes selected were:

(a) High initial soil moisture contents (close to field capacity).
(b) Low initial soil moisture contents (close to permanent wilting point).

The purpose of experimenting at the lower end of the critical soil moisture range was to investigate the usefulness of direct drilling techniques in marginal soil conditions and in drier regions. It was expected that the results thus obtained would help exploit timeliness factors for better crop establishment in adverse weather conditions.

The purpose of selecting the higher level of initial soil moisture content was to test the usefulness of the coulter designs for crop establishment in non-limiting moisture regimes, and thus to determine any adverse effects that these coulters might have on other soil physical conditions. It was considered important to formulate interactions between coulter designs, seedling emergence and soil physical factors in order to test the applicability of any one system in areas of both high and low precipitation and high and low ambient humidity conditions.

2.2.4 Ambient Conditions

Relative humidity, temperature, radiation and wind velocity play significant roles in determining soil moisture conditions, and consequently the establishment and growth of field crops. Lemon *et al.* [70], in their soil-plant-atmosphere study of evapotranspiration of corn crops found that the latent heat flux, at 15C° temperature and 3m. sec^{-1} wind velocity, increased from approximately 348 W/m^2 to 488.3 W/m^2 when ambient relative humidity was decreased from 80% to 20%. Similarly at 25C° constant temperature and 3m. sec^{-1} wind velocity, the latent heat flux increased from 418.5 W/m^2 to 697.6 W/m^2 as ambient relative humidity changed from 80% to 20%. They also observed that at higher humidity levels increased evaporation was inversely proportional to wind velocity. Apparently at higher ambient relative humidities, the increased wind velocity tended to re-wet the soil surface by desorption from the air to the soil. These findings have also been supported by other workers who correlated ambient temperature, relative humidity and radiation with the rate of soil surface moisture evaporation[26, 71].

The rapid soil surface drying phenomenon in higher evapotranspiration conditions might be expected to affect the seed performance. Soane[3] noted that direct drilled grooves made by triple disc coulters, left open, could lead to poor germination. Other authors have reported that direct drilled soil grooves protected from radiation by a mulch of plant tissues or sod could lead to greater water conservation and higher yields in warm dry climate[72]. There appears to be very little quantitative data available regarding the suitability of direct drilling systems in various climatic conditions. It was one of the purposes of this study therefore, to investigate the effects of two ambient relative humidity levels on soil/direct drill coulter design interactions and seed germination and seedling emergence. The two relative humidity conditions chosen were high r.h. (HRH Regime) 95% and low r.h. (LRH Regime) 60% with controlled temperature and radiation conditions.

2.2.5 Seed-Soil Contact and Cover

Seed-soil contact is important for soil moisture transfer to the seeds. Low moisture conditions and smaller seed-soil contact areas reduce the rate of water uptake by the seeds and thus cause delayed germination as long as the external potential is higher than the critical value for each seed species[6, 11, 13, 15].

Projecting these findings to field conditions it is important that seedbeds should be prepared so as to ensure high rates of soil moisture conductivity and large seed-soil water contact areas, while at the same time avoiding the creation of adverse conditions for radicle penetration and soil aeration. The significance of press wheels and harrows has long been appreciated in conventional cultivation[28, 34]. Lillard *et al.*[73] and Triplitt *et al.*[74] used press wheels for firming corn seedbeds in their no-till experiments. Lillard *et al.* (loc. cit) used two press wheels and a seed coverer. One press wheel was to firm the corn seeds into the soil and a coverer to completely close the groove slit created by the coulter so as to eliminate the air pockets in the vicinity of the seeds. A second press wheel was used to firm the soil over the seed row.

Baeumer[2] described a sod-seeder with a triple disc coulter which apparently did not give satisfactory results in the experiments of Kahnt. In experiments of Bakerman *et al.*(1968), the triple disc coulter was modified to incorporate a sod-mulcher and press wheels and this gave plant densities comparable to conventional drilling methods. The modified coulter, however, did not give satisfactory results on soils with thick layers of straw on the surface (loc-cit). Baker[67] used a bar harrow made out of short lengths of railway iron. He found that covering the seeds with loose soil and debris using a bar harrow immediately after direct drilling seeds with a hoe coulter gave a significantly higher initial seedling emergence compared with un-harrowed plots. This was more pronounced in dry soils compared with more moist soils. He noticed in subsequent experiments, however, that initial improvement in seedling emergence due to bar harrowing behind the hoe coulter could be reversed because of sub-surface mortality of seedlings in continued dry soils.

These seeds were apparently able to absorb enough soil moisture to imbibe and germinate as the seed-environment was protected for a short time from the rapid drying effect of the ambient conditions. This loose soil-seed environment with its air pockets[69] however, was probably not able to conduct the required soil moisture to the seedlings as the soil continued to dry. Baker[67] was not able to quantify the effects of seed-soil contact and coverage on the seedling emergence. He did however establish a subjective grading of cover according to its appearance and the quality of mulch, and this was shown to correlate strongly with seedling emergence.

From the foregoing discussion it appears that press wheels and coverers have been used in direct drilling to improve upon the performance of seeds without their proponents fully understanding their functions. There does not seem to have been any comprehensive attempt to formulate quantitative relations between the amount of seed-soil contact and coverage, the soil surface moisture conditions, and the ambient conditions. A part of the present study was, therefore, an attempt to test the role of methods of covering and pressing the direct drilled seeds. It was also intended to isolate the effects of seed-soil contact on soil moisture diffusion and absorption by the germinating seeds and seedlings.

Five combinations of covering and pressing the seeds after drilling were tested. These were:

(a) No pressure but bar harrowing after drilling the seeds.
(b) Bar harrowing after drilling the seeds followed by pressing over the top of the grooves at a pressure intensity of approximately 35 kPa.
(c) As in (b) but pressing at approximately 70 kPa.
(d) Pressing the seeds directly into the groove base immediately after drilling but before bar harrowing using a pressure of 35 kPa.
(e) As in (d) but with a pressure of 70 kPa.

2.2.6 Design Parameters of Pressing Devices

Two types of pressing device were designed to work in conjunction with each coulter type. Their functions, on the one hand were to apply pressure over the top of the groove after bar harrowing; and on the other hand to directly press the seeds into the soil after passage of the coulter but before bar harrowing. A total of 6 pressing devices and assemblies were designed and fabricated.

TYPE I: (To press on top of the "covered" grooves)

The widths of the widest portions of the chisel, hoe, and triple disc coulters was determined. These measurements were approximately 38 mm, 28 mm, and 25 mm respectively. The designs of the three almost flat press wheels thus had widths corresponding to these physical dimensions. Although these dimensions were arbitrarily chosen, in the absence of any other form of guidelines, it seemed reasonable to press upon the maximum width of the disturbed soil (even if the disturbance was sub-surface) and to avoid contact of the press wheels with the undisturbed shoulders alongside the grooves.

An equation developed by Reece (pers. comm.) to determine the loading capacity of pneumatic tyres was used to determine the approximate footprint areas and pressures of each wheel.

According to Reece (loc. cit.) the wheel contact area with the soil was equivalent to:

$$A = d^{0.56} . b^{1.53}$$

where d = Outer diameter of wheel
and b = Width of the wheel

This equation apparently gave a good approximation of the load requirements for given pressure intensities for wheels and was felt to be at least a useful guide for solid rubber tyred wheels. As the actual pressure levels chosen were to be arbitrary, any absolute error was felt to be of little consequence, and the relativity between the three would be unaffected.

The 200 mm diameter wheels were fabricated from mild steel. Solid rubber tyres of 6.25 mm thickness, and width corresponding to the wheels were glued to the wheels with epoxy resin. The rubber on the edges was ground to give the edges of the wheels a slight rounded appearance. The three types of wheels for the chisel, hoe, and triple disc coulters are shown in plates (3a, 4a, 5a) respectively.

Load requirements were determined from the following data:

(1) Wheel for the chisel coulter;

d = 200 mm

b = 38 mm

Loading requirement at 35 kPa = $P.\ d.^{0.56}\ b^{1.53}$

= 9.775 kg axle loading

(where P = ground pressure in kPa).

Loading requirement at 70 kPa = 19.55 kg axle loading.

(2) Wheel for the hoe coulter

d = 200 mm

b = 28 mm

Loading requirement at 35 kPa = $P\ .\ d^{0.56}\ .\ b^{1.53}$

= 6.08 kg axle loading

Loading requirement at 70 kPa = 12.16kg axle loading

(3) Wheel for triple disc coulter

d = 200 mm

b = 25 mm

Loading requirement at 35 kPa = 4.345 kg axle loading

Loading requirement at 70 kPa = 8.69 kg axle loading

TYPE II:

The purpose of the second type of press devices was to apply pressure directly over the seed before bar harrowing.

(1) Press device for chisel coulter:

The physical shape of the groove created by chisel coulter was such that any mechanism applying pressure directly over the seed had to create minimum soil disturbance over the top of the seed in order to preserve the characteristic "undisturbed" mulch cover. This requirement precluded the use of a wheel. Instead, for this coulter,

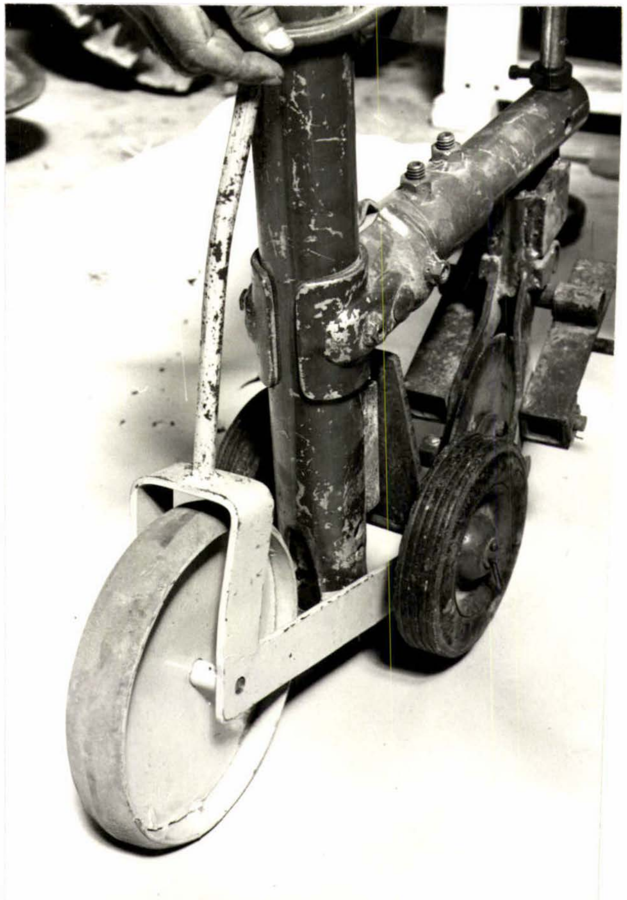


Plate 3(a) The press wheel assembly for the chisel coulter; for applying pressure over the covered seeds after bar harrowing

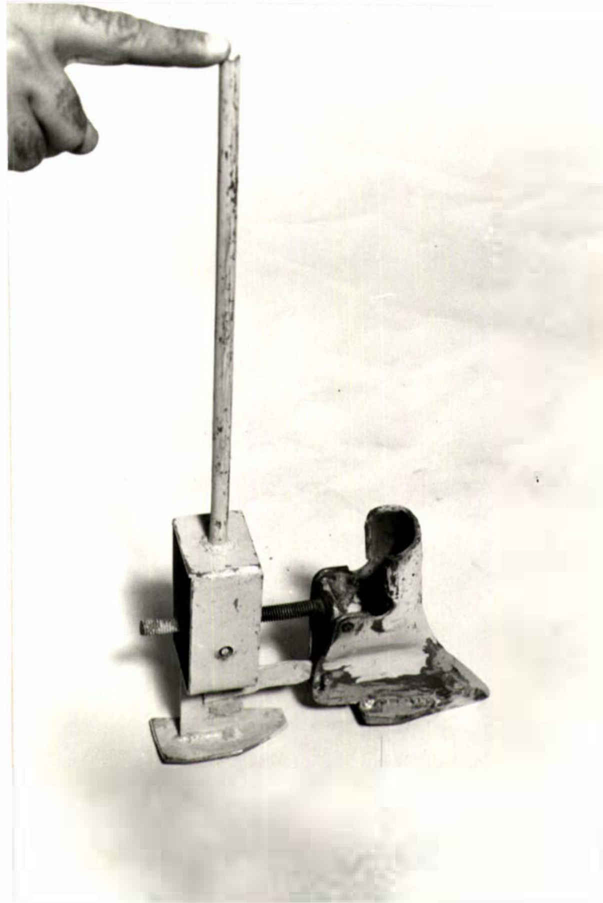


Plate 3(b) The press skid for the chisel coulter to directly press the seeds into the groove base before bar harrowing

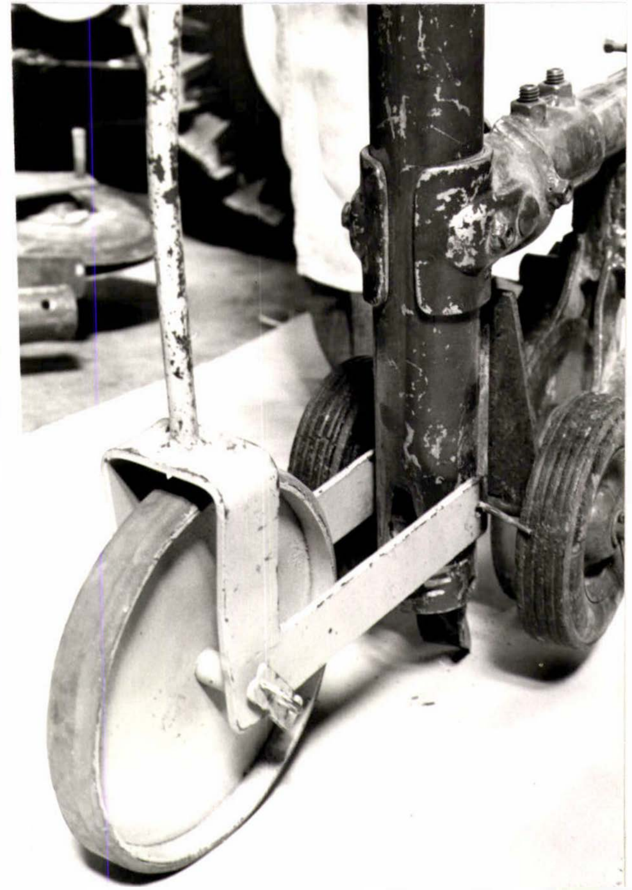


Plate 4(a) The press wheel assembl for the hoe coulter to apply pressure over covered seeds after bar harrowing

Plate 4(b) The press wheel assembly for the hoe coulter to directly press the seed into the groove base before bar harrowing

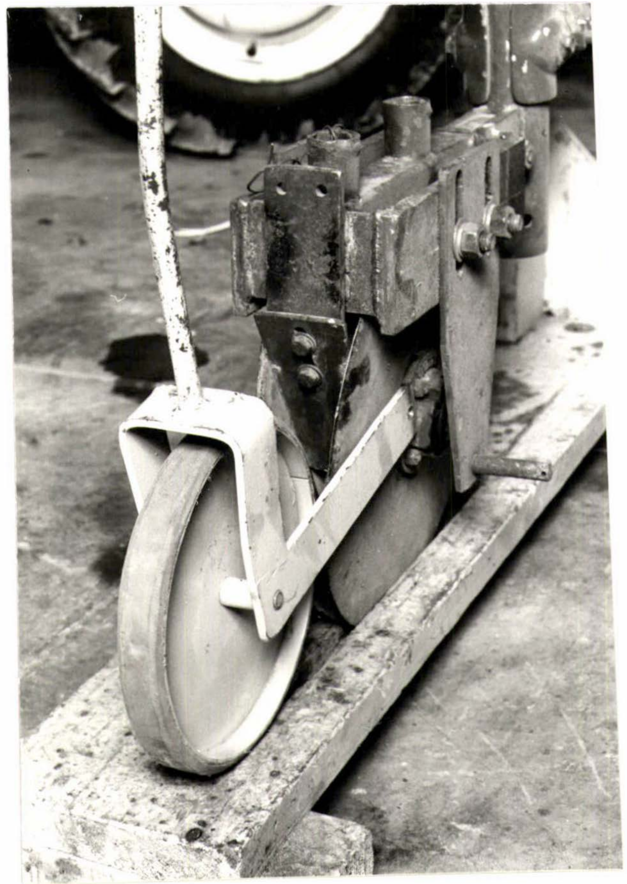


Plate 5(a) The press wheel assembly for the triple disc coulter to apply pressure over covered seeds after bar harrowing

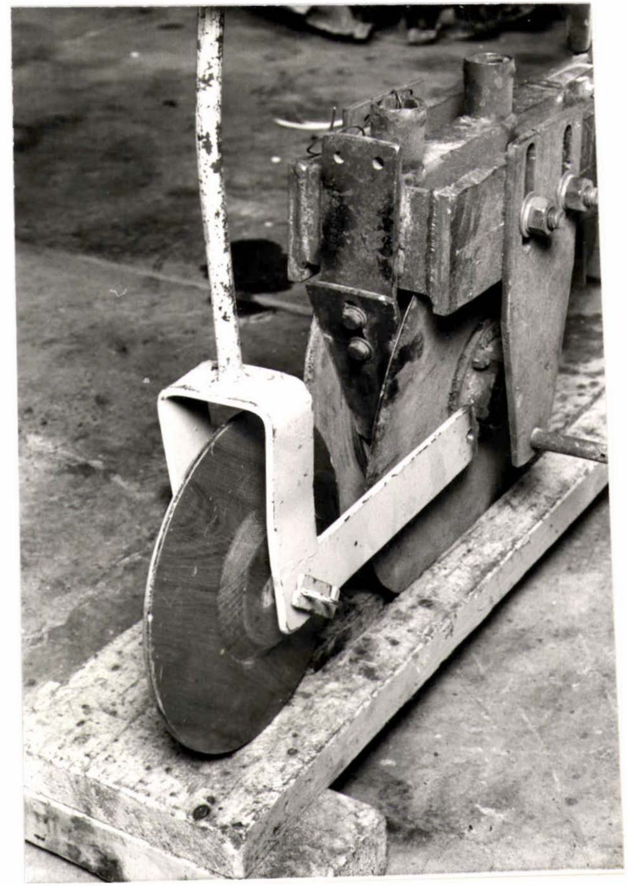


Plate 5(b) The press wheel assembly for the triple disc coulter to directly press the seed into the groove base before bar harrowing a press skid mechanism was designed. This consisted of a slightly curved horizontal steel plate with an effective contact area of 25 mm x 25 mm and a thin vertical upright beam welded to the plate which protruded through the top of the groove. This beam was pivotally attached to the rear of the coulter. The press assembly proved to be effective in pressing the seed and appeared to have minimal effect on the physical shape of the groove. The press device is shown in plate (3b).

Calculation of loading requirement;

Effective contact area = 625 mm^2

For 35 kPa pressure

Load = P . A . where A = contact area in mm^2

and P = pressure in kPa

Load = 35 kPa . 625 mm^2

= 2.23 kg

For 70 kPa pressure;

Load = 4.46 kg.

(2) Press wheel for hoe coulter:

The "V" shaped hoe coulter groove had a cross section which was approximately 10 mm wide at the base of the groove. A tyred narrow presswheel with a base width of 10 mm was designed and fabricated out of timber. The taper was such that the wheel did not contact the groove side walls. This wheel was pulled over the seed immediately after the passage of the coulter. The presswheel is shown in plate (4b). Load requirement for 35 kPa pressure:

d = 200 mm

b = 10 mm

Load = $P \cdot d^{0.56} \cdot b^{1.53}$ = 1.265 kg axle loading

Load requirement for 70 kPa pressure = 2.53 axle loading.

(3) Presswheel for triple disc coulter:

As with the hoe coulter, the "V" shaped groove created by triple disc left a narrow slit at the bottom of the groove of approximately 5 mm width. A narrow tapered presswheel with 5 mm base dimension was designed and fabricated out of timber. The presswheel is shown in plate (5b).

Load requirement for 35 kPa pressure = $P.\ d.^{0.56}\ b.^{1.53}$

= 0.447 kg axle loading

Load requirement for 70 kPa pressure, load = 0.895 kg axle loading.

2.2.7 Design of penetrometer and measurement of soil mechanical resistance

Penetrometers have frequently been used to evaluate soil compaction or soil density [(40, 31, 32, 71, 75)]. The penetrometric evaluation has been a useful tool to correlate root penetration and seedling emergence with soil physical conditions. Problems have arisen however, when attempts were made to formulate absolute values because of soil heterogenity, soil moisture content, and the shape and size of the probes used, in relation to the multidirectional expansion of the growing root tips.

Morton and Buchele[(31)] designed a soil penetrometer to simulate the root activity of actual plant seedlings. They used these penetrometers with vertical downward movement. Most of these studies were conducted in artificially compacted soil or conventional seedbeds. In direct drilled grooves drawn by different coulter types, the degree of soil cover over the seed was reported[(67)] to vary from negligible with the triple disc coulter to complete "undisturbed" mulch cover with the chisel coulter. Morton & Buchele[(31)] considered that where penetrometer designs showed good correlations with root growth studies, the device was more aptly termed a "mechanical seedling".

OBJECTIVES:

It was considered to be important to investigate the relationships between the rate and percentage of seedling emergence, and the soil physical and mechanical properties overlying the seed. This was in order to obtain an index of soil cover and soil strength over the top of the groove.

The specific objectives were as follows:

(a) To examine the soil strength over the top of the seed, as a function of coulter types and covering techniques.

(b) To investigate the force required and energy expanded by the emerging seedlings.

(c) To test the effects of the pressure application treatments on soil density and their interactions with seedling emergence.

(d) To determine the effects of ambient climate on soil drying rates, and in turn the interrelationships with soil strength and seedling emergence.

PENETROMETER DESIGN REQUIREMENTS:

To achieve the objectives outlined above the penetrometer had the following performance specifications:

(1) The penetrometer had to be designed to approximate the diameter of the seedlings.

(2) The penetrometer movement had to be directed upwards from the seed zone rather than downwards from the surface.

(3) The penetrometer movement had to be very slow to simulate, as nearly as possible, seedling growth.

(4) A large number of readings had to be taken to minimize the error factors inherent in penetrometer studies.

2.2.8 Design of Penetrometer Assembly and Method of Operation

The penetrometer design and operation may be divided into four sections:

(I) Soil block preparation

(II) Penetrometer probe (or mechanical seedling) design

(III) Penetrometer drive mechanism and assembly

(IV) Penetrometer alignment assembly.

(I) Soil block preparation

Holes of 6.25 mm diameter were drilled through the base plate of the steel bins before soil blocks were extracted. Sixteen equi-distant holes were drilled along each of the three anticipated drill row positions in the bins.

(II) Penetrometer probe (or mechanical seedling) design

Wheat seedling diameters measured in a pilot experiment averaged 1.1 mm. The "mechanical seedling" was designed to approximate the diameter of these wheat seedlings. The "mechanical seedlings" consisted of two lengths of rods welded together to make a total length of 300 mm. The upper part was of 1.1 mm diameter and 100 mm long and was fashioned from a mild steel welding rod. The head was tapered to an expanded cone with 2 mm diameter base ground at a 30^{o} angle to the tip. The purpose of the slightly larger diameter of the cone was to reduce the soil/metal friction encountered by the stem of the "mechanical seedling". A 200 mm long brass rod of 3 mm diameter was welded to the lower end of the "mechanical seedling". The purpose of this larger diameter bar was to increase the rigidity and compressive strength of the whole structure. The "mechanical seedling" is shown in Plate (6a).

(III) Penetrometer Drive Mechanism and Assembly

One of the more noteworthy advantages of the tillage bin test rig used was that it presented an elevated platform from beneath which the "mechanical seedling" could be inserted into the soil blocks. The drive mechanism and assembly, therefore, had to be capable of being manoeuvred within the vertical height of 0.6 m between the floor and the underside of the soil bins. The drive mechanism consisted of an instantly connecting electric motor of 0.185 kW. This motor rotated a threaded shaft at a low speed giving a linear advancement of 20 mm per minute. The threaded shaft was supported vertically by an adjustable tripod. The threaded shaft was attached to a proving ring by a thrust bracket. At the top end of the proving ring another thrust bracket freely held the "mechanical seedling". The proving ring held an inductive displacement transducer across its diameter. The "mechanical seedling" caused a deflection in the proving ring and inducting transducer, resulting in electrical signals which were amplified and recorded directly on a chart recorder. The penetrometer drive mechanism and assembly is shown in plate (6b).

(IV) Penetrometer Alignment Assembly

An electro-magnetic mechanism (plate 6b) was designed to hold and align the mechanical seedling in a vertical position beneath the bin and at the top of the proving ring. This electro-magnetic mechanism permitted quick and easy alignment at each of the hole sites, and from an awkward position for the operator lying on his back.

Plate 6(a) Right: The "mechanical seedling"penetrometer to measure soil impedence above the seed. Left: A 4 mm diameter rod to press holes through the soil block from beneath to the seed level before seedling".

Plate 6(b) The "Mechanical seedling" penetrometer drive mechanisms, alignment assembly (elector-magnetic) and inductive displacement transducer and proving ring unit.

EXPERIMENTAL PROCEDURE:

After the soil moisture content of the soil blocks was adjusted to the pre-selected level, 2 test blocks were aligned on the tillage bin support bed. At the time of drilling the pre-drilled holes in the bases of the bins were aligned so that each row to be drilled was directly above the holes. After drilling, pressing and bar harrowing, holes of approximately 4 mm diameter were drilled by hand vertically upward from the bin base through the soil blocks using a mechanical probe (Plate 6a). These holes reached within 40 mm of the soil surface. The purpose of these holes (of larger diameter than the "mechanical seedling") was to eliminate any possible contact of the mechanical seedling with the side walls.

The electro-magnetic mechanism was brought into alignment under the bins with each hole and the "mechanical seedling" was held in position in the hole. The tripod, bearing the proving ring and the sensor, was positioned directly beneath the mechanical probe. The electro-magnetic mechanism was switched off and the electic motor was used to rotate the threaded shaft. As the "mechanical seedling" moved slowly upward through the soil surface, the "emergence" force was directly recorded in mV on a chart recorder. The chart recorder was pre-calibrated to indicate these signals as force units (N), as shown in appendix (1a).

Once the "mechanical seedling" had travelled sufficiently to appear through the soil surface of the direct drilled grooves (approx. 40 mm), the motor was disconnected. The threaded shaft was re-wound manually and the "mechanical seedling" was withdrawn by hand. In this way an average of 16 readings per treatment were recorded at two sampling times (a) immediately after drilling, and (b) immediately after the soil blocks were brought back from the climate laboratory, which was an average of 20 days after drilling.

"Seedling emergence" force and the energy expended was calculated by averaging the 16 readings taken for each treatment at these two sampling dates.

2.2.9 In-groove Soil Moisture Measurement Methods

"The accurate measurement of soil moisture potential near to the soil surface/atmosphere interface has been a frustrating exercise because of the continuity of the liquid and gaseous water fluxes".[76]

Many authors[53,62,67,73] now agree that direct drilled soils retain more moisture near the surface compared with conventionally cultivated seedbeds. Baker[67] compared various direct drilled grooves in terms of their ability to retain soil moisture and their subsequent effects on seedling emergence. He found it difficult to measure the in-groove soil moisture status even though he had noted significant differences in seedling emergence apparently attributable to the physical characteristics of the grooves.

Noble[77] and Painter[76] reviewed a number of techniques to measure soil moisture potential and soil water contents. Painter (loc. cit.) suggested that tensiometers were not useful for the determination of soil moisture potential near the surface because the tensiometers broke down at -9 J/kg or below. A neutron probe caused problems because of the built-in sampling volume, which was affected by the steep gradients in the soil moisture near the surface. For similar reasons, other methods such as gamma ray absorption, thermal methods and electric capacitance were considered not to be useful tools to measure moisture levels near the surface. The following methods were considered and tested for their suitability to measure in-groove or surface soil moisture.

(a) Psychrometers

(b) Electric resistance blocks

(c) Gypsum beads)
(d) Glass paper) Indirect thermo-gravimetric methods

(e) Direct thermo-gravimetric methods.

(a) Psychrometers:

Thermocouple psychrometers have been designed and employed with varying degrees of success for measuring soil moisture potential[78,79,80]. The major problem with the technique has been the fact that the sensors are temperature dependent and the change in relative humidity with water potential is small. For example at 25°C a change of water potential of 15 bars was reportedly accompanied by approximately 1% change in relative humidity[81]. The same author stated that temperature measurement to within 0.001°C or better was necessary to accurately measure water potential. Another report[82] suggested that diurnal soil temperature changes prevented *in-situ* operation of thermocouple psychrometers within about 300 mm of the soil surface. Baker[67] attempted to use psychrometers of 38 mm sensor lengths and 6.4 mm diameter to measure soil moisture potential in direct drilled grooves at a seed depth of 38 mm. He was forced to abandon their use as in-groove soil moisture potential sensors because of the physical variability of the grooves, and the probably steep and often unpredictable soil temperature gradients present.

In the present study a further attempt was made to calibrate thermocouple psychrometers for their possible use in similar conditions to those earlier reported by Baker (loc. cit.). However, in these trials, the soil blocks were contained in temperature controlled rooms. The ambient temperature in these climate rooms was controlled to approximately ± 0.5°C. A number of psychrometers similar to those used by Baker (loc, cit.) were buried in the grooves direct drilled by three different types of coulters. A psychrometer micro-voltmeter was used to measure the e.m.f. The results, however, were again inconsistent and could not be interpreted as useful for measuring the in-groove soil moisture potential. The failure of the psychrometers was considered to be because of the following factors, associated with temperature variations:

(i) The diurnal temperature changes in the rooms produced temperature gradients in the soil.

(ii) Each different type of groove experienced different temperature gradients due to the characteristics of the groove cover which varied between coulter types.

(iii) Ambient temperature control to ± 0.5°C was not considered to be accurate enough to enable the measurement of corresponding small change in relative humidity and therefore soil moisture potential. This method was therefore discarded as a soil moisture potential measuring technique.

(b) Gypsum Blocks:

Gypsum blocks are simple, inexpensive and widely used. They consist of non-corrodible metal electrodes embedded in a block of porous insulating material and may be either parallel or concentric, in rod or mesh form. Many experimenters have reviewed their use(77, 83, 84). The major problems with their use have been the appreciable time lag before true readings could be obtained(77). The blocks have been found to be relatively insensitive at higher moisture regimes. At low moisture regimes the portable measurement meters available to this studyproved also to be inadeqaute to monitor e.m.f. as they were required to operate near the limits of their scales(76). Cox and Filby(84) stated that accuracy of resistance blocks was affected by hysteresis in their absorption-desorption characteristics, and by variations in the electrical conductivity of the soil water which followed from variations in solute strenth and soil strength.

A pilot trial was conducted to test the suitability of specially designed and moulded small scale gypsum blocks.

Design and calibration of small scale gypsum blocks:

Three different sizes of gypsum blocks were designed and constructed. Each was cylindrical with diameters of 6 mm, 7.5 mm and 15 mm respectively, and all were 15 mm in length. These are shown in plate (7). The inner electrode was fashioned from copper wire. The outer electrode was made from a 0.7 mm thick copper sheet. The sheet was rolled into a cylinder and soldered to form a casing for the plaster. A number of 3.5 mm diameter holes were pre-drilled in the copper sheet to facilitate exchange of water between the soil and the porous material. "Plaster of paris" was used as the porous material and care was taken to ensure that the inner electrode was concentric and equidistant from the cylinder throughout its length. No attempt was made to use nylon resin or any other porous material to increase the durability of blocks.

Some of the 6 mm diameter blocks were coated with another layer of plaster on the outer side at a later stage. This was for two reasons. Firstly it was found that the outer surface of the copper cylinder oxidized and it was thought that this might affect the sensitivity of the blocks. Secondly it was found that in some of the blocks, during the absorption process, the plaster underwent slight shrinkage and this created gaps between the plaster and the outer electrode. This gap was expected to retain moisture and affect the block sensitivity.

TEST PROCEDURE:

Soil blocks were drilled with three types of coulters. No seed was sown. A number of gypsum blocks of each size were first calibrated in water under vacuum. These blocks were buried in the soil at 38 mm depth in each groove. Care was taken to minimize the disturbance to the physical shape of the grooves. The soil blocks were then carried to the climate rooms which were maintained at pre-set conditions (as indicated in appendix 2). The soil blocks remained in the climate rooms until the 17th day after drilling. This enabled the gypsum blocks to be tested for a similar time period required for the wheat seedling emergence.

The different sized blocks, were found to be equally sensitive (see appendix 2a). Accordingly the smaller size (6 mm dia.) gypsum blocks were selected for further calibration, as these blocks could be expected to minimize the disturbance in the in-groove soil during their implantation. These blocks were calibrated in two soil moisture regimes (see appendix 2b). At the higher soil moisture level (near field capacity) the blocks were found to be insensitive. This confirmed earlier experiments by Painter[76]. At the lower initial soil moisture (near P.W.P.), however, the results were found to be more representative.

Calibrations were carried out to relate soil moisture potential obtained by the resistance blocks to that measured thermo-gravimetrically. The gypsum blocks were buried at seed level in the grooves drawn by the chisel coulter, hoe coulter and triple disc coulter respectively. The soil blocks were carried into the climate room and were subjected to the ambient conditions of 47% r.h. and 71% r.h. day/night and 25^{o}C day and 15^{o}C night temperature respectively (see Appendix 2). The soil samples remained under similar conditions for 17 days. Gravimetric soil samples were taken from the grooves. The results so obtained (Appendix 2C) indicated that the correlation coefficients between moisture contents obtained by the gypsum blocks and gravimetric measurements were low. The figures for the chisel coulter, hoe coulter and triple disc coulter grooves respectively were r = .32, .44 and 0.6). This confirmed earlier observations by Baker[67] that it was difficult to measure in-groove soil moisture status. On the other hand some doubt also exists as to the accuracy of sampling from within the groove for the gravimetric measurements because Baker[67] was also not able to obtain strong correlations between such measurements and seedling emergence performance. The results obtained above suggested that the gypsum blocks could not be successfully employed to measure in-groove soil moisture for the following reasons:

(a) Sensitivity was inconsistant, even within single gypsum blocks, and certainly between adjacent blocks in the same groove.

(b) The gypsum blocks were relatively insensitive at the higher soil moisture potential levels.

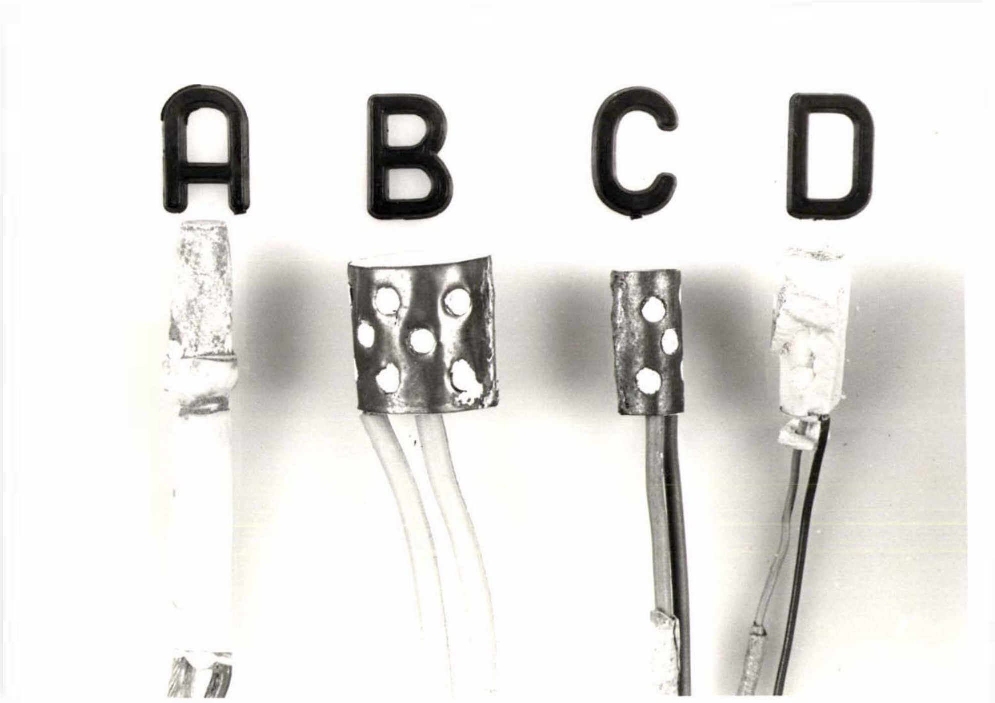
(c) The physical shapes of the drilled grooves, near the surface, and at seed depths was variable. This resulted in variability in the inter-face soil moisture fluxes and variable soil-block contact areas.

(c) Gypsum Beads:

Gypsum beads of 10 mm x 5 mm x 5 mm, were moulded from "plaster of paris". The intention was to bury these beads in the direct drilled grooves at the seed depth and measure the equilibriated soil moisture gravimetrically. The beads were oven dried at 80^{o}C and the initial weight was measured to an accuracy of 0.01g. These beads were left buried for at least four days and were sequentially "harvested" at daily intervals and moisture contents determined gravimetrically. The beads were tested in the lower soil moisture conditions i.e. wilting point percentage. Appendix (2d) shows, however, that the gypsum beads were not very sensitive as an indirect gravimetric determination of soil moisture. The correlation coefficient between the moisture contents of the gypsum beads and the soil moisture contents measured directly by gravimetric methods was r =0.63, 0.84, and 0.52 respectively in chisel coulter, hoe coulter and triple disc coulter grooves respectively. Although it was again possible that the direct gravimetric sampling methods may have been in question, the gypsum bead method was not used further because of inconsistent readings, as an effective method of soil moisture measurement.

(d) Glass Fibre Filter Paper:

A number of glass fibre filter papers of 25.4 mm diameter



'late 7. Soil moisture potential measurement sensors: (A) Psychrometer (38 mm long x 6.4 mm dia. - "wescor") (B) Gypsum block (15.0 mm long x 15.0 mm dia.) (C) Gypsum block (15.0 mm long x 7.5 mm dia.) (D) Gypsum block (15.0 mm long x 6.0 mm dia.)

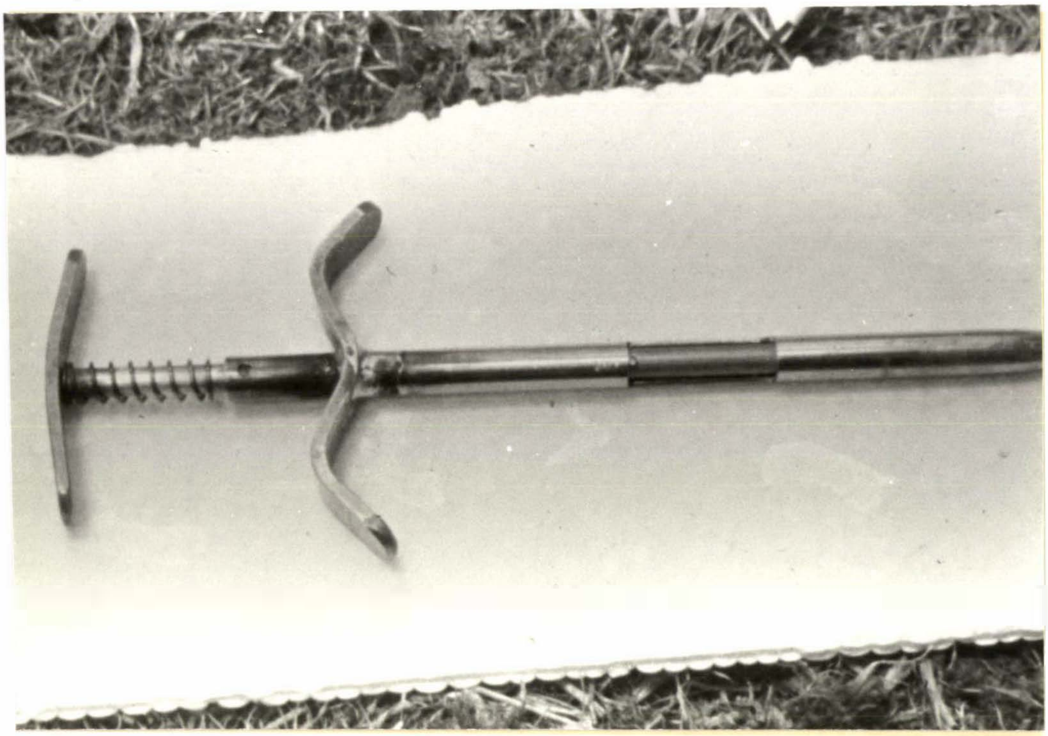


Plate 8. Core sampler (15.0 mm long x 7.5 mm dia.)

were folded and buried in the direct drilled grooves. Sampling of these papers was carried out after day four, while the soil blocks were in climate rooms, and subsequently at 2 days intervals. This moisture measuring technique appeared to indicate 2 to 3 times the actual soil moisture as measured by the direct thermo-gravimetric method but again correlation coefficients were low. The method was considered unsatisfactory and was abandoned in favour of a direct thermo-gravimetric method.

(e) Direct Thermo-gravimetric Method:

Painter[76] described thermo-gravimetric methods as being "reliable, simple, destructive and tedius" and felt that each of these adjectives became even more apt for near-surface moisture measurements, but that alternatives were few. Holmes *et al.*[85] earlier thought that thermo-gravimetric methods should form the basis of comparison for all direct and indirect methods of soil moisture measurements.

As pilot trials had not favoured other methods of soil moisture measurement (e.g. resistance blocks and psychrometers), it was felt that the only reasonable alternative at that stage was to use a direct thermo-gravimetric method for determination of soil moisture in the direct drilled grooves, using a core sampler. Appendix (1b) shows the soil moisture potential (bars) curve determined by pressure membrane plate for a fine sandy soil. This curve was determined as a reference to convert soil moisture percent into soil moisture potential.

2.2.10 Design of a Core Sampler and Procedure

A small scale core sampler (plate 8), similar in configuration to one earlier used by Mai[56], was designed. The effective length for sampling was 15 mm with a 6.25 mm diameter. It was decided to take core samples in the vicinity of the seeds in order to be representative of the soil micro-environment around the seeds. For similar reasons it was considered important to take samples vertically from 0 to 45 mm depth and horizontally 10 mm on either side of the mid-point of the grooves. This gave a profile of soil moisture distribution around the seed. Vertically the samples were taken at three depths; 0 - 15 mm, 15 - 30 mm and 30 - 45 mm. Soil moisture samples were also taken from undisturbed soil between the rows. Although Baker[67] had noted difficulty in sampling from the surrounds of the groove for direct thermo-gravimetric moisture content determination, his technique did not attempt to obtain a profile of the moisture distribution. Soil samples were taken at noon (climate laboratory time) every third day, while the soil blocks were in the climate rooms, until seedling emergence had stabilised.

2.2.11 In-groove Soil Temperature Measurement

Thermometers of various kinds have been used to measure soil temperature. Mercury in-glass thermometers and thermocouples are commonly used for this purpose.

Soil temperature measurement was felt to be important to help explain the effects of various coulter types on the soil micro-environment. A number of thermo-couples were constructed using copper-constantan. These thermocouples were moisture sealed in epoxy resin and buried in the direct drilled grooves immediately after drilling. Daily in-groove soil temperature measurements were recorded day and night using a micro-voltmeter with an in-built reference junction. Soil temperature was measured until seedling emergence had stabilized. Thermocouple calibration is shown in Appendix (1e).

2.2.12 Description of Climate Rooms

The New Zealand Department of Scientific and Industrial Research (D.S.I.R.) climate laboratory is located at the Plant Physiology Division headquarters adjacent to Massey University. The climate laboratory provides a wide range of experimental conditions that have been found to be useful tools for plant-environmental studies.

Each of the climate rooms measures 2.75 m x 2.75 m x 2.75 m with an effective growing area of 2 m x 2 m. The major climate factors; air humidity, light intensity, day length, carbon dioxide concentration, nutrient and water supply are controlled automatically, with diurnal changes if required. The conditioned air from ducting along the top of each side wall passes over the plant trolleys and is recycled through a false floor to the machinery chamber at the back of each room.

The air temperature can be controlled, usually in the range $-10^{o}C$ to $50^{o}C$ $\pm 0.5^{o}C$. Air relative humidity is controlled in terms of vapour pressure deficit (V.P.D.) from 25% to 95% r.h. ± 5%. Light intensity can be controlled from 90 W/m^2 to 190 W/m^2 with limited facilities up to 400 W/m^2 with photosynthetically active radiation (P.A.R. at range 400- 700 nm). Similarly carbon dioxide can be controlled from ambient to 900 ppm and fully automated nutrient and water is supplied independently or in combination.

The direct drilling experiments were designed to utilize these facilities for the investigation of soil-atmosphere and direct drilled seed interactions. Direct drilled soil blocks were supported on specially re-inforced trolleys which were wheeled into the climate rooms, pre-set to the required conditions. A maximum of 3 soil blocks could be accommodated in each room at any one time.

2.2.13 <u>Climatic Conditions During Experiments</u>

It was thought appropriate to test the direct drilling coulters in climatic conditions representative of a drying and non-drying regime. The two conditions chosen were warm-dry, and warm-humid. Reference to historical climate records for regions of N.Z. suggested that such conditions have often been found during the growing season in Canterbury or Otago (in the South Island) and Northland in the North Island of New Zealand respectively. More precisely, for experimental purposes two evaporative conditions were selected in the climate laboratory. These were normally in each of two rooms, (In fact the measured parameters were 92.4/95.1% r.h. day/night and 54.6/61.2% r.h. day/night) 90/95% r.h day/night and 55/60 % r.h. day/night with identical temperature regimes of $22/18^{o}C$ day/night. Light was kept at a minimum of 70 W (P.A.R.) for 12 hours per day. The r.h. conditions were equivalent to a day/night water vapour deficit (V.P.D.) of 12/8 day/night in the low r.h. room and 2/1 day/night in high r.h. room.

These climatic conditions prevailed from the day the drilled soil blocks were brought in the climate rooms until the seedling emergence plateau was reached.

2.2.14 <u>Measurement of the Seed and Seedling Performance</u>

The response of seeds to the imposed soil-climate-machine interactions was measured in terms of seedling emergence, seed fate and plant growth. Wheat seedlings were considered to have emerged when they appeared above the horizontal plane of the ground surface. Each treatment within an experiment was represented by 50 seeds of 98.4% potential germination. From day 5 when the seedlings usually started emerging, daily counts of emergence were taken until the rate of emergence had stabilized, usually on day 18 or 19.

At the end of day 19, the soil blocks were removed from the climate rooms. Immediately afterwards the wheat plants were harvested at ground level and dry matter measurements were determined. It was thought that after three weeks wheat growth, the seeding emergence vigour and perhaps early establishment would be reflected in vegetative responses to the determinants. Individual seed fate counts, as originally explained by Baker[67] were determined after the soil blocks were removed from the climate rooms. The purpose of this was to relate the failure of seedlings to emerge ("germinated but unemerged") or seeds to germinate (ungerminated) to other measured parameters. In each experiment the ungerminated seeds and/or unemerged seedlings were harvested with a hand scoop and the numbers counted and expressed as a percent of sown seeds.

2.2.15 Experimental Design

The following treatments were considered important to attain the objectives of this study;

(a) Initial soil moisture content (two levels, adequate and low)
(b) Ambient controlled relative humidity ranges (two levels, high and low)
(c) Method of seed cover (Bar harrowing before pressure application and after pressure application)
(d) Soil pressure intensities (Three levels, 0, 35 and 70 kPa)
(e) Coulter types (Chisel coulter, hoe coulter and triple disc coulter).

This resulted in a total of 72 treatments.

Constraints:

There were certain limitations imposed on the experimental design due to the facilities available. These were as follows:

(i) There were a maximum of 12 tillage bins available at any one time.

(ii) There were two climate rooms available at any one time, and each room could accommodate 3 soil blocks in these tillage bins.

(iii) In each soil block a maximum of three grooves at 150 mm spacing could be drawn to simulate field conditions and to avoid the risk of one groove affecting the soil in the adjacent grooves.

(iv) Because of the possible interactions of micro-environments between the in-groove soil, it was considered important to use only one coulter type in each soil block.

In the presence of such practical limitations it was considered difficult to attempt to compare all 72 treatments in one large experiment. This also meant that the experiment could not be conducted with large number of replicates.

It was, therefore, decided to divide the experimental programme into 4 separate experiments. The comparisons within each of these experiments involved coulter types, pressure intensities and controlled relative humidity response. Each experiment however began at a different soil moisture level and involved a different method of groove covering as follows:

Experiment (1a) Low initial soil moisture content, and pressing the grooves after bar harrowing.

(1b) Low initial soil moisture content and pressing the seeds into the groove base before bar harrowing.

Experiment (2a) High initial soil moisture content and pressing the grooves after bar harrowing.

(2b) High initial soil moisture content and pressing the seeds into the groove base before bar harrowing.

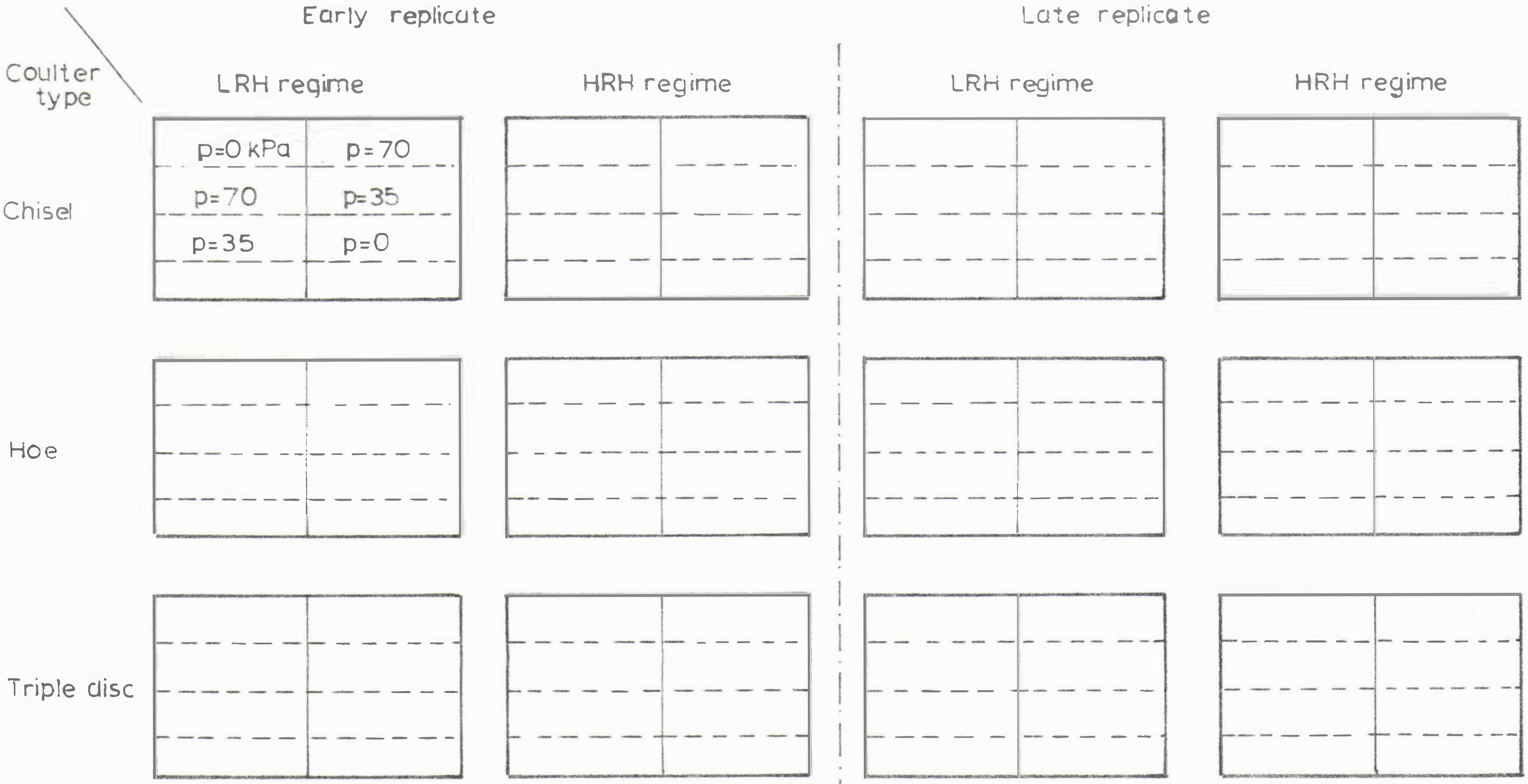
In this way each experiment consisted of 18 treatments and with a total of 4 replicates. For each experiment 12 soil bins were extracted at each time. Each soil bin was drilled with one coulter type, with three pressure level treatments randomly positioned in each half of the soil bin. This effectively gave 2 replicates of pressure treatments in each full soil bin. In this way 6 soil bins were drilled each time and were immediately carried into the controlled climate rooms in a manner that in each of the two rooms three soil bins represented all coulter types. This was called an early replicate. Remaining 6 bins were kept under rain canopies to maintain pre-determined moisture levels. These soil bins were drilled after 17 days and were subsequently carried to the climate rooms as described above. This was called the late replicate. Each time the soil blocks remained in the climate rooms until that time when potential seedling emergence had taken place. This time period was usually 17 days.

Figure 1 shows 12 soil bins depicting 18 treatment variables in a split-plot design for each of 4 experiments.

Seeds were sown at a nominal intra-row spacing of 20 mm using a vacuum spacing seeder designed by Copp [86] and later modified by Baker[67]. In each treatment a total of 50 seeds were sown.

2.2.16 Data Analysis

In each of 4 experiments, there were three plot treatment factors, viz; coulter types, climatic humidity conditions and time replicate. Pressure intensities was a split-plot factor. A Burrough's B7600 computer containing a programme pack "XALEMA/TEDDYBEAR" within 'Cande' was used to perform analysis of variance to test the interactions of coulter types, climatic conditions and pressure intensities in terms of seedling emergence and seed fate percent.



Plot treatment factors

Coulter types = 3 levels
r.h. regimes = 2 levels
Replicate(time) = 2 levels

Split-plot factor

Pressure intensities(P)= 3 levels

Figure 1. General plan of tillage bins in an experimental set up.

2.3 EXPERIMENT 1: INTERACTIONS BETWEEN DIRECT DRILLING COULTER DESIGNS, SEED, AND DRY SOIL UNDER CONTROLLED CLIMATIC CONDITIONS.

2.3.1 Experiment 1(a): Pressure applied over the covered grooves

Objectives

The principal objective of this study was to determine the effects of three coulter types and covering techniques on seedling emergence of wheat in a soil under moisture stress. The experiment involved the application of wheel pressure over the drilled grooves after bar harrowing. The three pressures were 0,35 and 70 kPa. The purpose of applying pressure was to press the soil over the grooves and thus possibly, to improve the seed-soil contact area, which in turn might have been expected to affect the soil liquid moisture availability to the seeds. The experiment was conducted under two contrasting controlled climatic conditions (see section 2.2.13 and appendix 3), the purpose of which was to test the effect of contrasting evaporative regimes on the liquid moisture contents in the seed micro-environment, which in turn might have been expected to influence seed germination and seedling emergence. Temperature variations in the vicinity of the seed were also measured using thermocouples. The specifications and raw data of this experiment are given in appendix (3 & 4).

Results and Discussion

(a) Seedling emergence

Table 1 shows the effects of coulter types, relative humidity regimes and pressure application on seedling emergence and seed fate of the direct drilled seeds in the dry soil. Analysis of variance of main plots show that there were highly significant differences in seedling percentage, due to coulter types. The chisel coulter recorded the highest seedling emergence figure of 59.3%, followed by the hoe coulter (16.1%). The emergence count for the triple disc coulter was only 1%. In fact the order of probability of all differences was unusually high at P = 0.001.

TABLE 1

The effects of coulter type, applied soil pressure over the covered grooves and relative humidity levels on seedling emergence and the seed fate of direct drilled wheat seeds in a dry soil

Treatment factors		Percent seedling emergence	Percent ungerminated seeds	Percent germinated but unemerged seeds
(a) Main treatments				
Coulter types	chisel	59.3 A	23.8 L	17.0 D
	hoe	16.1 B	57.9 D	25.9 D
	triple disc	1.0 C	27.0 L	71.8 E
Relative humidity regimes	LRH	21.8 a	41.9 m	36.2 d
	HRH	29.1 b	30.6 l	40.2 d
Coulter type x relative humidity interactions		NS	NS	NS
(b) Sub-treatments	No pressure	25.4 a	37.2 l	37.3 d
	35 kPa	25.7 a	35.7 l	38.9 d
	70 kPa	25.3 a	35.8 l	38.6 d
Humidity regimes x pressure interactions		NS	NS	NS
Coulter types x pressure interactions		NS	NS	NS

Unlike letters in a group of columns show significant differences, Capitals at (P = 0.01) and small letters at (P = 0.05).

The contrasting relative humidity regimes appeared to have had a significant (P = 0.05) effect on seedling emergence percent. The seedling emergence mean of all coulter types was 21.8% in the LRH regime compared to a mean of 29.1% in the HRH regime. There appeared to be no significant interactions however between coulter types and the relative humidity regimes.

Table 1 also shows the effects of applied pressures over the covered grooves in the sub-plots. There appeared to be no significant differences in seedling emergence as a result of the different pressure levels for any coulter type at either humidity regime.

Figs 2a & 2b show the rates of seedling emergence as affected by coulter types in the two relative humidity regimes. It appears that the overall rates of seedling emergence, up to their respective plateaus, were comparable between coulters at both humidity regimes. The plateaus appeared to occur on days 14 or 15 for the chisel and hoe coulters. With the triple disc coulter no clear plateau was observed because of the low seedling emergence counts throughout the experimental period. In the LRH regime the chisel coulter rate of seedling emergence appeared initially (days 6-8) to be greater than that of the hoe coulter. At the HRH regime however the initial rates of seedling emergence of these two coulters appeared to be little different.

(b) Ungerminated seeds:

There appeared to be a significantly (P = 0.01) higher number of ungerminated seeds in the hoe coulter grooves (57.9%) compared to those of both the chisel (23.8%) and the triple disc (27.0%) coulter grooves which were themselves not significantly different.

As with the counts of emergence, the contrasting relative humidity regimes appeared to have had a significant effect on the number of ungerminated seeds. In the HRH regime, there was a significantly (P = 0.05) lower number of ungerminated seeds (30.9%) compared with the LRH regime (41.9%).

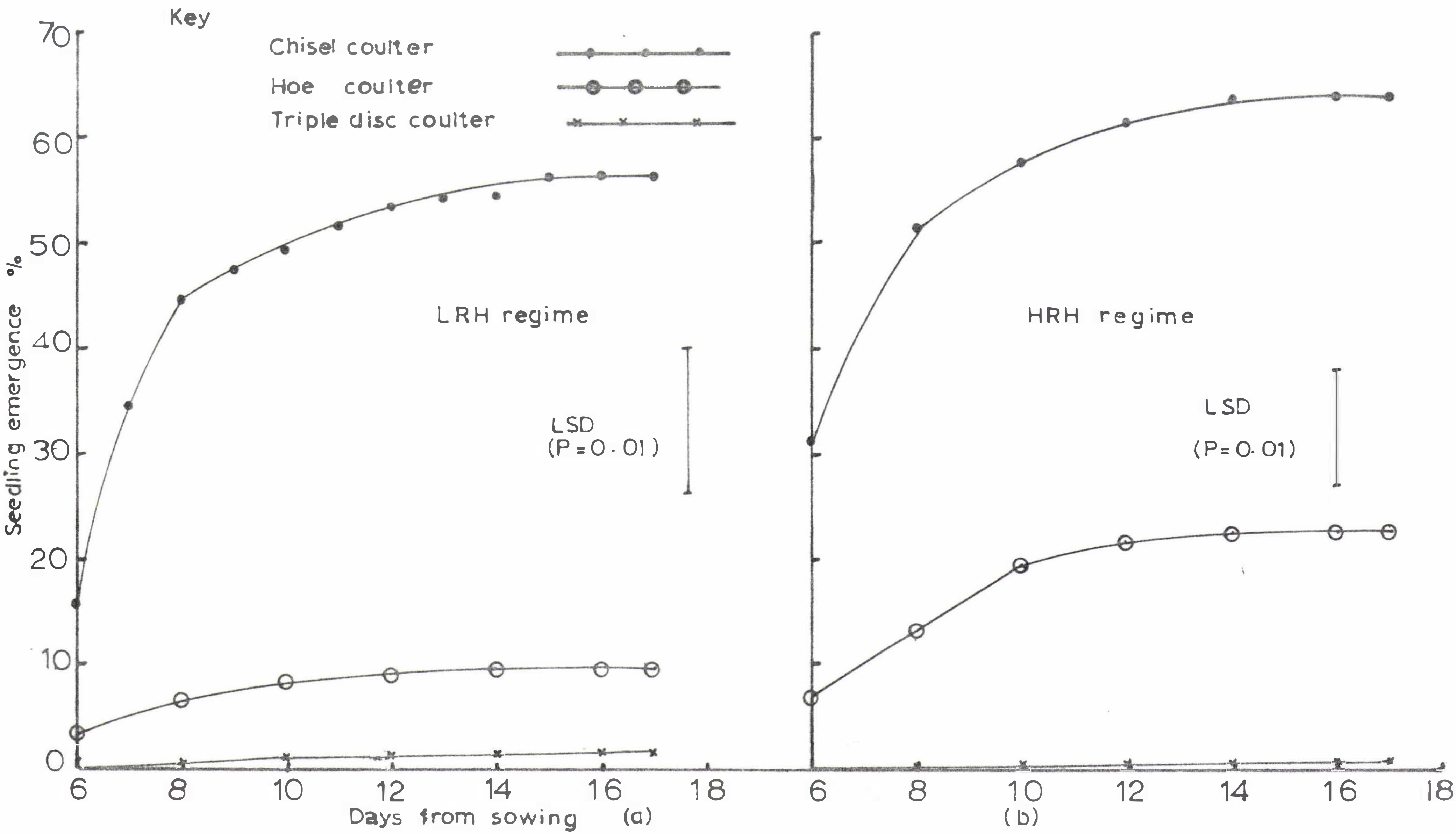


Figure 2 (a,b) The effects of direct drilling coulter type and relative humidity regimes on the percentage rate of wheat seedling emergence from a dry soil (pressure over covered seed)

Plate 9. General view of soil turf block in climate room (day 17)

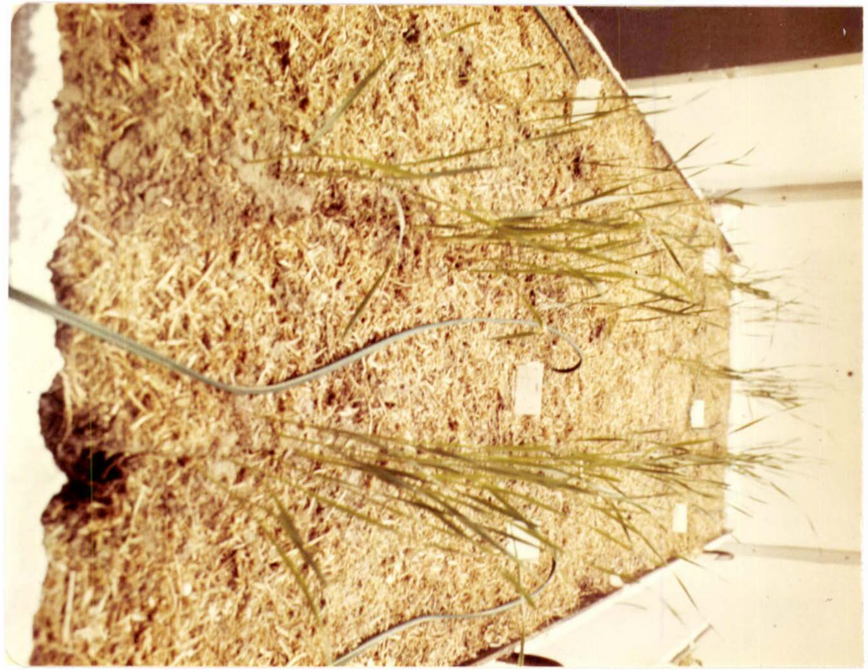


Plate 10a. Typical direct drilled wheat seedling emergence pattern in initially dry soil (day 17); sown with chisel coulter.

Plate 10b. Typical direct drilled wheat seedling emergence pattern in initially dry soil (day 17); sown with hoe coulter.

Plate 10c. Typical direct drilled wheat seedling emergence pattern in initially dry soil (day 17); sown with triple disc.

Application of pressures apparently had no significant effects on the number of ungerminated seeds. The interactions between pressure levels, coulter types and the contrasting relative humidity regimes were not significant.

(c) "Germinated but unemerged" seeds

From Table 1 there appeared to be a significantly (P = 0.01) larger number of seeds in the "germinated but unemerged" category with the triple disc coulter (71.8%) in comparison with both the chisel (17.0%) and hoe (25.9%) coulters. The number of "germinated but unemerged" seeds in the grooves of the chisel and hoe coulters were not significantly different.

The contrasting relative humidity regimes appeared to have had no significant effects on the numbers of "germinated but unemerged" seeds. Application of the three intensities of pressures over the covered grooves also apparently had no significant effects on the numbers of "germinated but unemerged" seeds. The interactions between coulter types, relative humidity regimes and the pressure levels were not significant.

Summary of seed fate

The failure to promote seedling emergence by the triple disc coulter appeared to be reflected in a high number of seeds in the "germinated but unemerged" category. On the other hand the low performance of the hoe coulter, in terms of seedling emergence, appears to have been reflected in a high number of seeds in the ungerminated category.

Not unexpectedly the lower number of ungerminated seeds at the HRH regime compared to that at the LRH regime, was inversely reflected in the percentages of emerged seedlings in the same relative humidity regimes.

Plate 9 shows the general view of the tillage bins in a climate laboratory on day 17. Plates 10a, 10b and 10c show typical seedling emergence patterns from the grooves of the chisel, hoe and triple disc coulters.

(d) In-groove soil moisture content:

The experiment started at an average soil moisture content of 17% (d.b.) for both the chisel and the hoe coulter treatments, with the triple disc coulter grooves at 19%. In this experiment soil moisture samples were taken from the grooves at depths of 0-15 mm, 15-30 mm and 30-45 mm. The purpose was to test the distribution of moisture in the in-groove soil profiles. However, from the raw data (appendix 3c) there appeared to be no significant differences in the liquid soil moisture levels at the selected depths in the grooves and all data at these depths were therefore bulked and are presented in the figures 3a & 3b.

Figs. 3a & 3b show the in-groove liquid soil moisture content from days 3 to 15 in the LRH and HRH regimes. From these figures it appears that from days 3 to 12 there continued to be significantly ($P = 0.05$) more moisture in the triple disc grooves in the LRH regime than with the chisel or hoe coulters. After day 12 the curves seemed to converge slightly. In the HRH regime the triple disc coulter may have also maintained its initial advantage but trends were indistinct.

The LRH regime appeared to produce a somewhat lower overall soil moisture level with the hoe coulter in comparison to the HRH regime. The chisel and triple disc coulter grooves however did not appear to respond as much to the different relative humidity levels, although their trends were similar to that of the hoe coulter.

It is possible that some of the apparently drier soil in the chisel and hoe coulter grooves, compared to the grooves of the triple disc coulter may have been due to transpiration from the larger number of emerged plants in the former grooves, but this was not measured. If indeed the triple disc grooves contained more moisture in the liquid phase than the chisel and hoe coulter grooves this might have been expected to be seen in the physical characteristics of the grooves. Visual examination suggested that in the soil alongside the neatly cut triple disc grooves it was likely that there were more unbroken capillary channels than in the vicinity of the more shattered grooves of the hoe and chisel coulters. It could be expected that because of this, liquid moisture would be more readily transferred to the seed-soil interface to imbibe the seeds in the triple disc groove at an early stage. Certainly, as table 1 shows that this

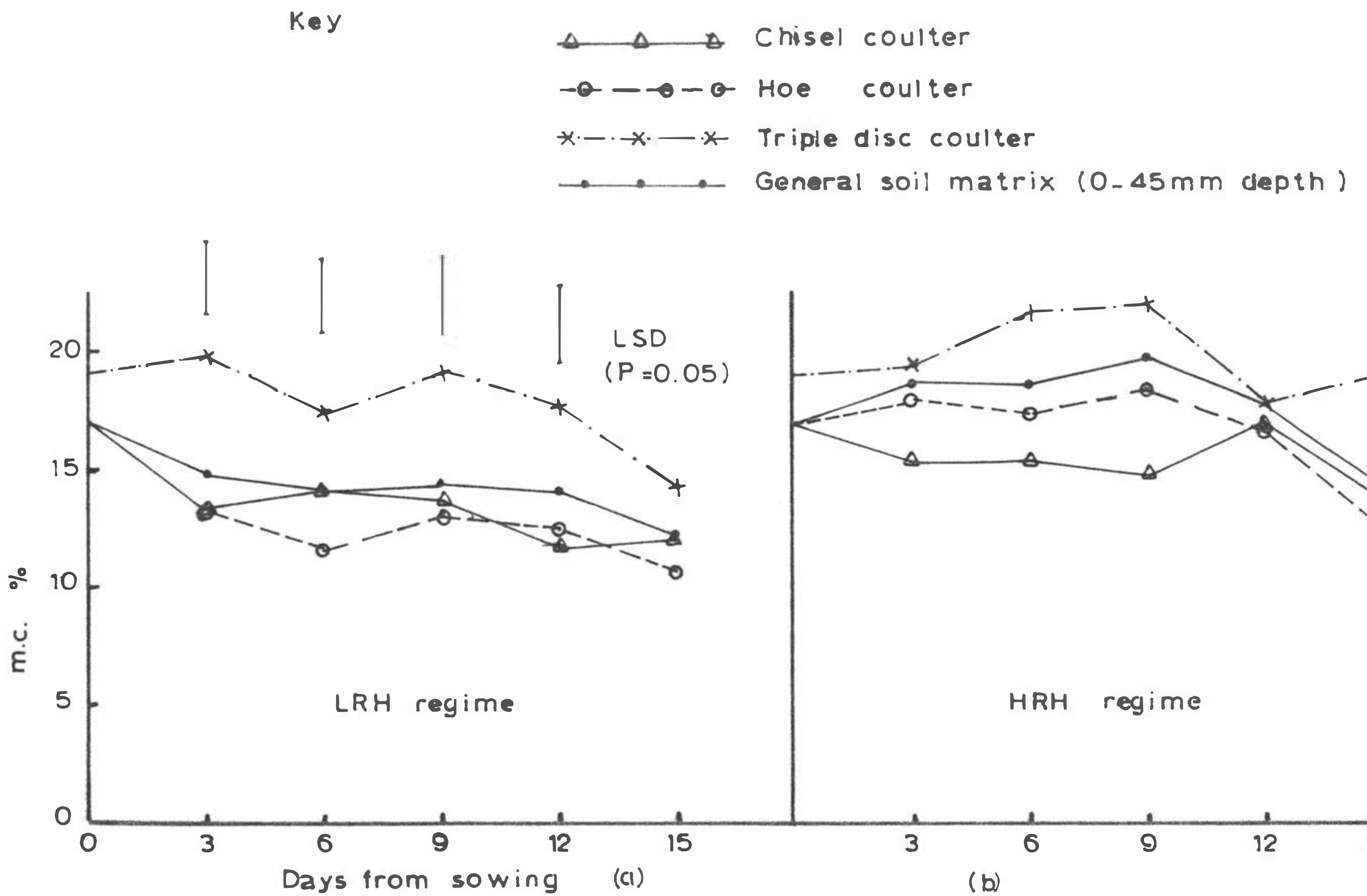


Figure 3 (a,b) The effects of direct drilling coulter types on in-groove liquid soil moisture content in a dry soil (pressure over covered seed) coulter lost nothing in germination counts by comparison with the chisel coulter. However it appeared that this favourable moisture regime may have subsequently evaporated from the otherwise exposed internal surfaces of the triple disc coulter grooves. A well defined thin layer of dry soil was noticeable on the surface of the groove walls after a few days. This may have then acted as a barrier to further moisture diffusion from the soil to the seed after the latter had germinated. Because of this possible decreasing moisture availability, these seedlings apparently became desiccated and died, as shown in table 1. This hypothesis is further strengthened by the measured low seedling mortalities with the chisel and hoe coulters, by comparison. However it does not fully explain the apparently lower liquid soil moisture levels in the latter two grooves which nevertheless resulted in markedly higher seedling emergence counts. Perhaps their loose soil and/or mulch cover helped contain the moisture in a vapour phase within these grooves, and this may have been more readily available to the seeds or seedlings, even at lower liquid soil moisture contents. Later experiments in this study sought to examine these hypotheses.

(e) Soil impedence measurements

Table 2 shows the effects of coulter type, pressure application over the covered grooves, and relative humidity regimes on measured soil impedence over the seeds. Analysis of variance of the main treatment factors in the main plots showed that there were no significant differences ($P = 0.05$) between coulter types in the energy expenditure for penetration of the "mechanical seedling" through the soil surface. The trend, however, was of higher ($P = 0.1$) energy expenditure when the hoe coulter was used at an average of 119.1×10^{-3}Nm compared with those of chisel coulter at an average of 99.1×10^{-3}Nm and triple disc coulter at 97.2×10^{-3}Nm.

The contrasting relative humidity regimes apparently had no significant effects on the energy expended for penetration.

Table 2 also shows the effects of the intensities of applied pressures in the sub-plots. There appears to be a significant ($P = 0.05$)

TABLE 2

The effects of direct drilling coulter types, pressure application over covered grooves, and relative humidity regimes on soil impedence in a dry soil.

Treatment factors (a) Main treatments		Energy expended for penetration ($Nm \times 10^{-3}$)	Maximum force of penetration (N)	Shear point distance (mm)
Coulter type	chisel	99.1 a	4.1 b	16.6 cd
	hoe	119.1 a	5.2 b	9.3 d
	triple disc	97.2 a	4.3 b	19.4 c
Relative humidity regimes	LRH	101.0 a	4.6 b	18.8 c
	HRH	109.2 a	4.4 b	11.4 d
Coulter type x relative humidity regime interaction		NS	NS	NS
(b) sub-treatments				
Pressure intensity	No pressure	101.0 ab	4.9 lm	14.6 r
	35 kPa	97.8 b	3.7 m	19.1 s
	70 kPa	126.9 a	4.8 l	11.5 r
Coulter type x pressure interaction		NS	NS	NS

Unlike letters in a group of columns show significant differences at (P = 0.05) increase in the energy expenditure for penetration when pressures were applied at 70 kPa compared with 0 or 35 kPa pressures. The energy expended for penetration at 70 kPa pressure was 126.9×10^{-3} Nm. There appeared to be a consistently slight, though insignificant, decrease in the energy expended at applied pressures of 35 kPa (97.8×10^{-3}Nm) compared with 101.0×10^{-3}Nm at zero pressure. If this was indeed a true effect it is difficult to offer reasons for it. Perhaps the unpressed soil underwent some loosening with 35 kPa pressure but required at least 70 kPa pressure to recompact it to a state of greater strength than the undisturbed soil.

Table 2 also shows the effects of coulter type, pressure application and the relative humidity regime on the maximum force requirement for penetration of the "mechanical seedling" through the soil surface. There appeared to be no significant effects of coulter types on the penetration force requirement and a mean penetration force across all coulters was 4.5 N. Similarly, the contrasting relative humidity regimes had no significant effects on the penetration force requirement. The patterns of differences were similar to those of the energy requirements described above. Indeed this was to be expected as the energy expenditure was calculated from the averaged penetration force measured.

The distance of the shear point from the surface appeared to be significantly ($P = 0.05$) greater in the triple disc grooves (19.4 mm) compared with that of the hoe coulter grooves (9.3 mm). This latter distance was not significantly different than that of the chisel coulter (16.6 mm). Not unexpectedly, with all coulter types, the distance of occurrence of shear point inversely mirrored the enegy and force measurements. There appeared to be significant effects from the contrasting relative humidity regimes on the distances of the occurrence of shear points from the surface. The mean distance of shear point occurrence in the LRH regime was 18.8 mm from the soil surface and this was significantly ($P = 0.05$) greater than that in HRH regime which was 11.4 mm. An analysis of variance of the sub-plots indicates that there were significant ($P = 0.05$) differences in the distances of the shear points from the surface as a result of pressure application over the covered grooves. It appears that the mean shear points occurred at 19.1 mm depth at an applied pressure of 35 kPa and this was significantly ($P = 0.05$) larger than both 14.6 mm at zero pressure, and 11.5 mm at 70 kPa which were themselves not significantly different.

An examination of the grooves showed that the hoe coulter groove was characterised by the quantity of loose soil (due to shattering) compared with the more cleanly cut triple disc coulter groove, and the somewhat hollow nature of the grooves of the chisel coulter. It is perhaps not surprising therefore that the "mechanical seedling" encountered slightly higher penetration resistance and required a larger penetration force in the hoe coulter groove compared to those of the chisel and the triple disc coulter grooves. The occurrence of the shear points at slightly greater distances from the surface in the LRH regime, compared to those in the HRH regime suggests that in the LRH regime, more rapid drying rates may have increased the soil strength over the seeds, compared with the more moist soil surface in the HRH regime.

The average energy expenditure for penetration in the hoe coulter groove was at 119.1×10^{-3}Nm. When this figure is related to the "mechanical seedling" diameter (cone diameter of 2mm) and the total distance travelled (38 mm) the average penetration pressure requirement was 9.97 bars. Similarly, the average penetration pressures in the chisel and triple disc coulter grooves were 8.3 and 8.14 bars respectively. Taylor *et al.*[25] had noted that soil resistance to penetration of up to 7 bars had little or no effect on cereal seedling emergence. It appears that the penetration resistances in this study were slightly higher than the critical figure of Taylor. However the readings in this study are within the non limiting range suggested by Hughes *et al.*[90]. These authors suggested that seedling emergence of common bermuda grass and weeping lovegrass was not reduced by indentation penetrometer resistance up to 11 bars in a soil with 56% clay. In the present study, visual examination of the emerged and unemerged seedlings from the grooves on day 18 failed to reveal any effects which might be attributable to soil resistance.

Fig. 4 shows typical grooves of the chisel, hoe and triple disc coulters. It also shows typical areas of the curves depicting the energy expenditure and the maximum force requirements at shear

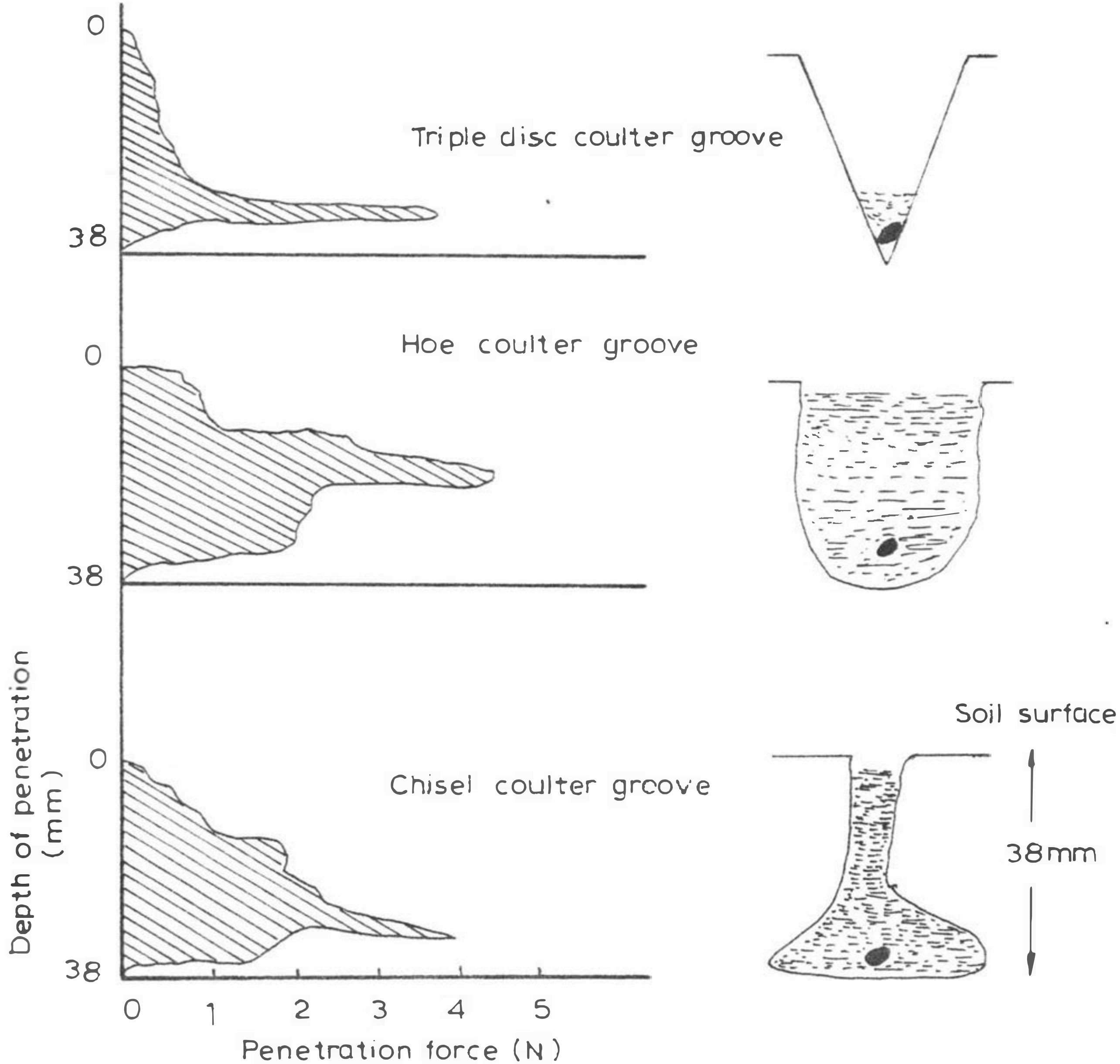


Figure 4. Typical penetration force and the energy expended (area under curves) obtained by the "mechanical seedling" in three types of coulter.

points for each coulter.

(f) In-groove soil temperature:

Table 3 shows the effects of coulter types, relative humidity regimes and pressures applied over the covered grooves on the in-groove soil temperatures at the controlled day/night temperature of 22/18^{o}C. There appeared to be no significant differences in the day-time temperatures between the chisel and hoe coulter grooves. In the triple disc coulter grooves (24.4^{o}C), the temperature was significantly (P = 0.05) higher than in the chisel (23.5^{o}C) and hoe (23.6^{o}C) coulter grooves.

There were apparently significant effects due to the contrasting relative humidity regimes on the day-time in-groove temperatures. In the HRH regime, the day-time in-groove temperature was 24.5^{o}C and this was significantly (P = 0.05) higher than in the LRH regime (23.2^{o}C).

The interactions between the coulter types and the relative humidity regimes were significant at 1% probability level.

Table 4 shows these interactions. In the LRH regime, day-time in-groove temperatures of the triple disc coulter were significantly (P = 0.01) higher than in the chisel and hoe coulter grooves which were in themselves not significantly different. The in-groove temperature of the triple disc coulter was significantly (P = 0.01) higher than the controlled ambient temperature of 22^{o}C. However the chisel and hoe coulters in-groove temperatures were not significantly different than the controlled ambient temperature.

In the HRH regime, the in-groove day-time temperatures were not significantly different in any coulter groove. However these temperatures were significantly (P = 0.01) higher than the controlled ambient temperature.

Relatively higher day-time temperatures in the triple disc grooves were not unexpected, as the seed-soil interface (where measurements were taken) was usually exposed to direct radiation because of the lack of seed cover discussed earlier.

TABLE 3

The effects of coulter type, relative humidity regimes and pressures applied over the covered grooves on the in-groove soil temperatures at controlled day/night temperature of 22/18^{o}C

Treatment factors (a) main treatments	In-groove temperature (C^{o}) Day-time	Night-time
Coulter types		
Chisel	23.5 b	21.6 l
hoe	23.6 b	21.8 l
triple disc	24.4 g	21.7 l
Relative humidity regimes		
LRH	23.2 b	21.2 l
HRH	24.5 a	22.3 k
Coulter type x relative humidity interaction	**	NS
(b) Sub-treatment		
Pressure intensities		
No pressure	23.9 b	21.7 l
35 kPa	23.8 b	21.7 l
70 kPa	23.9 b	21.7 l

Unlike letters in a group of columns show a significant difference at ($P = 0.05$)

TABLE 4

The effects of coulter types and relative humidity regimes on the in-groove day-time temperature at controlled day-time temperature of 22°C (interactions)

Relative humidity regimes	In-groove temperature in C° Coulter types		
	Chisel	Hoe	Triple disc
LRH	22.7 B	22.5 B	24.4 A
HRH	24.4 A	24.7 A	24.5 A
Controlled day-time temperature	22 B	22 B	22 B

Unlike letters show significant differences at (P = 0.01)
NS = not significant at (P= 0.05)

Table 3 also shows the analysis of variance in the sub-plots. There appeared to be no significant differences in the day-time in-groove temperatures due to three intensities of applied pressures over the covered grooves.

Table 3 also shows the effects of coulter types, relative humidity regimes and applied pressures on the in-groove night-time temperature. There appeared to be no significant differences in the night-time temperature in any of the three coulter type grooves. However a mean of 21.7°C temperature was significantly (P = 0.01) higher than the controlled ambient night temperature of 18°C.

The contrasting relative humidity regimes had a significant effect on the in-groove night-time temperature. In the HRH regime, (22.3°C), the night time temperature was significantly (P = 0.05) higher than in the LRH regime (21.2°C).

There appeared to be no significant interactions between coulter types and the relative humidity regimes in terms of the night-time temperature.

Analysisof variance in the sub-plots shows that there were no significant differences in the night-time in-groove ,temperature due to three intensities of applied pressures over the covered grooves.

It is likely that temperature changes could have had only minor direct effects on germination as they were at all times within the optimal range for wheat seed.

2.3.2 Experiment 1(b): Pressure applied directly over the seeds before covering

Objectives:

This experiment was designed to test the effects of three different coulter types on seedling emergence of wheat in a soil under moisture stress. Seeds were directly pressed in each coulter groove at pressures of 0, 35 and 70 kPa using especially designed wheels for the hoe and triple disc coulters and a sliding press mechanism for the chisel coulter groove. In all other respects experiment 1(b) was identical to experiment 1(a). The specifications and raw data are given in appendix(5a,b).

Results and discussion

(a) Seedling emergence

Table 5 shows the effects of coulter types, relative humidity regimes and pressure application on seedling emergence and seed fate of the direct drilled seeds. Analysis of variance of the main plots shows that there were highly significant differences in seedling emergence percentage due to coulter types. As in experiment 1(a), the significance order of probability was unusually high ($P = 0.001$). The chisel coulter promoted the highest seedling emergence (57.5%), and this was significantly higher than the hoe coulter (46.3%). The figure for the triple disc coulter was 19.8% and this was significantly lower than the hoe and chisel coulters.

The contrasting relative humidity regimes had significant ($P = 0.01$) effects on seedling emergence counts. The mean seedling emergence of all coulter types in the HRH regime (48.0%) was significantly ($P = 0.01$) higher than the comparable figure in the LRH regime (34.3%).

The interactions (relative humidity x coulter types) were not significant however.

Table 5 also lists the effects of applied soil pressure over the uncovered seeds as sub-plot data. There appeared to be significant ($P = 0.05$) effects of applied pressures on seedling emergence.

TABLE 5

The effects of coulter type, applied pressure over uncovered seeds, and relative humidity levels, on seedling emergence and seed fate of direct drilled wheat in a dry soil

Treatment factors		Percent seedling emergence	Percent Ungerminated seeds	Percent germinated but unemerged seeds
(a) Main treatments				
Coulter types	Chisel	57.5 A	12.7 Q	29.6 M
	Hoe	46.3 B	35.4 R	18.5 N
	Triple disc	19.8 C	8.7 Q	71.5 L
Relative humidity regimes	LRH	34.3 A	22.4 Q	42.5 L
	HRH	48.0 B	14.6 R	37.1 M
Coulter type x humidity interaction		NS	NS	NS
(b) Sub-treatment				
Pressure intensities	No pressure	29.8 a	29.9 q	40.1 lm
	35 kPa	43.4 b	13.0 r	43.4 m
	70 kPa	50.3 c	13.5 r	36.0 l
Coulter types x Pressure Interaction		NS	NS	NS
Humidity x pressure interaction		NS	NS	NS

Unlike letters in a group show significant differences, capitals (P = 0.01)
small letters (P = 0.05)

Seedling emergence was lowest when no pressure was applied (29.8%). At 35 kPa pressure, seedling emergence counts increased significantly (P = 0.05) to 43.4%. Where pressures of 70 kPa were applied, seedling emergence was further increased significantly (P = 0.05) to 50.3% compared with the counts at 0 and 35 kPa.

There were no significant interactions between, on the one hand, coulter types and pressure levels, and on the other hand, humidity regimes and pressure levels.

Figs. 5a & 5b show the rates of seedling emergence and the magnitudes of final seedling emergence as affected by coulter types and pressure intensities in both the LRH and HRH regimes. It appears that the overall rates of seedling emergence up to their respective plateaus were comparable with all coulters in both humidity regimes. The plateaus appeared to occur on days 14 or 15 for most treatments in the LRH regime. In the HRH regime, the plateaus appeared to be slightly earlier on days 12 or 13.

(b) Ungerminated seeds

From Table 5 there appeared to be a significantly (P = 0.01) higher number of ungerminated seeds in the hoe coulter grooves (35.4%) compared to those in the chisel (12.7%) and triple disc (8.7%) coulter grooves. The numbers of ungerminated seeds in the chisel and triple disc coulter grooves were not significantly different.

The contrasting relative humidity regimes appeared to have significantly affected the number of ungerminated seeds. In the HRH regime, there were significantly (P = 0.01) lower numbers of ungerminated seeds (14.6%) than in the LRH regime (22.4%).

Application of pressures at the three intensities also resulted in significantly (P = 0.05) reduced numbers of ungerminated seeds in some situations. At zero pressure, there were 29.9% ungerminated seeds and this was significantly (P = 0.05) higher than both of the corresponding counts at 35 kPa (13.0%) and 70 kPa (13.5%), which were themselves not significantly different.

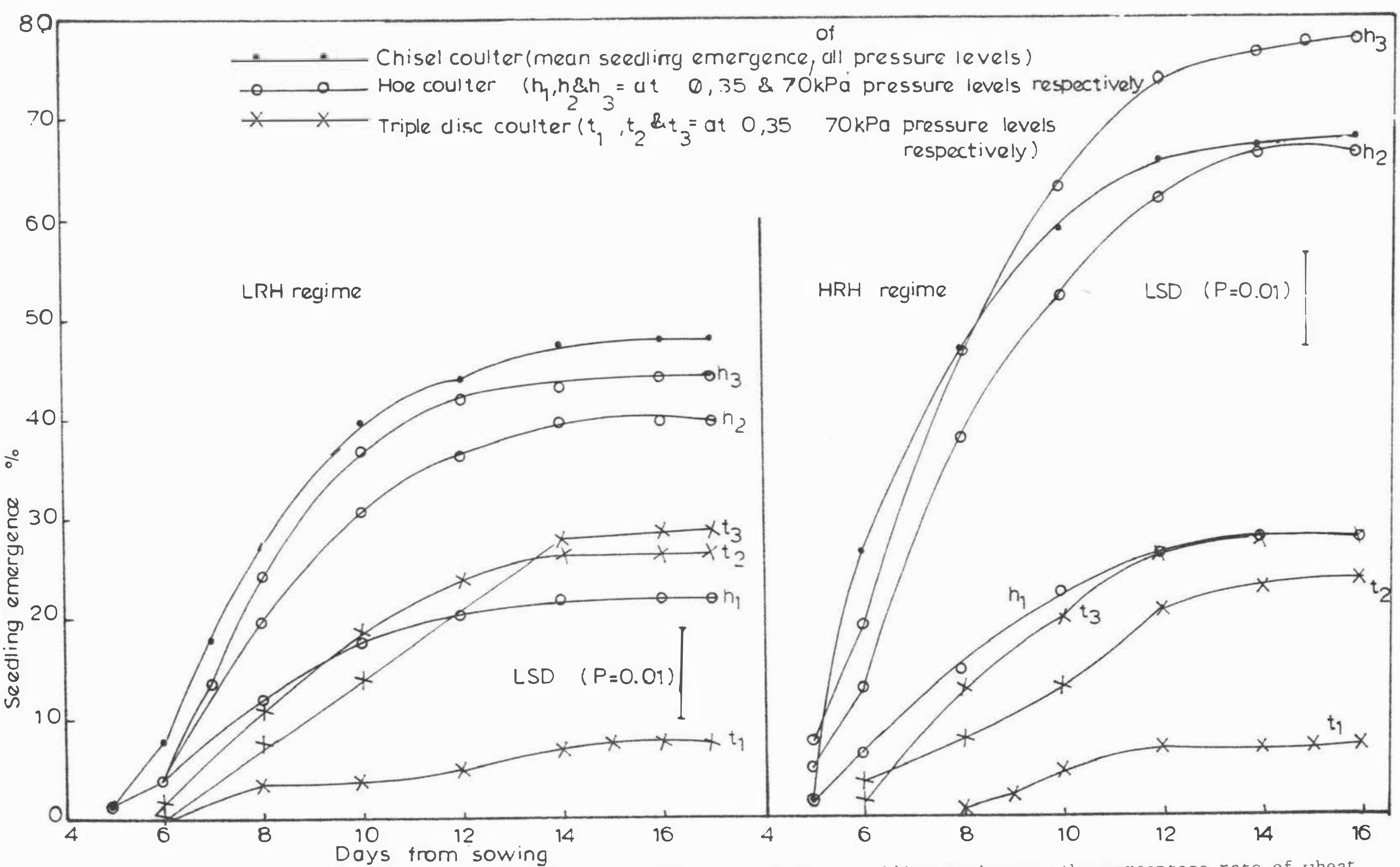


Fig. 5(a,b) The effects of direct drilling coulter type and relative humidity regimes on the percentage rate of wheat seedling emergence from a dry soil (pressure over uncovered seed)

(c) "Germinated but unemerged" seeds

Table 5 also shows the percentages of "germinated but unemerged" seeds. There appeared to be a significantly (P = 0.01) larger number of seeds in the "germinated but unemerged" category with the triple disc coulter (71.5%) in comparison with the chisel coulter (29.6%) which was itself significantly larger (P = 0.01) than the hoe coulter (18.5%).

The contrasting relative humidity regimes appeared to have significant (P = 0.01) effects on the number of "germinated but unemerged" seeds. In the HRH regime, the number of "germinated but unemerged" seeds (37.1%) were significantly (P = 0.01) lower than those in the LRH regime (42.5%).

The analysis of variance of the sub-plot data shows that the applied pressure of 70 kPa significantly (P = 0.05) decreased the number of "germinated but unemerged" seedlings to 36% compared with 43.4% from 35 kPa pressure. The number of "germinated but unemerged" seeds from zero pressure was 40.1% but this was not significantly different than the counts from either 35 kPa or 70 kPa.

Summary of seed fate:

As in experiment 1(a), the failure of seedlings to emerge from the grooves of the triple disc coulter appears to have been reflected in a higher percentage of "germinated but unemerged" seeds. By contrast, the comparatively low performance of the hoe coulter, in terms of seedling emergence, was mirrored in a high percentage of ungerminated seeds. Not surprisingly, the lower numbers of ungerminated and "germinated but unemerged" seeds in the HRH regime compared with those in the LRH regime inversely mirrored the higher percentage of seedling emergence in the HRH regime.

Application of pressures at the three intensities directly over the uncovered seeds appears to have significantly decreased the number of the ungerminated and "germinated but unemerged" seeds and this too inversely reflected the seedling emergence pattern.

(d) Herbage dry matter yield:

Table 6 shows the effects of coulter types and relative humidity regimes on the mean herbage dry matter yield of plants on day 17. These data were the averages of the yields at all pressure levels with each coulter type. From table 6, when considering yields per plant, it appears that there were no significant differences in yield per plant betwen the chisel coulter (0.029 gm) and the triple disc coulter (0.028 gm). With the hoe coulter (0.022 gm), the dry matter yield was significantly (P = 0.05) lower than either the chisel or triple disc coulters.

The contrasting relative humidity regimes had a significant (P = 0.05) effect on the yield per plant. In the HRH regime (0.031 gm), the yield was significantly higher than in the LRH regime (0.021 gm).

There were no significant interactions between coulter types and relative humidity regimes in terms of dry matter yield per plant.

Table 6 also shows the dry matter yields per 100 seeds sown. Not unexpectedly there were significant (P = 0.01) differences in yields due to coulter types. The chisel coulter promoted the highest yield (1.79 gm/100 seeds sown) and this was significantly (P = 0.01) larger than the hoe coulter (1.09 gm/100 seeds sown) and the triple disc coulter (0.56 gm/100 seeds sown). The hoe and triple disc coulters were themselves significantly different.

TABLE 6

The effects of coulter types and the relative humidity regimes on day 18 dry matter yields of direct drilled wheat.

Treatment Factor		Dry matter yield gm per plant	Dry matter yield gm per 100 seeds sown
Coulter types			
	Chisel	0.029 a	1.79 A
	Hoe	0.022 b	1.09 B
	Triple disc	0.028 a	0.56 C
Relative humidity regimes			
	LRH	0.021 b	0.77 A
	HRH	0.031 a	1.52 B
Coulter types x relative humidity interaction		NS	NS

Unlike letters in a group of columns show significant differences, capitals (P = 0.01) and small letters (P = 0.05).

The contrasting relative humidity regimes also had a significant effect on the yield per 100 seeds sown. In the HRH regime, the dry matter yield (1.52 gm/100 seeds sown) was significantly (P = 0.01) higher than in the LRH regime (0.77 gm/100 seeds sown).

There were no interactions between coulter types and the relative humidity regimes in terms of yields per 100 seeds sown.

The dry matter yields (when considered as a function of the number of seeds sown) not unexpectedly appeared to reflect the pattern of seedling emergence in all coulter types and relative humidity regimes. Thus no effect on plant vigour was apparent as a result of the different populations between coulter types. On the contrary, the higher population with the chisel coulter also resulted in heavier plants which suggests less stress had been experienced by individual plants.

(e) In-groove soil moisture content

Table 7 shows the effects of coulter types and the relative humidity regimes on the mean soil block matrix and in-groove soil moisture contents. Not unexpectedly almost all readings declined with time. Main plot analysis of variance were therefore computed for the mean data covering days 1 to 12.

There appeared to have been significantly (P = 0.05) more moisture maintained in the chisel coulter grooves (20.2%) compared with the hoe (15.7%) and triple disc coulters (15.9%) and the general soil matrix (17.5%). There appeared to be no significant differences in the mean in-groove soil moisture levels of the hoe and the triple disc coulters, nor between these two treatments and the soil matrix.

The contrasting relative humidity regimes had significant effect on the in-groove soil moisture content. In the HRH regime, there appeared to be maintained a significantly (P = 0.05) higher soil moisture content (18.4%) than in the LRH regime (16.2%).

There appeared to be no interactions between coulter types and the relative humidity regimes in terms of soil moisture content.

TABLE 7

The effects of coulter type and relative humidity regimes on the in-groove Soil moisture contents

Soil moisture %

Treatments	Days from drilling 1	3	6	12	mean (days 1-12)
Coulter types					
Chisel	21.0	22.3	19.0	18.5	20.2 a
Hoe	17.7	16.9	15.8	12.7	15.7 b
Triple disc	18.8	16.8	14.5	13.5	15.9 b
General soil matrix	18.5	17.6	17.4	16.5	17.5 b
Humidity regimes					
LRH	18.7	17.1	15.9	13.2	16.2 l
HRH	19.2	19.7	17.4	17.4	18.4 m
Coulter type x relative humidity interactions					NS

Unlike letters show significant differences at (P = 0.05).

Figs 6a and 6b show the in-groove and general soil matrix moisture contents over time in the LRH and HRH regime respectively. From figures 6a and 6b, it is apparent that the rate of soil moisture loss in the HRH regime was less than that in the LRH regime. No clear differences in rates of soil moisture loss between coulter types and the general soil matrix were apparent.

(f) In-groove soil temperature

Table 8 shows the effects of coulter types and relative humidity regimes on the in-groove day-time and night-time temperatures from day 3 until day 9.

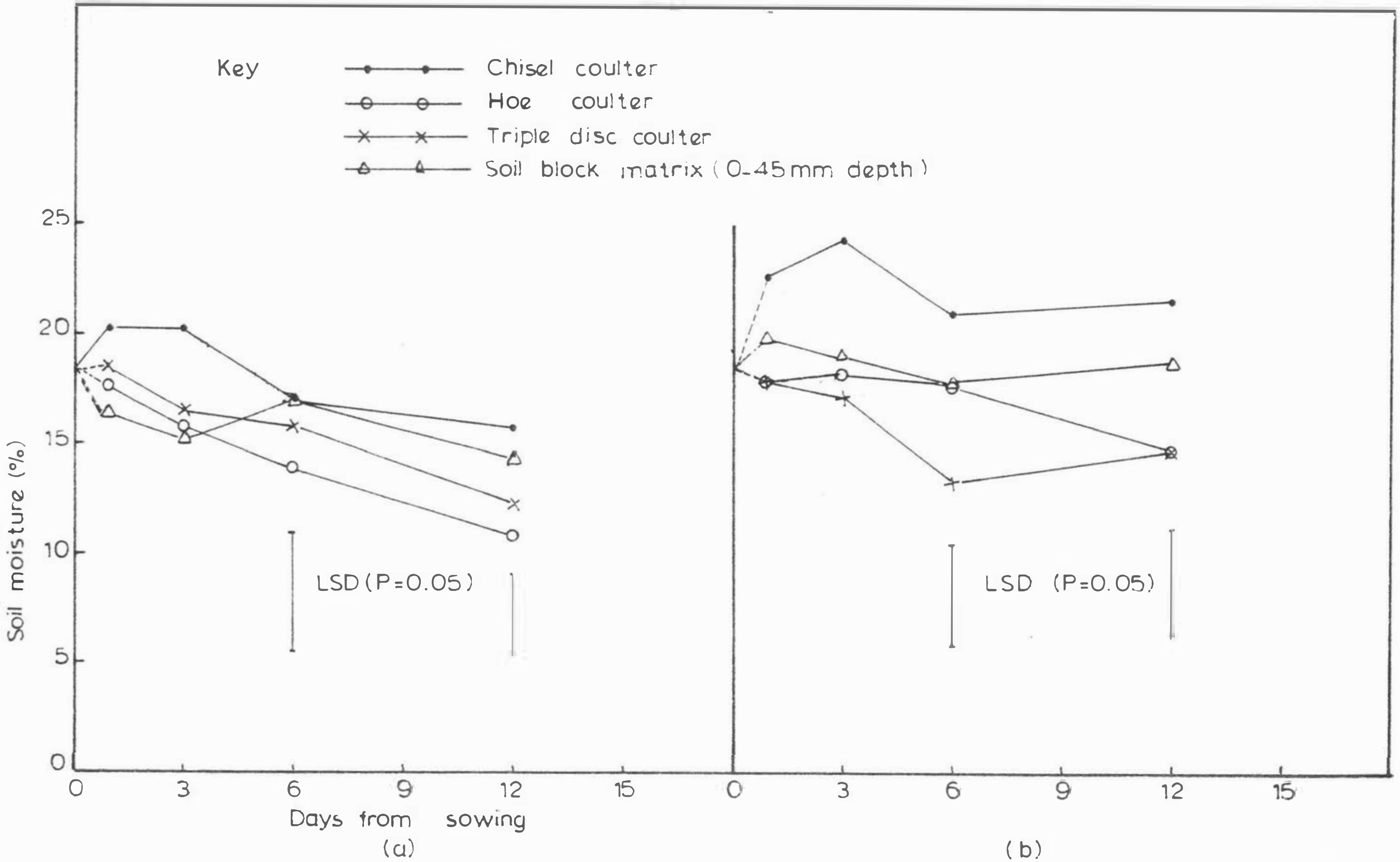


Fig. 6 (a,b) The effects of direct drilling coulter type and relative humidity regimes on in-groove liquid soil moisture content in a dry soil (pressure over uncovered seed)

Effects of time

The daytime in-groove temperatures increased significantly (P = 0.05) from 23.3^{o}C on day 3 to 24.9^{o}C on day 6. The differences between day 6 and day 9 temperatures were however not significant.

There appeared to be no interactions on the one hand, between coulter types and relative humidity regimes, and on the other hand, between coulter types and time.

TABLE 8

The effects of coulter types and relative humidity regimes on the in-groove soil temperature at controlled ambient temperature of 22^{o}C/18^{o}C day/night

Treatment factors	Day time in-groove temperature (C^{o})	Night time in-groove temperature (C^{o})
Time effects (days after sowing)		
3	23.3 a	19.4 l
6	24.9 b	21.5 m
9	25.2 b	22.4 m
Interactions		
Coulter type x relative humidity	NS	NS
Coulter type x time effects	NS	NS
Coulter types		
Chisel	24.6 a	21.0 l
Hoe	24.2 a	21.3 l
Triple disc	24.6 a	21.0 l
Relative humidity regimes		
LRH	24.1 a	22.0 l
HRH	24.9 a	20.2 m

Unlike letters in a group of columns show significant differences at (P = 0.05).

Similarly, the night-time temperatures increased significantly ($P = 0.05$) from 19.4^{o}C on day 3 to 21.5^{o}C on day 6. There were no significant changes in the night-time temperatures from day 6 to day 9.

Again, coulter type interactions with relative humidity regimes, on the one hand and time on the other were not significant.

Mean temperatures

The daytime mean of all three sampling times in-groove soil temperatures appeared to be similar in all coulter types and averaged 24.5^{o}C. This was significantly ($P = 0.01$) higher than the controlled daytime temperature of 22^{o}C.

The contrasting relative humidity regimes apparently had no significant effect on the mean in-groove daytime temperatures.

Night-time mean in-groove temperatures were not significantly different in the grooves of the three coulter types. These temperatures (mean of 21.1^{o}C) were however significantly ($P = 0.01$) higher than the controlled night temperature of 18^{o}C.

The contrasting relative humidity regimes significantly affected the night-time in-groove temperatures. In the LRH regime, the night-time in-groove temperatures (22.0^{o}C) were significantly ($P = 0.05$) higher than those in the HRH regime (20.2^{o}C).

Although there appeared to be significant increases in the in-groove temperatures from day 3 until day 6 and 9, it is likely that in-groove temperature changes would have had only minor direct effects on seed germination as they were at all times generally within the optimal range for wheat seed germination. Instead, as with experiment 1(a), they probably represent indirect reflections of changing liquid soil moisture contents.

Discussion

It is clear that there was greater seedling emergence when the chisel coulter was used compared with the other two coulter types. At least part of the reason for this might have been because in this experiment this coulter maintained relatively favourable in-groove liquid moisture (Fig. 6), although other experiments have not substantiated this. The relatively well covered groove might have reduced direct radiation effects at the seed-soil interface and helped maintain a higher soil liquid or vapour moisture potential.

With all coulters it appeared that an improved seed-soil contact had helped increase the moisture (liquid) transportation from the soil to the seed when pressures were applied over the seeds before covering. The effect of pressure was more pronounced on germination, when ungerminated seed counts fell by more than half from 29.9% to 13.5% as a result of pressing at 70 kPa. On the other hand the corresponding counts of "germinated but unemerged" seeds fell by only a maximum of 16% from the highest count to that at 70 kPa.

The significantly (P = 0.01) larger number of ungerminated seeds with the hoe coulter compared with the chisel and triple disc coulter might be explained by the appearance of the grooves. In the drier soil, the hoe coulter apparently resulted in an appreciable amount of soil surface rupture and shattering. This appeared to have left loose soil with "air pockets" over the seeds. Such an observation was first reported by Phillips and Young[(69)] and was categorized as grade II cover by Baker[(67)]. The loose soil surface apparently subjected the seed-soil interface to an early and relatively rapid desiccation under the dry ambient conditions. As a result the seeds appeared to have a lower availability of liquid moisture for imbibition and germination.

With the triple disc coulter there were significantly higher numbers of "germinated but unemerged" seeds compared to the chisel and hoe coulter grooves. This, together with the low count of ungerminated seeds with this coulter, suggests that initially there was adequate liquid soil moisture available at the seed-soil interface of the triple disc coulter groove and that this resulted in reasonable number of germinated seeds. The subsequent high mortality rate of these germinated seeds appears to be a consistent trend and might be explained by a combination of the following factors:

(a) The requirements of moisture to the relatively large number of germinating seeds(9, 21, 22, 23) might have reduced the moisture potential at the seed-soil interface. If this was a factor it would have probably occurred before the seed radicle had penetrated into more moist soil layers alongside.

(b) The initially imbibed seeds might have been rapidly subjected to a "moisture desorption process"(14) away from the seed-soil interface to the drier soil-ambient interface. Since the moisture potential close to the seed radicle could be expected to be at or above -5 bars and the ambient air (r.h. controlled at 90%) was at less than -100 bars, it is likely that there would have been a moisture gradient away from the seed-soil interface.

(c) The exposed internal surface of the groove might have caused a rapid initial moisture evaporation after imbibition, thus creating a dry thin layer of soil superimposed on the groove surface. This might have acted as a barrier to further moisture transportation from the more moist adjacent soil regions. As in experiment 1a, such a dry soil layer was visually apparent.

These experiments therefore further strengthened the need to study more closely the mechanisms of soil in-groove moisture availability to the sown seeds. Before this aspect could be initiated however, completion of study of the effects of the range of test conditions imposed, took priority.

2.4 EXPERIMENT 2: INTERACTIONS BETWEEN DIRECT DRILLING COULTER DESIGNS, SEED AND WET SOIL UNDER CONTROLLED CLIMATIC CONDITIONS.

2.4.1 Experiment 2(a): Pressure applied over the covered grooves

Objectives:

The objective of this study was to test the performance of three coulter types, in terms of seedling emergence and seed fate in a soil with an adequate initial soil moisture regime. In all other respects experiment 2(a) was identical to experiment 1(a). The specifications and raw data of this experiment are given in appendix (6).

Results and discussion:

(a) Seedling emergence:

Table 9 shows the effects of coulter types, applied pressure over the covered grooves and relative humidity regimes on seedling emergence and seed fate. The analysis of variance of the main treatment factors in the plots shows that there were significant differences in percent seedling emergence due to coulter types. The hoe and chisel coulters, promoted the highest seedling emergence (69.8% and 60.4% respectively). The figure of the hoe coulter was significantly (P = 0.05) higher than that with the triple disc coulter (45.7%), but seedling emergence with the chisel coulter was not, significantly different than either the hoe or triple disc coulters.

Table 9 shows that the contrasting relative humidity regimes had no significant effects on seedling emergence. This was not unexpected, however, because of the adequate initial soil moisture contents of all turf blocks.

The analysis of variance in the sub-plots show that the applied pressures had significant effects on percentage seedling emergence. In the absence of applied pressure, seedling emergence was 54.9%. This increased significantly (P = 0.05) to 61.5% at 35 kPa. At an applied pressure of 70 kPa, however, seedling emergence was 59.4% and this was not significantly different than that at either 0, or 35 kPa.

TABLE 9

The effects of coulter type, applied soil pressure over the covered grooves and relative humidity levels on seedling emergence and the seed fate of direct drilled wheat seeds in an adequate soil moisture regime.

Treatment factors		Percent seedling emergence	Percent ungerminated Seeds	Percent "germinated but unemerged" seeds
(a) main treatments				
Coulter types	Chisel	60.4 ab	0 p	39.5 m
	Hoe	69.8 a	0.8 p	29.4 m
	Triple disc	46.3 b	0 p	51.0 l
Relative humidity regimes	LRH	57.8 a	0.8 p	39.9 l
	HRH	59.4 a	0 p	40.0 l
Coulter type x relative humidity regimes interaction		NS	NS	NS
(b) sub-treatments				
Pressure intensity				
	No pressure	54.9 a	0.8	40.9 l
	35 kPa	61.5 a	0	38.6 l
	70 kPa	59.4 ab	0	40.5 l
Coulter type x pressure intensity interaction		*	NS	NS

Unlike letters in a column show significant differences at (P = 0.05).

There appeared to be an interaction of coulter types and applied pressures over the covered grooves. Table 10 shows these interactions. It appears that with the chisel coulter seedling emergence increased significantly (P = 0.05) from 55.4% to 68.3% when a pressure of 35 kPa was applied compared with no pressure. However seedling emergence percent decreased significantly (P = 0.05) to 57.4% when the applied pressure was further increased to 70 kPa with the same coulter. When the hoe coulter was used there were no significant effects on seedling emergence from changing pressures at any level. With the triple disc coulter, there appeared to be an initial increase in seedling emergence at 35 kPa applied pressure compared to that at zero pressure, but this remained unchanged with a further pressure increase to 70 kPa. It is difficult to offer reasons to explain the lower seedling emergence in the chisel coulter grooves and even the unchanged emergence in the triple disc coulter groove, at an applied pressure of 70 kPa compared to that at 35 kPa. It seems reasonable that with both these coulters the pressure at 35 kPa provided better seed-soil contact. Perhaps at 70 kPa, there might have been some degree of over-compaction above the seeds, which might then have physically retarded the shoots and offset the gains made through improved soil-seed contact. Figs. 7a and 7b show the rates of seedling emergence. The respective plateaus of percentage seedling emergence appear to occur on or about day 14 with all coulter types except with the triple disc coulter, in the HRH regime where seedling emergence plateaued on day 10. The rates of seedling emergence appeared to be comparable in all coulter types in the LRH regime.

(c) "Germinated but unemerged" seeds

Table 9 also shows the effects of the treatment factors on the percentages of "germinated but unemerged" seeds. There appeared to be a significantly (P = 0.05) higher number of "germinated but unemerged" seeds in the grooves of the triple disc coulter (51.0%) compared to those of the chisel (39.5%) and hoe (29.4%) coulters which were themselves not significantly different.

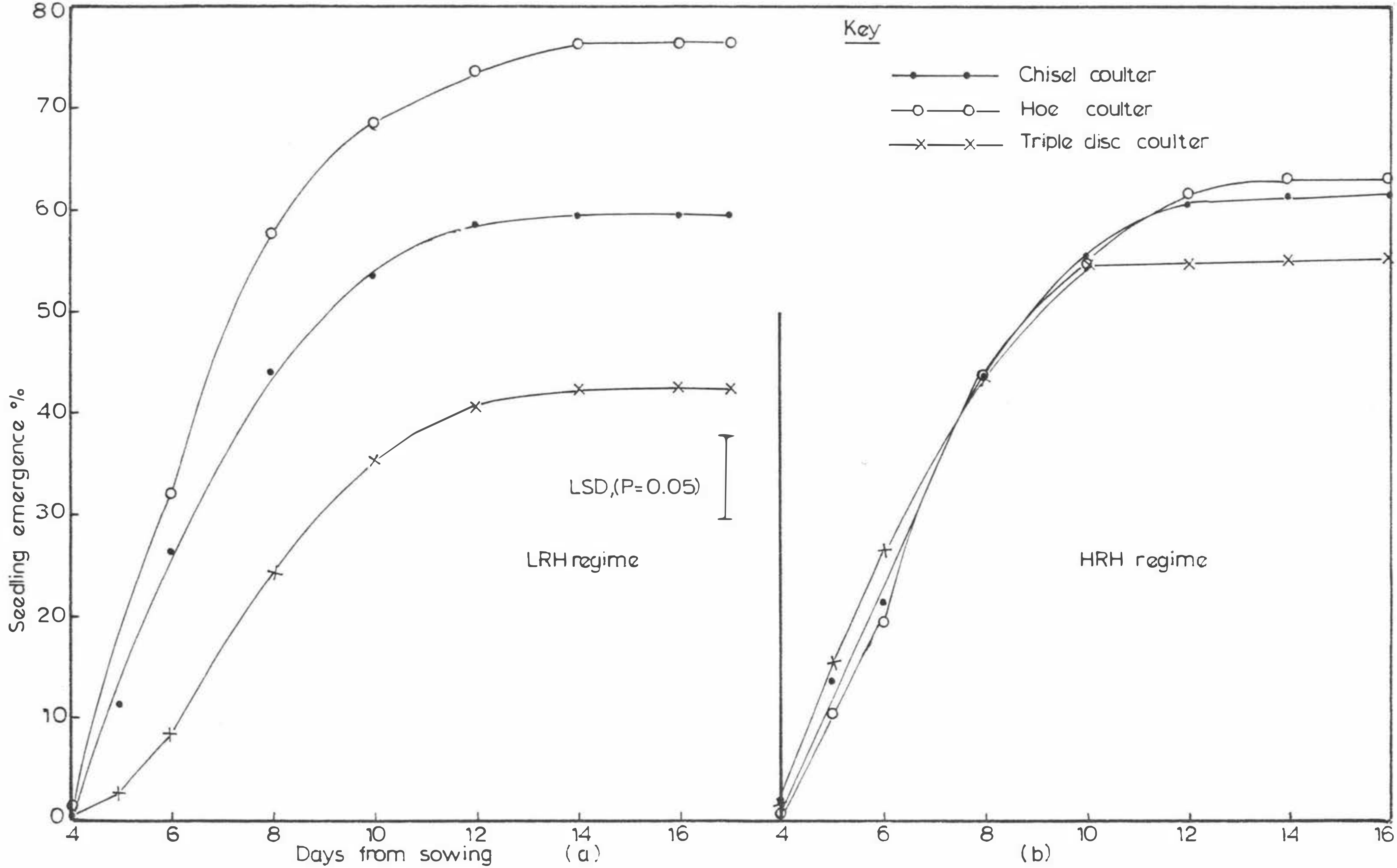


Figure 7. (a,b) The effects of direct drilling coulter types and relative humidity regimes on the percentage rate of seedling emergence of wheat in an adequate soil moisture level (pressure over covered seed)

TABLE 10

The interaction of coulter types and applied pressures on seedling emergence of direct drilled wheat

	Percent seedling emergence		
Coulter types	Chisel	Hoe	Triple disc
Pressure intensity (kPa)			
0	55.4 b	71.6 a	37.8 c
35	68.3 a	66.4 a	49.8 b
70	57.4 b	71.3 a	49.5 b

Unlike letters show significant difference at P = (0.05)

The contrasting relative humidity regimes apparently had no significant effect on the number of "germinated but unemerged" seeds. Similarly the applied pressures at three intensities apparently had no significant effects on the number of "germinated but unemerged" seeds.

Summary of seed fate:

The significantly lower seedling emergence with the triple disc coulter compared with the hoe coulter appears to have been reflected in a corresponding higher percentage of "germinated but unemerged" seeds. Clearly, however the more favourable soil moisture conditions had reduced the differences between coulter types and the triple disc coulter was only inferior to the chisel coulter (in terms of seedling emergence) at the lower order of probability of P = 0.10. Further confirmation of the favourable seed environment was seen in the number of ungerminated seeds which appeared to be almost zero with all coulter types.

(d) Herbage dry matter yield:

Table 11 shows the effects of coulter types and relative humidity regimes on the dry matter yield on a per plant shoot weight basis

TABLE 11

The effects of coulter types and relative humidity levels on herbage dry matter yield at day 18

Treatment factors	Yields in gm/ plant shoot weight	Yields in grams/100 seeds sown
Coulter types		
Chisel	0.028 a	1.7 A
Hoe	0.023 ab	1.6 A
Triple disc	0.017 b	0.79B
Relative humidity regimes		
LRH	0.021 a	1.24 m
HRH	0.025 a	1.49 m
Coulter types x relative humidity regimes interactions	NS	NS

Unlike letters in a group of columns show significant differences, capitals at (P = 0.01) and small letters at (P = 0.05).

at day 18. The triple disc coulter promoted a significantly (P = 0.05) lower yield of 0.017 gm/plant compared to the chisel coulter (0.028 gm/plant). The yield of plants drilled with the hoe coulter (0.023 gm/plant) were not significantly different from either the chisel or triple disc coulters. The low yield of the triple disc sown plants lends weight to the belief that these plants were still under some stress despite the favourable growing conditions.

Table 11 also shows the effects of coulter types on herbage dry matter yields of 100 sown seeds at day 18. Not un-expectedly there appeared to be significant differences in the dry matter yield between coulter types when yield was measured on the basis of 100 seeds sown. There appeared to be a significnatly (P = 0.01) higher yield of 1.7 gm/100 seeds sown from the chisel coulter grooves compared to 0.79 gm/100 seeds sown with the triple disc coulter. The shoots from the hoe coulter (1.6 gm/100 seeds sown) also appeared to have a significantly (P = 0.01) higher yield than those from the triple disc coulter, but were found not to be significantly different to those from the chisel coulter.

The dry matter per 100 seeds sown, in this case indicated that although there were slightly fewer plants to emerge from the chisel coulter grooves, the greater weight of each of these plants compensated for the lower population, giving a similar overall yield to those sown by the hoe coulter.

The contrasting relative humidity regimes apparently had no significant effect on the dry matter yield, either on a per plant or per 100 seeds sown basis.

The interactions between coulter types and the relative humidity regimes were not significant.

(e) In-groove soil moisture content

Figs 8a and 8b show the effects of coulter types and relative humidity regimes on in-groove liquid moisture contents. The experiment started at an average soil block (0 to 45 mm depth) moisture content of 45.0% for all coulter types. There appeared to be no significant differences between the three coulter types at any of the sampling dates. In-groove soil moisture appeared also to differ little from those taken from the matrix of the soil blocks.

From table 12 the in-groove moisture contents in both relative humidity regimes appeared to decline slowly over time. In the HRH regime, the in-groove liquid moisture contents appeared to be similar to those in the LRH regime until day 12, after which the LRH soil moisture fell more rapidly than in the HRH regime. By day 15 it appeared that the soil liquid moisture contents were significantly (P = 0.05) lower in the LRH regime than in HRH regime.

(f) In-groove soil temperature

Table 13 shows the effects of coulter types, relative humidity regimes and time on the in-groove soil temperatures. There appeared to be no significant effect of time on the in-groove day-time

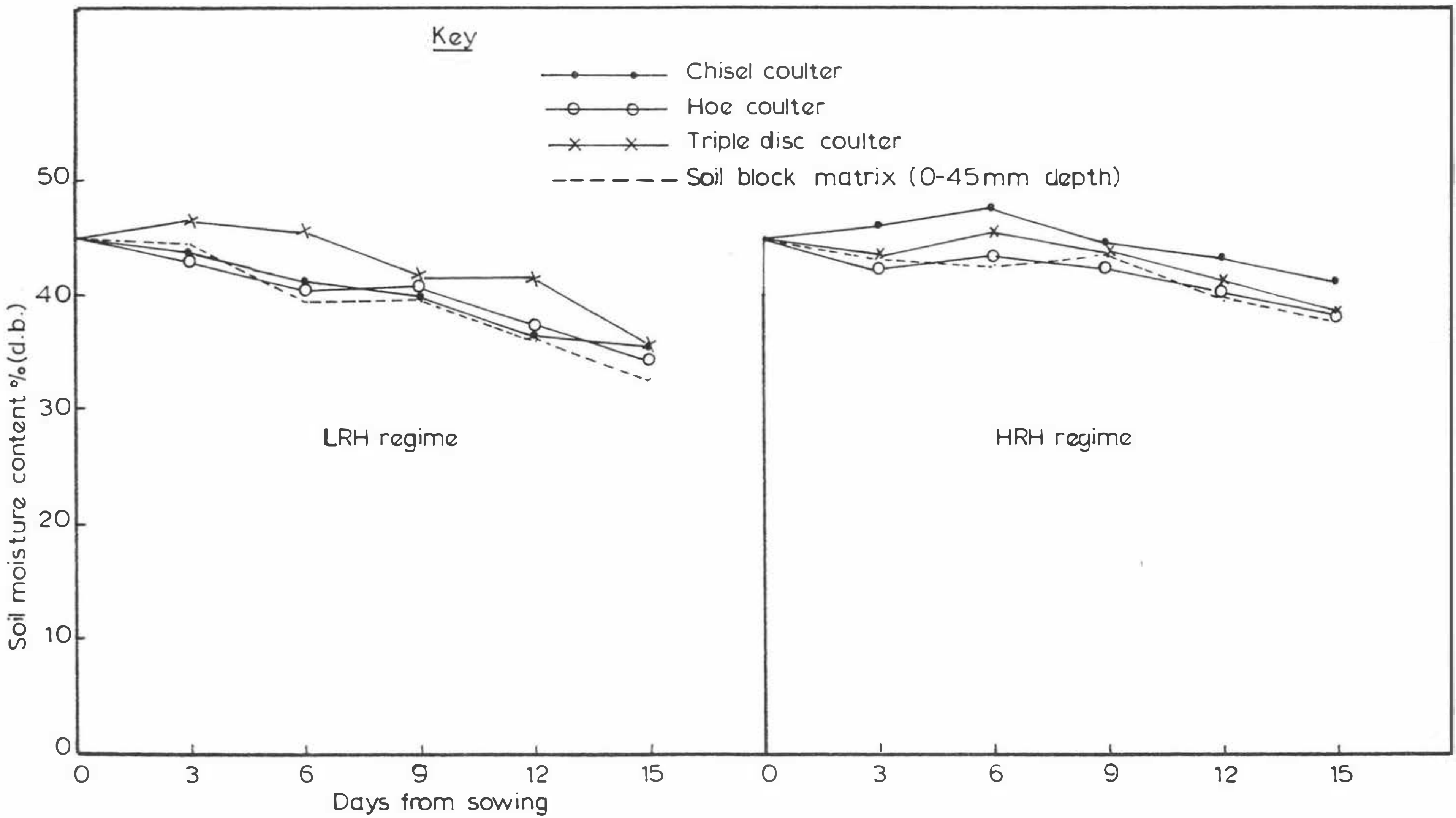


Figure 8. The effects of direct drilling coulter types and relative humidity regimes on in-groove liquid soil moisture content in an adequate soil moisture level (pressure over covered seed)

TABLE 12

The effects of relative humidity regimes and time on in-groove soil moisture content (of all coulter types).

Days from sowing	In-groove moisture content (% d.b.)				
	3	6	9	12	15
r.h. regimes					
LRH	44.5	39.5	39.8	36.0	32.6
HRH	43.9	42.7	43.8	39.7	38.0
level of significance (5%)	NS	NS	NS	NS	*

TABLE 13

The effects of coulter type and relative humidity regimes on in-groove soil temperatures following direct drilling

Treatment factors	Day-time in-groove temperature (C^o)	Night-time in-groove temperature (Co)
Time effect (days)		
4	19.0 a	17.7 l
7	19.9 a	17.8 l
10	19.6 a	17.6 l
13	19.8 a	17.7 l
Coulter type		
Chisel	19.3 a	17.6 l
Hoe	19.5 a	17.8 l
Triple disc	19.8 a	17.8 l
Relative humidity regimes		
LRH	18.8 b	17.3 l
HRH	20.3 a	18.2 m
Coulter type x relative humidity interaction	NS	NS

Unlike letters in a column show significant differences at (P = 0.05) temperatures. However the in-groove temperatures at all times were significantly (P = 0.01) lower than the controlled ambient temperature (22.0^{o}C).

There appeared to be no significant differences in the mean day-time in-groove temperatures due to coulter types. As stated earlier however, the mean day-time temperature of 19.5^{o}C was significantly lower than the controlled ambient temperature of 22.0^{o}C.

The contrasting relative humidity regimes had significant effect on the in-groove day-time temperatures. In the HRH regime, the day-time temperature (20.3^{o}C) was significantly (P = 0.05) higher than in the LRH regime (18.8^{o}C).

The interactions between coulter types and the relative humidity regimes were not significant.

Table 13 also shows the effects of coulter types and relative humidity regimes on the in-groove night-time temperature.
As with the day-time readings, there appeared to be no significant differences in the in-groove night-time temperature at any time during the experiment and the daytime readings were not unexpected, as the soil moisture contents remained high during the experimental period.

There also appeared to be no significant differences in the in-groove night temperature due to coulter types.

The contrasting relative humidity regimes appeared again to have a significant effect on the in-groove night-time temperatures. In the HRH regime, the in-groove night-time temperature (18.2^{o}C) was significantly (P = 0.05) higher than in the LRH regime (17.3^{o}C).

Brief summary of experiment 2(a)

At adequate initial soil moisture conditions, the seedling emergence was expected to be higher than in experiments 1(a) and 1(b). Any seed-soil contact variations due to applied pressures over the covered grooves appeared to be of no consequence. This confirmed the results of Hillel[7] who suggested that seed-soil contact was not of importance at high moisture potentials, as there was a continued supply of moisture in the liquid phase through unbroken capillary action. Germination counts of almost 100% of the seeds sown also indicated a plentiful and continuous moisture availability to the seeds. What was of concern however, was the continuing large count of "germinated but unemerged" seedlings in the triple disc grooves.

2.4.2 Experiment 2(b) Pressure applied directly over the seeds before covering

Objectives:

The objective of this study was to examine the effects of three coulter types and two relative humidity regimes on the seed fate of direct drilled wheat seeds in a soil with an adequate initial soil moisture regime. In contrast to experiment 2(a), the seeds were directly pressed before bar harrowing in this experiment. In all other respects experiment 2(b) was identical to experiment 2(a). The specifications and raw data of this experiment are given in appendix (7).

Results:

(a) Seedling emergence:

Table 14 shows the effects of the three coulter types, two relative humidity regimes, and three applied pressures over the uncovered seeds before bar harrowing, in terms of seedling emergence. The table shows that there were significant differences between coulter types. The chisel coulter (75.8%) promoted significantly (P = 0.01) more seedling emergence than did the triple disc coulter (37.8%). The hoe coulter (69.7%) also performed significantly (P = 0.01) better than the triple disc coulter in this respect, but there was no significant difference in performance between the chisel and hoe coulters.

The contrasting relative humidity regimes appeared to have no significant effects on the percentage seedling emergence, which averaged 60.9%.

The data from the sub-treatments shows that the applied pressure at the three intensities had no significant effects on seedling emergence.

There were no significant interactions between coulter types, relative humidity regimes and the applied pressure levels.

TABLE 14

The effects of coulter type, applied soil pressure over uncovered grooves and relative humidity levels on seedling emergence and the seed fate of the direct drilled wheat seeds in an adequate soil moisture regime

Treatment factors		Percent seedling emergence	Percent ungerminated seeds	Percent "germinated but unemerged" seeds
(a) main treatments				
Coulter type	Chisel	75.8 A	0	23.3 P
	Hoe	69.7 A	0	30.2 P
	Triple disc	37.8 B	0	62.1 Q
Relative humidity regimes	LRH	61.6 a	0	38.8 f
	HRH	60.6 a	0	38.3 f
Coulter type x r.h. regime interaction		NS	NS	NS
(b) Sub-treatments				
Pressure intensity	No pressure	58.8 a	0	41.1 p
	35 kPa	63.7 a	0	36.2 p
	70 kPa	60.8 a	0	38.3 p
Coulter type x pressure intensity interaction		NS	NS	NS
r.h. regimes x pressure interaction		NS	NS	NS

Unlike letters in a column show significant differences, Capitals (P =0.01), and small letters at (P=0.05).

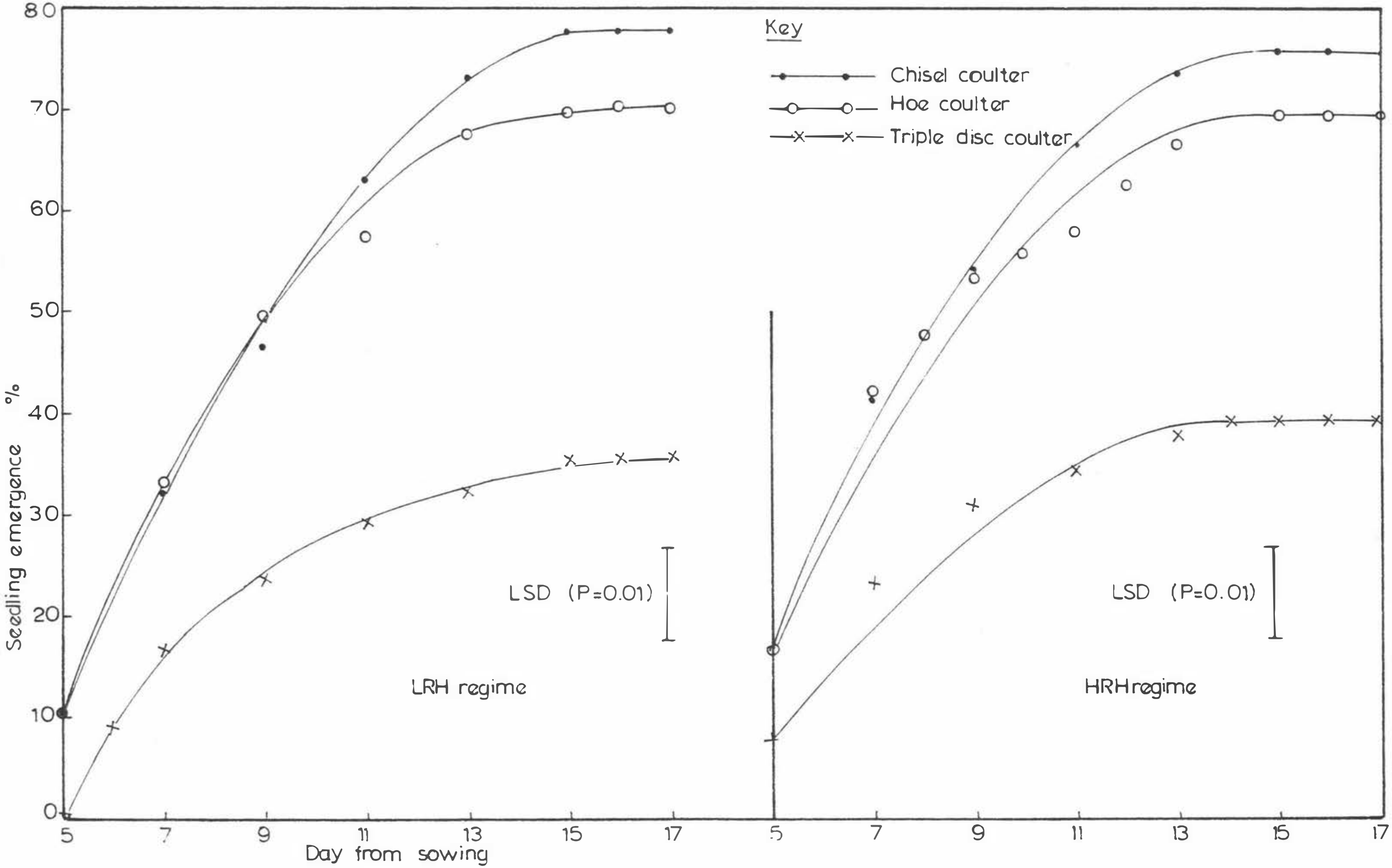


Figure 9(a,b) The effects of direct drilling coulter type and relative humidity regimes on the percentage rate of seedling emergence of wheat in an adequate soil moisture level (pressure over uncovered seed).

Figs. 9a & 9b show the rates of seedling emergence. The respective plateaus of percentage seedling emergence appear to occur on or about day 15 with all coulter types. The rate of seedling emergence with the chisel coulter appeared to be comparable with that of the hoe coulter until day 9 and thereafter the hoe coulter rate appeared to decrease somewhat. This pattern appeared to be repeated in both the LRH and HRH regimes.

(b) Ungerminated seeds

Table 14 also indicates that no seeds remained ungerminated during the experiment, with any of the coulter types. As in experiment 2(a) this was not unexpected as there was at all times, adequate soil moisture available for the seeds to germinate.

Similarly, no effects were noticed either due to the contrasting relative humidity regimes, or due to the three levels of applied pressures, as in all cases the number of ungerminated seeds was zero.

(c) "germinated but unemerged seeds"

Table 14 also shows the effects of the treatment factors on percent "germinated but unemerged" seeds. There appeared to be a significantly (P = 0.01) higher number of "germinated but unemerged" seeds in the grooves of the triple disc coulter (62.1%) compared with those in the chisel coulter (23.3%) and hoe coulter (30.2%) grooves, which were themselves not significantly different.

The contrasting relative humidity regimes appeared to have no significant effects on the number of "germinated but unemerged" seeds, with the mean at both relative humidity regimes being 38.5%.

The three levels of applied pressures apparently had no significant effects on the number of "germinated but unemerged" seeds. There were no significant interactions between coulter types, relative humidity regimes and applied pressures.

(d) In-groove soil moisture

The experiment started at an average soil moisture content of

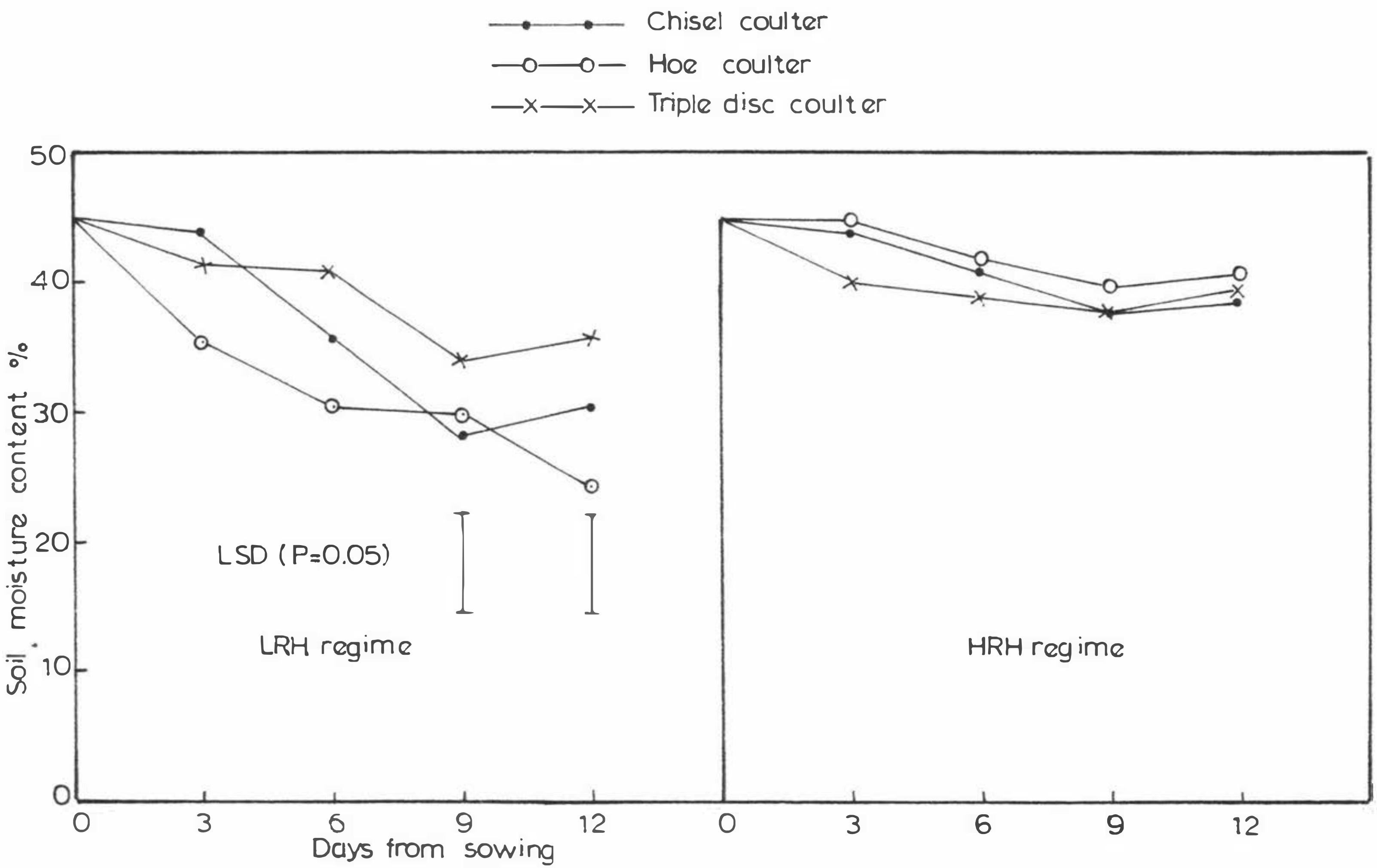


Figure 10. The effects of direct drilling coulter type and relative humidity regimes on in-groove liquid soil moisture content in an adequate soil moisture level (pressure over uncovered seed).

45.0%. Fig. 10 shows the in-groove soil moisture contents from day 3 to day 12 with the three coulter types and at the two relative humidity regimes. There appeared to be no significant differences in the in-groove soil moisture content between the three coulter types in the HRH regime. However, in the LRH regime there appeared to be significantly (P = 0.05) higher soil moisture content in the triple disc coulter grooves than in the chisel and hoe coulter grooves on day 9 until day 12 (the termination day).

Table 15 shows the effects of relative humidity regimes and the time on the in-groove soil moisture contents in all coulter types. There appeared to be lower levels of in-groove soil moisture in the LRH regime than in the HRH regime and this was significant (P = 0.05) on day 9 onward.

In this experiment in-groove temperatures were not measured, as previous experiments had shown that any such small differences which might occur had little or no effect on seedling emergence percent.

Visual appraisal of the emerged seedlings suggested that there were no marked differences in plant vigour or size between treatments. Dry matter yields were therefore not recorded in this experiment.

Summary

As in experiment 2(a), under an adequate moisture regime, the three coulter types gave higher seedling emergence counts compared with equivalent treatments in dry soils. In this experiment, pressure application over the uncovered grooves apparently had no significant effects on seedling emergence. Similarly, ambient climatic variations had no significant effects on emerging seedlings.

Plates (11a - 11f) show the general patterns of the seedling emergence with all coulter types both at the LRH and HRH regimes.

TABLE 15

The effects of relative humidity regimes and time on the in-groove soil moisture content

Days from sowing	In-groove soil moisture content % (d.b.)			
	3	6	9	12
Relative humidity regimes				
LRH	40.0	35.6	30.5	29.8
HRH	42.7	40.4	38.3	39.3
Level of significance (P = 0.05)	NS	NS	*	*

Plate 11. Typical direct drilled wheat seedling emergence pattern in initially adequate soil moisture (day 17); In the low relative humidity regime with the:

(a) chisel coulter (b) hoe coulter (c) triple disc coulter

Plate 11. Typical direct drilled wheat seedling emergence pattern in initially adequate soil moisture (day 17): In the high relative humidity regime with the:

(d) chisel coulter (e) hoe coulter (f) triple disc coulter

2.5 SUMMARY OF RESULTS AND CONCLUSIONS OF EXPERIMENTS 1 & 2

The results of 4 individual experiments (1a, 1b, 2a & 2b) were combined together to test the effects of initial soil moisture levels and the applied pressure positions in the main plot on seed fate of direct drilled wheat. Although each experiment was conducted in predictable and controlled climatic conditions, and all 12 turf blocks had been extracted from the field at the same time and stored under plastic rain canopies with controlled water supply, experimental conditions could not be regarded as identical. Since each of the 4 individual experiments was conducted at different times, combining the 4 experiments was expected to introduce unaccountable effects as a result of the changed parent vegetation, soil fauna activity, simulated grazing patterns, and ambient temperature regimes before drilling. In any pooled analysis it was not possible to extract such effects from the main treatment effects. However, from the results of previous experiments with these direct drilling coulters[56, 67], the main treatments were expected to exert the predominant effects, compared to those associated with the effects of time. It was therefore considered justified to combine these experiments to arrive at some general conclusions.

Detailed computational data of the pooled analysis of variance of the seed fate in this experiment are given in appendix (7d).

<u>Seedling emergence</u>

Table 16 shows the pooled effects of the main treatments (viz. initial soil moisture levels, and the position of applied pressures), the sub-treatments (relative humidity regimes and the three coulter types) and the sub-sub-treatments (intensities of applied pressures) on the seed fate of direct drilled wheat. From table 16 there appeared to be highly significant differences in seedling emergence between the low and adequate initial soil moisture levels.

Seedling emergence counts may have increased when pressures were applied directly over the uncovered seeds, compared to when pressures were applied over the covered seeds. This increase in seedling emergence however fell just short of statistical significance at the 5% level of probability, and was significant at $P = 0.10$.

TABLE 16

The effects of initial soil moisture levels, applied pressure positions, coulter types and relative humidity regimes on the seed fate of direct drilled wheat

Treatment factors	Percent seedling emergence	Percent ungerminated seeds	Percent "germinated but unemerged" seeds
(a) main treatments			
- initial soil			
moisture levels	33.7 B	27.5 D	39.0 L
low	59.9 A	0.1 E	39.0 L
adequate			
- applied pressure			
positions over			
covered seeds	42.3 A	18.2 D	39.1 L
over uncovered			
seeds	51.3 A	9.4 E	39.2 L
(b) Sub-treatments			
- relative humidity			
high	49.3 A	11.3 D	39.4 L
low	44.0 A	16.3 E	39.7 L
- coulter types			
chisel	63.5 A	9.2 D	27.3 L
hoe	50.6 B	23.4 E	26.0 M
triple disc	27.0 C	8.9 D	64.1 N
(c) sub-sub treatment			
pressure intensity			
0 kPa	42.4 B	16.8 D	39.8 L
35	48.6 A	12.2 E	39.3 LM
70	49.0 A	12.3 E	38.4 M

Unlike letters in a column show significant difference at (P = 0.01)

In the high relative humidity regime, the seedling emergence count was higher than in the low relative humidity regime but this difference too was significant only at a lower order of probability of P = 0.10.

Seedling emergence appeared to be significantly (P = 0.01) higher when the chisel coulter (63.5%) was used than when the hoe coulter (50.6%) and the triple disc coulter (27.0%) were used. The latter two treatments were also significantly different.

The analysis of variance of the sub-sub-plots showed that seedling emergence counts increased significantly (P = 0.01) when pressures were applied both at 35 and 70 kPa compared to those without pressure application. There were however no significant differences in seedling emergence counts between 35 and 70 kPa pressures.

Table 17 shows the interactions (initial soil moisture levels x coulter types and initial soil moisture levels x relative humidity regimes) from the pooled data. It appears that at the low initial soil moisture level, there were significant differences between all three coulters; with chisel coulter promoting the highest seedling emergence counts and the triple disc coulter giving the lowest seedling emergence. At the adequate soil moisture level, there appeared to be no significant differences in the seedling emergence counts between the chisel and hoe coulters. The triple disc coulter however promoted significantly (P = 0.01) lower seedling emergence compared to the chisel and hoe coulters.

Seedling emergence counts significantly increased (P = 0.05) when the controlled relative humidity regime was changed from LRH to HRH at the low initial soil moisture levels. At the adequate initial moisture regime, the contrasting relative humidity regimes had no significant effect on the number of emerged seedlings.

<u>Ungerminated seeds</u>

Table 16 also shows the treatment effects on the number of ungerminated seeds. The number of ungerminated seeds was significantly (P = 0.01) higher (27.5%) at the low initial soil moisture level than at the adequate initial soil moisture level. There was a

TABLE 17

The effects of initial soil moisture levels, coulter types and relative humidity regimes on seedling emergence percent (interactions)

Percent seedling emergence

	Initial soil moisture levels	
	Low	adequate
Coulter types		
Chisel	58.4 D	67.7 A
Hoe	31.3 E	69.8 A
Triple disc	10.5 F	42.0 B
Relative humidity regimes		
High r.h. (HRH)	38.6 Bb	59.6 Aa
Low r.h. (LRH)	28.2 Bc	60.0 Aa

Unlike letters in a column show significant differences, capitals (P = 0.01), small letters (P = 0.05).

negligible count of ungerminated seeds at the latter moisture level.

When pressures were applied directly over the seeds before covering, the number of ungerminated seeds was reduced significantly (P = 0.01) to 9.4% compared to 18.2% when pressures were applied over the covered seeds.

The contrasting relative humidity regimes had significant effects on the number of ungerminated seeds. In the HRH regime, the number of ungerminated seeds (11.3%) was significantly (P = 0.01) lower than those in the LRH regime (16.3%).

When pressures were not applied, the number of ungerminated seeds (16.8%) was significantly (P = 0.01) higher than at applied pressures of 35 and 70 kPa, which themselves were not different (12.3%).

Table 18 shows the treatment interactions, in terms of the number of ungerminated seeds. At the initially low soil moisture level, the number of ungerminated seeds resulting from pressure direction on the seeds was significantly (P = 0.01) less (by approximately 50%) than when pressure was applied over the covered seeds. The position of applied pressures had no significant effects on the number of ungerminated seeds when seeds were sown in the soil with initially adequate moisture, as the number of ungerminated seeds was almost zero in both cases.

The number of ungerminated seeds was significantly (P = 0.01) higher in the grooves of the hoe coulter (46.5%) compared to the chisel (18.2%) and triple disc (17.8%) coulter grooves which were themselves not different at the low soil moisture level. At the adequate soil moisture level however the differences between the three coulter types were not significant in terms of the number of ungerminated seeds, as the number in all grooves was almost zero.

From table 18, it appeared also that the number of ungerminated seeds decreased significantly (P = 0.01) from 33.4% at no pressure to an average of 24.3% at both 35 or 70 kPa pressure, at the low initial soil moisture. At the higher initial soil moisture level, the intensities of pressure application had no effect, as the number of the ungerminated seeds was again zero.

TABLE 18

The effects of initial soil moisture levels, positions of applied pressures, relative humidity regimes, coulter types, and pressure intensities on percent ungerminated seeds (interactions)

Percent Ungerminated Seeds

Treatment factors	Soil moisture regimes		Pressure positions		Coulter types			Relative humidity regimes	
Pressure positions	Low	Adequate	Over covered seed	Over uncovered seed	Chisel	Hoe	Triple disc	High	Low
over covered seed	36.2 A	0 C			11.8 C	29.4 A	13.5 D	15.3 B	21.1 A
Over uncovered seed	18.8 B	0.3 C			6.3 C	17.5 B	4.0 E	7.3 C	11.5 C
Coulter types									
Chisel	18.2 B	0 C						6.0 C	12.1 C
Hoe	46.5 A	0.4 C						19.6 B	27.3 A
Triple Disc	17.8 B	0 C						8.2 C	9.5 C
Pressure intensities (kPa)									
0	33.4 A	0.4 C	18.9 A	14.9 B	9.5 C	29.3 A	12.5 D		
35	24.0 B	0.4 C	17.8 A	6.5 C	9.1 C	20.2 B	7.5 E		NS
70	24.7 B	0.0 C	17.9 A	6.7 C	8.6 C	20.9 B	7.4 E		

Unlike letters in a column show significnat differences
(P = 0.01)

When pressures were applied over the covered seeds, the intensities of pressure (viz. 35 and 70 kPa) had no significant effects on the number of ungerminated seeds compared with no pressure. However, applied pressures of 35 or 70 kPa over the uncovered seeds decreased the number of ungerminated seeds significantly (P = 0.01), and equally; compared with no pressure.

The number of ungerminated seeds in the chisel coulter groove was not affected by applied pressures. The numbers of ungerminated seeds in the hoe and triple disc grooves were however significantly (P = 0.01) reduced at applied pressures of 35 and 70 kPa compared with those without pressure. The difference in the number of ungerminated seeds between 35 and 70 kPa pressures was not significant in either coulter groove.

Table 18 also shows that the number of ungerminated seeds was reduced significantly (P = 0.01) when pressures were applied directly over the uncovered seeds both in the hoe and triple disc coulter grooves compared to the applied pressures over the covered seeds. However the position of applied pressures had no significant effect on the number of ungerminated seeds in the chisel coulter groove.

The contrasting relative humidity regimes appeared to have had a significant effect on the number of ungerminated seeds in the hoe coulter grooves. The number of ungerminated seeds in the LRH regime was significantly (P = 0.01) lower than in the HRH regime. The contrasting relative humidity regimes had no effect on the number of ungerminated seeds in the grooves of the chisel and triple disc coulters.

Table 18 also shows that the interaction (r.h. regimes x pressure intensities) was not significant.

"Germinated but unemerged" seeds

Table 16 shows the effects of the treatment factors on the number of "germinated but unemerged" seeds. It appears that the number of "germinated but unemerged" seeds was not affected when the initial soil moisture level was decreased from adequate to low.

Similarly, applied pressures, either before covering or after covering of the seeds had no significant affect on the number of "germinated but unemerged" seeds.

The anlaysis of variance at the sub-treatment level showed that the contrasting relative humidity regimes had no significant effects on the "germinated but unemerged" seed counts.

The number of "germinated but unemerged" seeds in the triple disc coulter groove was highly significantly (P = 0.01) more than those in the chisel and hoe coulter grooves. The number of seeds in the same seed fate category was significantly (P = 0.01) higher in the chisel coulter groove than in the hoe coulter groove. The proportion of "germinated but unemerged" seeds was 39.8% when no pressures were applied. At 35 kPa pressure, the number of "germinated but unemerged" seeds was not significantly affected compared to that without pressure. The number was significantly (P = 0.01) reduced to 38.4% at 70 kPa pressure compared to that without pressure. There was no significant difference between 35 and 70 kPa, in terms of the number of "germinated but unemerged" seeds.

Table 19(a) shows the interactions, in terms of the "germinated but unemerged" seeds. The interaction (initial soil moisture regimes x position of applied pressures) was not significant.

With the triple disc coulter the number of "germinated but unemerged" seeds decreased significantly (P = 0.01) from 71.7% to 56.6% when the initial soil moisture level was changed from low to adequate. By contrast, the number of "germinated but unemerged" seeds in the chisel coulter and hoe coulter grooves increased significantly (P = 0.01), from 23.3% to 31.4% and from 22.2% to 29.8% respectively.

When pressures were applied directly over the uncovered seeds, the number of "germinated but unemerged" seeds was significantly (P = 0.01) more in the grooves of triple disc coulter, and less in the chisel and hoe coulter grooves, compared to the counts from applied pressures over the covered seeds in the same coulter grooves.

TABLE 19(a)

The effects of initial soil moisture levels, position of applied pressures, relative humidity regimes and coulter types on the "germinated but unemerged" seeds (interactions)

Position of applied pressure	Percent "germinated but unemerged" seeds					
	Initial soil moisture regimes		Position of applied pressure		Relative humidity regimes	
	Low	Adequate	Over covered seed	over uncovered seed	HRH	LRH
Over covered seeds	NS		-		40.1 A	38.1 B
over uncovered seeds					37.7 B	40.7 A
Coulter types						
chisel	23.3 E	31.4 D	28.2 E	26.5 D	26.9 C	27.9 C
hoe	22.2 E	29.8 D	27.7 E	24.3 D	27.1 C	24.9 D
triple disc	71.7 A	56.6 B	61.4 B	66.8 A	62.9 B	65.4 A

Unlike letters in a row show significant differences (P = 0.01)

In the low relative humidity regime, the number of "germinated but unemerged" seeds was significantly (P = 0.01) more in the triple disc coulter groove, and less in the hoe coulter groove compared to that in the HRH regime with the same coulter grooves. The contrasting relative humidity regimes, however, had no significant effect on the number of "germinated but unemerged" seeds in the chisel coulter grooves.

In the LRH regime, the number of "germinated but unemerged" seeds decreased significantly (P = 0.01) when pressures were applied over the covered seeds, compared to that in the HRH regime. When pressures were applied directly over the uncovered seeds, the number of "germinated but unemerged seeds" increased significantly (P = 0.01) more in the LRH regime than in the HRH regime.

Table 19(b) shows the interactions between treatments in the sub-sub-plots, in terms of the "germinated but unemerged" seeds. It appears that the number of "germinated but unemerged" seeds at the low initial soil moisture level increased significantly (P = 0.01) at 35 kPa pressure compared to no pressure, but decreased significantly at 70 kPa pressure compared to no pressure treatment. When the initial soil moisture level was adequate, the number of "germinated but unemerged" seeds decreased significantly (P = 0.01) at 35 kPa, compared to those at no pressure. However, the number increased again at 70 kPa to be equivalent to that at no pressure.

When pressures were applied over the covered grooves at 35 and 70 kPa, the number of "germinated but unemerged" seeds was not significantly different than that at no pressure. When 70 kPa pressure was applied over the uncovered seeds, the number of "germinated but unemerged" seeds decreased significantly (P = 0.01) compared to that at 35 kPa pressure, or without pressure; which were themselves not different.

In the HRH regime, the number of "germinated but unemerged" seeds decreased significantly (P = 0.01) at 70 kPa compared to that at 35 kPa or zero pressure, which themselves were not significantly different. In the LRH regime, in contrast to the HRH regime, the number of "germinated but unemerged" seeds increased significantly (P = 0.01) at 70 kPa compared with that at no pressure. The number at 35 kPa was not different than that at either 0 or 70 kPa.

TABLE 19(b)

The effects of coulter type, initial soil moisture levels, applied pressure positions, relative humidity regimes and pressure intensities on the percentage "germinated but unemerged" seeds. (Interactions)

Pressure intensities (kPa)	Initial soil moisture regimes		Pressure positions		Relative humidity		Coulter types		
	Low	Adequate	Over covered seeds	over uncoved seeds	HRH	LRH	Chisel	Hoe	Triple disc
0	38.7 B	41.0 A	39.1 D	40.6 D	41.2 M	38.5 L	28.0 R	25.9 S	65.7 Q
35	41.1 A	37.4 B	38.7 D	39.9 D	39.2 M	39.3 LM	25.5 S	28.4 R	63.9 P
70	37.3 B	39.4 A	39.6 D	37.2 E	36.4 L	40.3 M	28.6 R	23.8 T	62.7 P

Unlike letters in a column show significant differences (P = 0.01)

From table 19(b), it also appears that in the chisel coulter groove the number of "germinated but unemerged" seeds decreased significantly (P = 0.01) at 35 kPa compared to that at 0 and 70 kPa pressure, which themselves were not significantly different. In the hoe coulter groove, the number of "germinated but unemerged" seeds increased significantly (P = 0.01) at 35 kPa compared to 0 kPa. However, at 70 kPa the number again decreased significantly compared to both at 0 and 35 kPa. In the triple disc coulter groove the number of "germinated but unemerged" seeds was significantly (P = 0.01) higher at 0 kPa compared to that at 35 and 70 kPa, which themselves were not different.

For a fuller understanding of the treatment effects reference may be made to appendix (7d).

Discussion of main treatment effects

Most of the effects of the sub & sub-sub-treatments within the pooled analysis have been discussed within reports of the individual experiments, although some additional differences have been exposed because of the larger pool of data. Discussion will therefore be limited to the main pooled treatment differences and any additional sub-treatment differences thought to be relevant. In discussing the interactions, only the first order interactions are considered, as the second order interactions and above, were considered to be of doubtful value when interpreted within the objectives of the whole study.

It appears from table 16 that differences in seedling emergence between the two contrasting relative humidity regimes were significant at a lower order of probability of (P = 0.01). However, it is also apparent from the interactions (table 17) between the relative humidity regimes and initial soil moisture levels that seedling emergence significantly (P = 0.05) increased when the relative humidity regime was changed from LRH to HRH at the low initial soil moisture level. The contrasting relative humidity regimes had no effect on seedling emergence, on the other hand, when the initial soil moisture was adequate.

From table 16 it also appears that the overall magnitude of difference between seedling emergence counts for the chisel and triple disc coulters was two-fold. From table 17, it appears however that at the low initial soil moisture level, the difference in seedling emergence was six-fold with the same coulter types. In both situations, the hoe coulter performance was intermediate. This indicates that, in the available soil moisture range, the proportionate differences between the magnitudes of seedling emergence counts for the three coulter types (viz. chisel, hoe and triple disc) were indirectly related to the initial soil moisture level.

Table 18 shows that at the low initial soil moisture level, the number of ungerminated seeds in the hoe coulter groove (46.5%) was more than twice that in the chisel and triple disc coulter grooves. At the same time, the number of "germinated but unemerged" seeds (table 19 a) in the triple disc coulter groove was more than three times that in the chisel and hoe coulter grooves at similar soil moisture levels. When the initial soil moisture level was increased there was almost 100% seed germination with all coulters.

Because the data presented throughout this report for the seed fate category of "germinated but unemerged" seedlings are expressed as percentages of the total numbers of seed sown, it is difficult to obtain realistic comparisons between the fates of germinated seeds when differences in initial soil moisture levels had already altered the germination patterns in this manner within the grooves. Table 20 therefore lists pooled counts of the numbers of unemerged seedlings, expressed as percentages of the germinated seeds within the main treatments of initial soil moisture level, and sub-treatments of coulter types. Table (20) is compiled from data presented in tables 18 and 19(a).

TABLE 20

The effects of coulter type, initial soil moisture levels and position of applied pressures on unemerged seedlings; as a percentage of germinated seeds (interactions)

	Unemerged seedlings (percentage of germinated seeds) Coulter type		
Soil moisture levels	Chisel	Hoe	Triple disc
Low	28.4	41.5	87.2
Adequate	31.4	29.9	56.6
Level of significance	NS	*	**
Position of applied Pressures			
Over covered seeds	31.9	39.2	71.0
Over uncovered seeds	28.3	29.5	69.6
Level of significance	NS	*	NS

Table (20) indicates that the inability of seedlings to emerge after germination was affected by both the initial soil moisture level and the coulter type. The chisel coulter appeared to be insensitive to initial soil moisture level in this respect. The triple disc coulter was clearly significantly (P = 0.01) sensitive of the three coulter types, in this respect, while the hoe coulter sensitivity was intermediate between the triple disc and chisel coulters.

Table 18 also shows that when pressures were applied directly over the uncovered seed, the number of ungerminated seeds decreased compared to when pressure was applied over the covered seeds with all coulter types. Table (20) also lists pooled counts of the numbers of ungerminated seedlings, expressed as percentage of the germinated seeds within the main treatments of the position of applied pressure and the sub-treatments of coulter types.

From table (20) it appears that the hoe coulter was the most sensitive to the positioning of the pressure in terms of assisting the germinated seedlings to emerge. The proportion of germinated seed which became unemerged seedlings fell significantly (P = 0.05) from 39.2% to 29.5% (a difference of 9.7%) with this coulter, while the reductions with the chisel and triple disc coulters were considerably less (3.6%) and 1.4% respectively) and were not significant.

Summary of other parameters in experiments 1 & 2

Herbage dry matter yield:

The herbage dry matter yields of the wheat seedlings harvested at day 18 suggested that at the low initial soil moisture level, the hoe coulter had promoted significantly lower yields/plant compared to the chisel and triple disc coulters, which themselves were not significantly different. At the adequate initial soil moisture level, there appeared to be no significant differences in the dry matter yields between the three coulter types. The herbage dry matter yields per 100 seeds sown generally reflected the seedling emergence patterns of each coulter type.

Soil impedence measurements:

The penetrometer studies, employing a simulated "mechanical seedling", showed that impedence *per se* in these experiments was in a range which was not expected to have significant effects on true emergence. Thus, no comparisons were made using the pooled data.

In-groove soil moisture:

At the low initial soil moisture level, the in-groove liquid soil moisture loss curves showed significantly (P = 0.05) higher moisture losses in the LRH regime than that in the HRH regime. This was most noticeable after day 9. Liquid moisture losses usually tended to be higher in the hoe coulter grooves compared to the chisel and triple disc coulter grooves which may have accounted for the comparatively high percentage of ungerminated seed with the hoe coulter.

At the adequate soil moisture level, the in-groove liquid soil moisture loss curves (fig. 8 & 10) suggested that there were no significant differences between coulter types.

In-groove soil temperature:

There appeared to be a steady increase in soil in-groove temperature with time in all coulter grooves. This appeared to reflect in the main, the decreasing soil liquid moisture content data.

Fig. 11 shows the percentages of seedling emergence, ungerminated seeds and "germinated but unemerged" seeds in a series of histograms, as a function of coulter types, initial soil moisture levels, and the positions and intensities of applied pressures in the HRH regime. The data in fig. 11 are discussed above and are presented in tables 16, 17, 18, 19, & 20. The figure, however, is presented in summary and as a more rapid reflection of the trends of the pooled data.

Conclusions

The results from experiments 1 & 2 confirm the earlier results of Baker(38) conducted in partially controlled ambient conditions. Furthermore the effects of coulter types on the components of seed fate

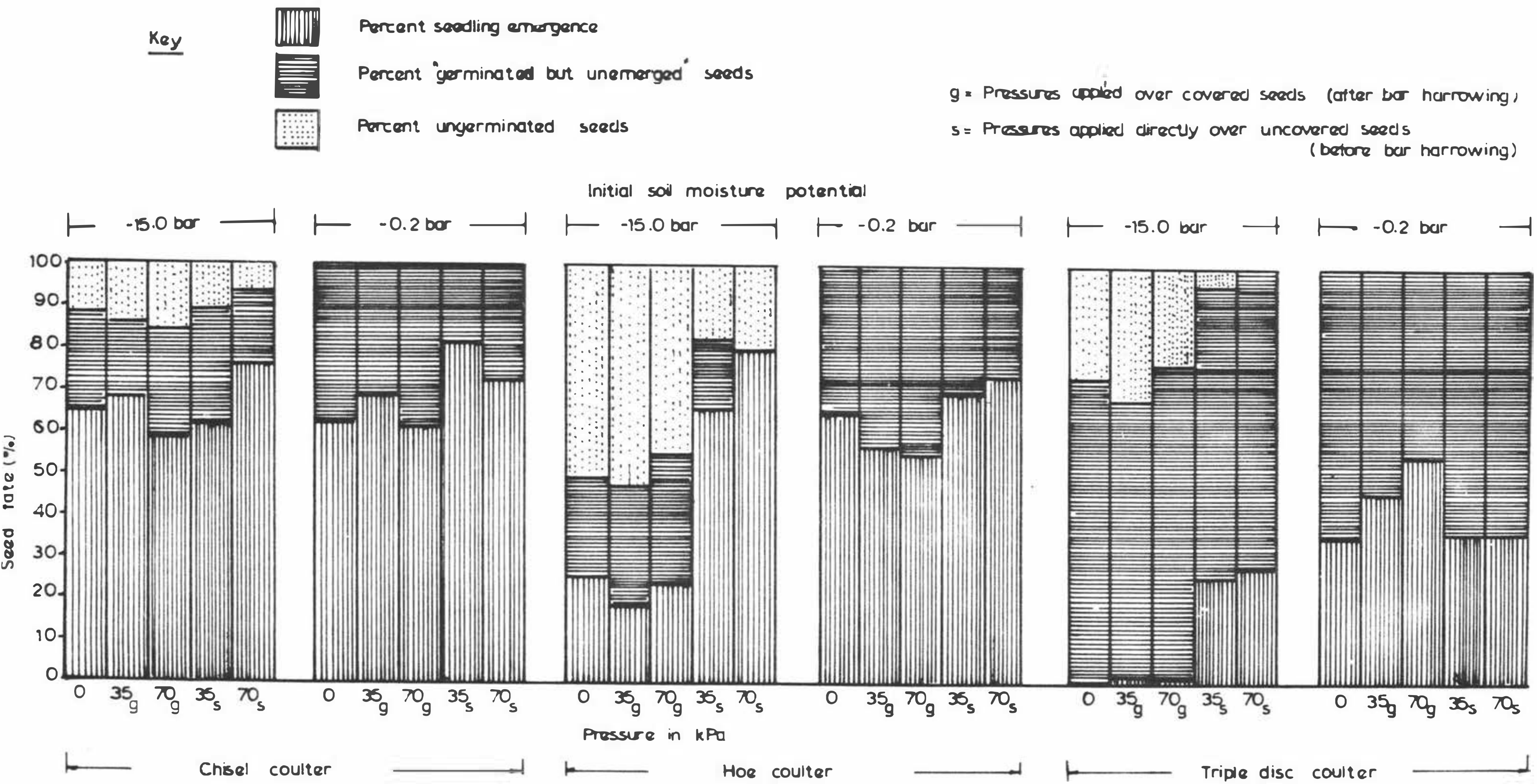


Fig.11 The effects of initial soil moisture regimes, coulter types and applied pressure intensities in the high relative humidity regime on the fate of direct drilled wheat seeds.

are also in broad agreement with these earlier experiments. It appears that when seeds were sown under adequate initial soil moisture conditions, both the chisel coulter and the hoe coulter could be expected to give equal seedling emergence performances. The triple disc coulter, even under these favourable conditions, did not perform well in terms of seedling establishment.

In the drier soil, seedling emergence from grooves created by the experimental chisel coulter was significantly superior to both the hoe and triple coulters. In these dry soils, the performance of hoe coulter was improved to equivalent to that of the chisel coulter by incorporating a press wheel which pressed the seeds directly into the base of the groove before bar harrowing. Similarly, the performance of the triple disc coulter was improved to some extent by providing a press wheel which pressed the seeds into the base of the groove before covering. This latter coulter appeared to require a different form of covering, in addition to the press wheels, to improve its performance to close to that of the chisel or hoe coulter assemblies. Clearly further work was required to determine the causes of the differences reported in experiments 1 & 2.

The following hypotheses are put forward, if not to define the measured effects, at least to pinpoint the areas which might be the subject of further experiments within this investigation.

(I) "Mositure Potential Captivity"

It appears logical that a higher "moisture potential captivity" in the seed zone was at least partly responsible for the significantly larger seedling emergence counts with the chisel coulter; and conversely the lower counts with the hoe and triple disc coulters in dry soils. The contrasting physical shapes of the grooves suggest that while the chisel coulter grooves may not have been any more capable than the hoe and triple disc coulters of retaining moisture in the liquid form it may have been more capable of retaining soil moisture in the vapour phase. This appeared to be because of the dominance of the mulch material in the covering medium as first suggested by Baker [(67)].

(II) "Moisture Potential Diffusion"

The hypothesis of "moisture potential diffusion" suggests that an increased area of seed-soil contact which seems to have been induced by pressing the seeds into the bases of the "V" shaped grooves, might have been responsible for an increased initial supply and subsequent availability of liquid soil moisture to the seeds, which ultimately resulted in increased seed germination and to a lesser extent seedling emergence. This appeared to be the case with the triple disc coulter and was also noticeable with the hoe coulter design, although to a lesser extent than with the triple disc. In the hoe coulter groove, because of the improved seed-soil contact after passage of the press wheels, and the loose soil cover over the top of the seeds after passage of the bar harrow, it is possible that both "moisture diffusion" and "moisture potential captivity" at the seed-soil interface were improved. Without these post drilling improvements the poorer seed-soil contact and inadequate seed cover (containing more air voids) of the hoe coulter groove at the seed zone appeared to be subjected to a high moisture stress, and resulted in desiccation of the seed-soil interface at an early stage after drilling. This resulted in a high percentage of ungerminated seeds. With the triple disc coulter there appeared to be plentiful moisture available in the liquid phase to promote seed germination in the unmodified grooves, as the seeds appeared to be wedged in a moist layer at the base of a "V" shaped groove. Subsequently however, these seeds appeared to be subjected to a lower "moisture potential captivity" and high rates of sub-surface seedling mortality resulted. Because of the neatly cut nature of the triple disc grooves, the bar harrow was only partially effective in scuffing loose soil or rubble into the grooves, to afford some degree of cover.

(III) The exposed internal groove surfaces of the triple disc grooves resulted in the appearance of a thin dry layer of soil on the groove wall surfaces a few days after drilling. This may have subjected the seeds to a lower "moisture potential diffusion "from the soil to the seed interface some time after implantation and imbibition. The end result appeared to be the initiation of a "moisture desorption process" away from the imbibed seeds which may also have contributed to the higher seedling mortality rate with the triple disc coulter.

The hypotheses put forward above might be only first approximations but appear to justify further studies to investigate their validity and to possibly quantify the important interactions involved. For this reason a study was initiated to further examine the reasons underlying the failure of the triple disc coulter, or conversely, the success of chisel coulter. It was considered important to attempt to further improve the performance of the triple disc coulter and thereby to note the steps taken in achieving this. The results of these experiments are reported in experiment 3.

CHAPTER 3

STUDY OF LIMITING FACTORS CAUSING SEEDLING EMERGENCE FAILURE IN SMALL UNDISTURBED TURF BLOCKS

3.1 INTRODUCTION

In earlier experiments the triple disc coulter appeared not to have performed well in terms of seedling emergence. In drier soils the seedling emergence from the grooves created by this coulter was almost negligible, although this was significantly improved when a pressure of 70 kPa was applied over the direct drilled seeds before covering.

Experiments were therefore performed to test a number of different modifications to the triple disc groove which might be expected to improve its ability to encourage seedling emergence. A large number of treatments were used. These included combinations of soil and other forms of cover and pressure applied over grooves either cut with a hand-drawn knife (to avoid smearing), or drawn by a triple disc coulter assembly. Details of treatments are given in the description of the 3 individual experiments.

In-groove soil liquid moisture content was monitored to gain an insight into the effects of ambient conditions on in-groove soil drying rates, and in turn the effects of these parameters on seed germination and seedling emergence.

3.2 MATERIALS AND METHODS

Undisturbed turf blocks (measuring 457 mm long x 304 mm wide and 100 mm deep) were collected from a "Rangitikei sandy loam" soil. Wooden boxes were used for this purpose. The undisturbed soil blocks were extracted by using a specially designed turf cutting frame. This frame was pushed vertically into the soil. A spade was used to dig away the surrounding area and the soil blocks were carefully uplifted. The broken underside of the soil blocks were trimmed flush with the underside of the boxes. The soil blocks were transported to the laboratory and were treated in the same manner as the larger tillage bins (described earlier) for their moisture stabilization. The soil moisture level was brought to approximately -15 bars before drilling. The soil blocks were then "drilled" with wheat seed and transported to the climate rooms.

The climate rooms were pre-set to 20/18°C temperature and 55/60% r.h. day/night. The purpose of subjecting the turf blocks to moisture stress conditions was that it had become apparent that these were the limiting conditions under which seedling emergence failed. In earlier experiments under more humid conditions there were smaller differences between the three coulter types in terms of seedling emergence. The largest differences in coulter performances were found under moisture conditions near -15 bars.

The soil blocks remained in the climate rooms (Plate 12a) until seedling emergence counts had stabilized. Seeds were implanted singly by hand in all the treatments.

3.3 EXPERIMENT 3: (PILOT EXPERIMENT) THE EFFECTS OF COULTER DESIGN, COVERING AND PRESSING TECHNIQUES ON SEEDLING EMERGENCE AND SEED FATE.

Objectives:

Initially an unreplicated pilot trial was conducted which was expected to test the feasibility of using small turf blocks for this purpose, and to indicate the importance of seed placement in relation to the rate of drying of the groove walls. The treatments were as follows:

(i) Seeds sown immediately after forming the grooves
(ii) Seeds sown 12 hours after forming the grooves
(iii) " " 24 " " " " "
(iv) " " 36 " " " " "
(v) " " 48 " " " " "
(vi) Seeds sown and covered with loose soil
(vii) Seeds covered with loose soil and followed by pressing on the top of the groove at 70 kPa.
(ix) Uncovered seed directly pressed in^to the base of the groove

at 70 kPa and covered with loose soil

(xi) Seeds drilled and covered with clear polythene.

In each treatment 20 seeds were sown. In later experiments some of these treatments were eliminated.

Results and Discussion

The unreplicated seedling emergence counts from this pilot trial suggested that seedling emergence had been almost zero when seeds were sown in the absence of any type of cover. Seeds sown at various time lapses after forming the grooves apparently suffered in that their rates of moisture imbibition were progressively slower as the time interval increased. Seedling emergence appeared to be improved from 0 to 30% in the triple disc grooves when pressures were applied directly over the seed at 70 kPa. Similar results occurred when seed was pressed and then covered with loose soil. Seedling emergence appeared also to be improved when grooves were covered with clear polythene, compared with no cover.

It was apparent from these results that more detailed work was justified to attempt to more fully record and understand the processes of soil moisture availability to the seeds direct drilled using a triple disc coulter.

3.4 EXPERIMENT 4: THE EFFECTS OF COULTER DESIGN AND PRESSING AND COVERING TECHNIQUES ON SEEDLING EMERGENCE AND SEED FATE.

3.4.1 Experiment 4(a) Coulter design and selected pressing and covering techniques

Objectives:

In this main experiment the following treatments were tested in an effort to isolate the effects of smear, soil-seed contact, and cover on seedling emergence and soil moisture drying rates.

(A) Simulated triple disc coulter "V" shaped grooves cut with a knife (no smear)

(i) Seed placed in the grooves, but no cover or pressure applied.

(ii) Unpressed seed, covered with loose soil

(iii) Seed pressed directly into the base of the groove at 70 kPa

(iv) Unpressed seed, covered with clear polythene.

(B) Grooves formed by triple disc coulter

(i) Seed placed in the grooves, but no cover or pressure applied

(ii) Unpressed seed, covered with loose soil

(iii) Seed pressed directly into the base of the groove at 70 kPa

(iv) Unpressed seed, covered with clear polythene.

The experiment was a completely randomised block design with three replicates. In each treatment 20 seeds were sown. Gravimetric matrix (undisturbed soil between grooves) soil liquid moisture was determined using a core sampler. Specifications and raw data are given in appendix 8.

Results and Discussion

(a) Seedling emergence and seed fate:

Table 21 shows the seedling emergence and seed fate data in experiment 4(a). From the table it appears that when seeds had been sown in the grooves made either by a hand-drawn knife or the triple disc coulter itself little or no seedling emergence was apparent where the grooves were uncovered or covered with loose soil.

Seedling emergence was significantly increased (P = 0.01) to 23.3% and 18.3% respectively in both the knife cut grooves and the grooves formed by the triple disc coulter, when the seeds were pressed into the groove base at 70 kPa. These results confirmed those obtained in the tillage bin experiments. There was no significant difference between the methods of groove formation in terms of seedling emergence.

When the turf was covered with transparent polythene, seedling emergence with both groove formation methods was increased significantly (P = 0.01) compared to those with no cover. There were however, no significant differences between polythene covering and when seeds were pressed at 70kPa.

TABLE 21

The effects of seed drilling and covering techniques on the seedling emergence and fate of direct drilled wheat seeds

Treatments	Emergence %	Germinated but unemerged seeds % (Dead + viable)	Germinated but unemerged seeds % Total	Ungerminated seeds %
(A) Knife cut sloped groove				
(i) No cover	2.5 A	(22.4 + 10.4)	32.8 R	64.6 L
(ii) Loose soil cover	6.6 A	(37.8 + 53.5)	91.3 Q	2.0 K
(iii) Seed pressure at 70 kPa	23.3 B	(39.1 + 16.9)	56.0 R	20.6 N
(iv) Polythene cover	35.8 BC	(38.7 + 23.6)	62.3 Q	2.8 K
(B) Triple disc groove				
(i) No cover	0 D	(2.6 + 3.8)	6.4 S	93.5 M
(ii) Loose soil cover	0 D	(60.2 + 13.6)	73.8 Q	27.8 N
(iii) Seed pressed at 70 kPa	18.3 B	(32.6 + 6.6)	39.2 R	42.4 N
(iv) Polythene cover	38.5 BC	(36.6 + 19.8)	56.4 R	4.4 K

Unlike letters in a column show significant differences at (P = 0.01)

Plates (12b to 12g) illustrate respective grooves and the pattern of seedling emergence.

Table 21 also shows the seed fate counts in both types of grooves. When the seeds were uncovered, there appeared to be a significantly higher (P = 0.01) percentage of ungerminated seeds when the triple disc coulter was used compared to the knife-cut grooves. This difference, however, was mirrored in the corresponding number of "germinated but unemerged" seeds which were 32.8% in the knife cut grooves and 6.4% with the triple disc coulter.

When loose soil cover was provided over the seeds the percentage of "germinated but unemerged" seeds was significantly increased (P = 0.01) to 91.3% with the knife cut grooves and 73.8% with the triple disc coulter, while the number of ungerminated seeds declined especially in the knife cut grooves. This suggested that loose soil cover was probably able to maintain higher soil moisture potential initially to allow the seeds to germinate. This was more so in the knife cut groove where for some reason, the seeds were apparently able to exploit the soil moisture from the interior sub-surface at the groove base.

A further examination of the seeds in "germinated but unemerged" category was made by irrigating the recovered seeds and seedling. The collection of this data was inadvertently pooled across all replicates and could not therefore be statistically analysed. The data suggested however that there were larger numbers of viable seedlings in the knife cut grooves compared to the grooves formed by the triple disc coulter. In the absence of irrigation, and where seeds had been pressed at 70 kPa, there appeared to be a larger proportion of ungerminated seeds (42.4%) in the triple disc formed grooves compared to 20.6% in the knife cut grooves. This difference was also reflected in higher seedling emergence data in both cases. When the polythene cover was provided on the knife cut grooves, there was a significantly (P = 0.01) larger proportion of "germinated but unemerged" seed (52.3%) compared to 2.8% ungerminated seeds. A similar observation was made in the triple disc coulter grooves.

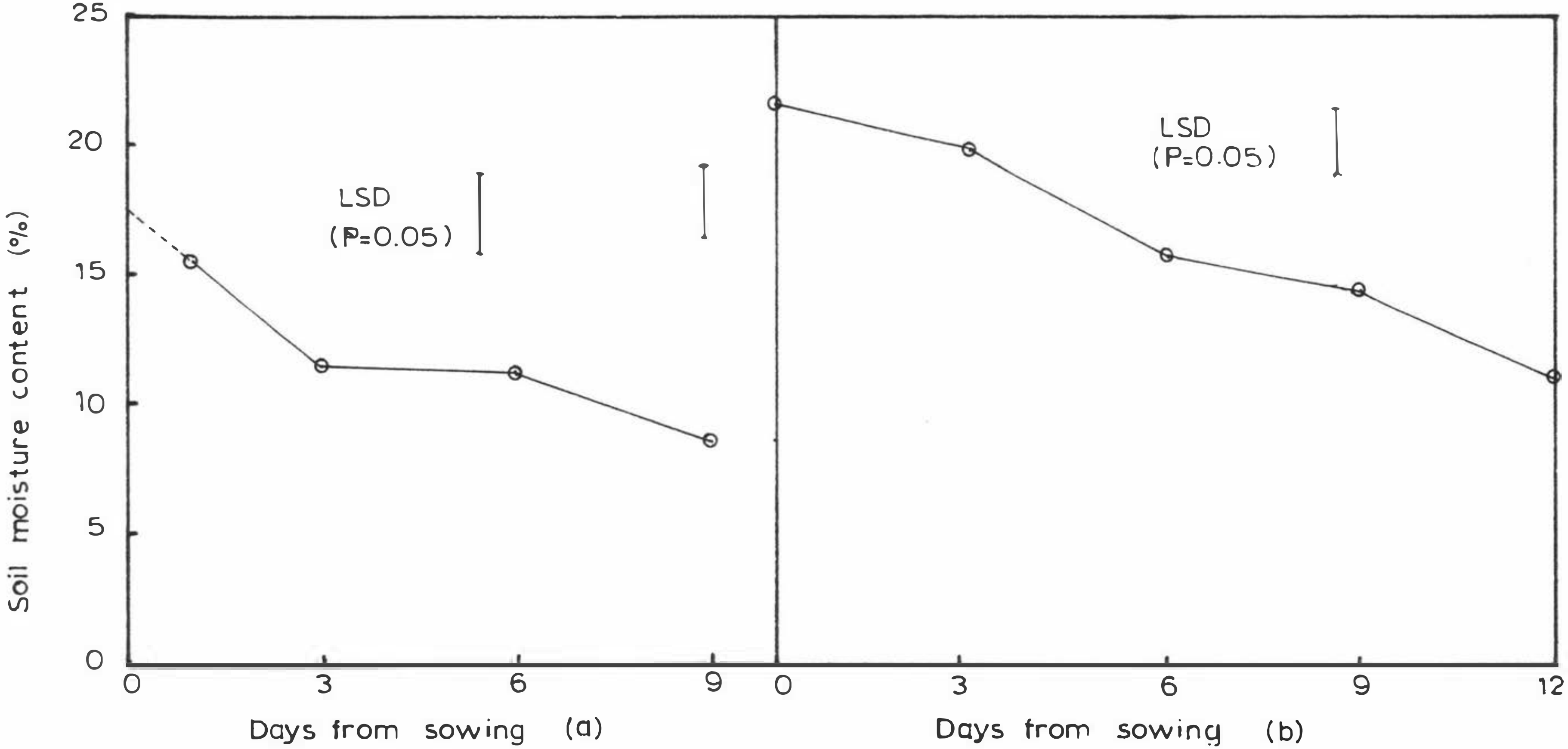


Figure 12. The effects of ambient conditions and time on soil moisture content.

Plate 12 Typical seedling emergence pattern in initially dry soil on day 17;

(a) General view of small undisturbed soil blocks in a climate room

(b) The hand-drawn knife cut grooves without cover and pressure (note no seed germination/emergence).

(c) The triple disc coulter groove without cover and pressure (note no seed germination/emergence).

Plate 12. Typical seedling emergence pattern in initially dry soil on day 17:

(d) The hand-drawn knife cut groove with 70 kPa pressure directly over seed

(e) The triple disc coulter groove with 70 kPa pressure directly over seed.

(f) Both the hand-drawn knife cut and Triple disc coulter grooves covered with clear polythene

(b) Soil moisture content

The initial soil moisture content at the start of the experiment was at 15.5% (d.b.). The matrix liquid soil moisture contents and their drying rates are shown in Fig 12a. The figure shows that a significant (P = 0.05) loss of soil moisture had occurred by day 3 compared to that on day 1. Liquid soil moisture fell gradually after that and by day 9 the moisture content was down to 8.7%

3.4.2 Experiment 4(b): Promising selected coulter designs, Pressing and covering techniques

Objectives:

The results from experiment 4(a) were encouraging in terms of seedling emergence when covering and pressure treatments were applied. It was possible also that portions of the dry soil surface might have been pushed into the base of the triple disc formed grooves, creating an overlay on the more moist interior of the grooves. This was thought to have been a possible cause of the generally larger number of ungerminated seeds in these treatments. It was therefore considered desirable to clear some of the grooves of this dry soil using a domestic vacuum cleaner. A larger number of seeds (40) were sown per treatment to increase the sampling accuracy of the results and the replicate number was increased to 4 in a completely randomised block design.

The treatments were as follows:

(A) Simulated triple disc coulter "V" shaped grooves cut with a knife (no smear).
   - (i) Seed placed in the grooves, but no cover or pressure applied.
   - (ii) Seed pressed directly into the base of groove at 70 kPa.
   - (iii) Unpressed seed covered with loose soil.
   - (iv) Unpressed seed covered with clear polythene.

(B) Grooves drawn by triple disc coulter

(i) Seed placed in the grooves, but no cover or pressure applied.

(ii) Seed placed in the grooves, cleared of loose soil using a domestic vacuum cleaner.

(iii) Grooves cleared of loose soil, and seed pressed directly into the base of the groove at 70 kPa.

(iv) Seed placed in the grooves as in (i) and followed by pressure at 70 kPa.

(v) Unpressed seed covered with loose soil.

(vi) Unpressed seed, covered with clear polythene.

Similar measurements were used as in experiment 4(a).

Results:

Table 22 shows the final (day 17) seedling emergence counts. From the table similar trends as were described in experiment 4(a) were apparent. There appeared to be negligible seedling emergence in the uncovered grooves and those covered with loose soil for both the knife-cut grooves and those formed by the triple disc coulter. Seedling emergence increased significantly in both types of grooves when the seeds were pressed directly at 70 kPa or covered with polythene but there were no significant differences in seedling emergence between the two types of grooves, nor between the triple disc grooves cleared of dry soil, or left intact. The seed fate was not determined in this experiment.

Discussion of Experiments 3, 4a, and 4b

The seedling emergence and seed fate patterns observed in experiments (3, 4a and 4b) were similar to those obtained in the tillage bin experiments with the triple disc coulter. With both the knife cut grooves and those formed by the triple disc coulter, there appeared to be no significant differences in seedling emergence, in the absence of any form of groove cover. This suggests that either such localised smearing and/or compaction which had occurred with the triple disc coulter and which was absent from the knife cut grooves, were not directly responsible for seedling emergence in dry soils, or no such smearing and/or compaction had occurred.

TABLE 22

The effects of groove formation and seed covering techniques on seedling emergence

Treatments	Seedling emergence %	
(A) Simulated triple disc coulter "V" shaped grooves cut with a knife (no smear)		
(i) Seed placed in the grooves but no cover or pressure applied	0	B
(ii) Seed pressed directly into the base of groove at 70 kPa	35.0	A
(iii) Unpressed seed covered with loose soil	2.5	B
(iv) Unpressed seed covered with clear polythene	24.3	A
(B) Grooves drawn by triple disc coulter		
(i) Seed placed in the grooves, but no cover or pressure applied	3.7	B
(ii) Seed placed in the grooves, cleared of loose soil using a domestic vacuum cleaner	0	B
(iii) Grooves cleared of loose soil, and seed pressed directly into the base of the grooves at 70 kPa.	30.0	A
(iv) Seed placed in the grooves as in (i) and followed by pressure at 70 kPa	32.5	A
(v) Unpressed seed covered with loose soil	0	B
(vi) Unpressed seed, covered with clear polythene	20.6	A

Unlike letters show significant difference at (P = 0.01)

Later, this was supported by work reported by Mai[56], who did not detect any measured smearing effects of the triple disc coulter in "Tokomaru silt loam" soil at soil moisture contents less than 25%, although compaction had occurred at higher soil moisture levels.

When a loose soil cover was provided over the grooves, there was some seedling emergence evident but a large and significant proportion of seeds had germinated but had not emerged. This implies that the improved seed cover may have helped to maintain higher moisture potential at the seed-soil interface, but that these grooves were not able to sustain a high enough moisture potential during the sub-surface seedling development period. The roots had possibly not been able to penetrate and establish themselves in the lower and more moist regions of the soil surrounding the groove during this period. This possibility appeared to be particularly pronounced in the grooves formed by the triple disc coulter where a larger proportion of "germinated but unemerged" (dead) seedlings were recovered than from the knife cut grooves. It was thought that, the triple disc coulter with its cutting and wedging action, had carried down drier soil from the surface into the base of the grooves. In the generally dry soil moisture regime this might have resulted in the soil-seed interface being at a lower moisture potential than that of the knife-cut grooves. Although some support of this hypothesis was suggested by the higher proportion (53.5%) of viable seedlings in "germinated but unemerged" category, in the knife cut grooves compared to the grooves formed by the triple disc coulter (13.6%). The removal of this dry soil in experiment 4(b) did not improve the emergence performance. No firm conclusions on this aspect can therefore be made at this stage. Seedling emergence improved significantly ($P = 0.01$) both in the knife cut grooves (to 32.5%) and in the grooves formed by the triple disc coulter (to 35.0%), when the seeds were pressed into the base of the grooves. These increases support the hypothesis of the importance of an "improved moisture diffusion" by improving contact at the soil seed interface. When the grooves were covered with transparent polythene, the seedling emergence percentage increased to levels comparable to those obtained by applied pressures directly over the seeds. The polythene cover was expected to maintain 100% relative humidity within the groove. Indeed condensation of moisture was apparent on the inner surfaces of the polythene and there was almost 100% seed germination which supported the belief of a high moisture potential availability. However unexpectedly high percentages of "germinated but unemerged" seeds (62% in the knife cut, and 56% in the triple disc grooves) were observed under the polythene. In the presence of an apparently high in-groove relative humidity, higher percentages of seedling emergence were expected. There appeared to be no simple explanation for the decline in seedling emergence from the polythene covered grooves. The fact that of the unemerged seedling 37% were dead suggests that the environment, although moist, was also anaerobic and this supported other harmful phenomena, perhaps associated with fungi.

3.5 CONCLUSIONS AND RESEARCH PRIORITIES

This study was able to confirm in more detail earlier results obtained in experiments 1a and 1b. These results also strengthened the view that there was no harmful smearing and/or compaction at the seed-soil interface from the use of the triple disc coulter in dry soils. The hypothesis that an "improved moisture diffusion" occurred in the liquid and/or vapour phase, when seeds were pressed into the base of the grooves, was given added credibility. This also implied, however, that in order to quantify the relationships between seedling emergence and the mechanism of soil moisture availability to the seed, a parallel laboratory study of wheat seed moisture iso therms would first be required.

From the above study it was also apparent that the nature of the seed cover was important in improving the "moisture potential captivity" in the seed-soil interface, which in turn might have had an effect on seedling emergence. The study has so far been unable to measure the seed-soil interface moisture potential and the quantitative effects of this parameter on seedling emergence performance. Further experimental investigation was therefore felt to be justified and is described in the following section.

CHAPTER 4

STUDY OF THE GERMINATION OF WHEAT SEEDS UNDER CONTROLLED CONDITIONS

4.1 INTRODUCTION

In earlier experiments it appeared that under dry soil and ambient conditions, moisture supply to the seed was an important limiting factor. It was repeatedly demonstrated that seed germination and seedling emergence could be improved by:

(a) Providing a stubble mulch cover over the seed, as with the chisel coulter.

(b) Applying pressure directly over the seed in the groove formed by triple disc and hoe coulters. This appeared to be due to improved seed-soil contact.

(c) Providing better loose soil or polythene cover over the open grooves formed by the triple disc or hoe coulters. This appeared to maintain the seed-soil interface relative humidity at higher levels than in uncovered grooves. It seemed appropriate therefore to attempt to measure the seed-soil interface moisture in terms of relative humidity in the direct drilled grooves as a function of combinations of pressure and covering techniques. It was also considered desirable to attempt to relate these seed-soil interface microenvironment measurements to the wheat seed, imbibition isotherms and to the percentage of seed germination and seedling emergence.

4.2 MATERIALS AND METHODS

Determination of wheat seed moisture absorption isotherms

The rate of seed germination may be determined by the rate of water absorption by viable seeds. Different seed species must reach different critical moisture levels before germination can take place. A number of authors[6,7,8] concluded that the process of water absorption was controlled by either:

(a) Seed properties, or:

(b) Soil properties.

Williams and Shaykwich[10] found experimentally that seed properties controlled the initial rate of absorption in most soils but the subsequent increase in the seed conductive properties caused the seed and soil properties to be similar, so that the overall rate of absorption was controlled by the soil properties.

Experiments were conducted to determine the "Karamu" wheat moisture absorption isotherms in salt solutions of different molalities. Water vapour absorption rates of "Karamu" wheat seed were also determined by exposing the seeds to controlled vapour pressures over the top of the salt solutions without the seeds having physical contact with the solution.

Experimental Methods

Seed Preparation: Wheat seeds (variety Karmau) of 96.0% viability were stored in sealed polythene bags under constant humidity conditions. The mean moisture content of the seeds thus treated was found to be 16.5% (d.b.). The maintenance of seed at constant initial moisture contents was considered critical, since the experiments of Hillel[7] had shown that the rates of absorption and germination depended upon the antecedent moisture contents. This meant that the drier the seed, the more rapidly it would absorb moisture, and germinate.

Salt solution preparation: Sodium chloride (NaCl) solutions were prepared. The six solutions represented the following moisture potentials:

NaCl Solutions (molality)	Moisture Potential at 20°C (-bars)	Ref.
Saturated solution	387.3	Wilie (88)
2M	95.7	Lang (89)
1M	45.5	"
0.5 M	22.5	"
0.25M	11.4	"
Distilled water	0	"

It was expected that these salt solutions would give a wide pattern of seed absorption isotherm characteristics.

Experimental Procedure: Twelve samples of wheat seeds, weighing 8g each were used. The first set of experiments consisted of measuring seed absorption isotherms in the vapour form without the seed having any physical contact with the liquid solutions. Salt solutions of 100 ml each were placed in six jars. The seeds contained on a dish shaped gauze, were lowered into the jars to a position 10 mm above the solutions. The open ends of the jars were sealed to maintain the water vapour pressure inside.

Increases in seed weights were measured every 24 hours and the seed germination and plumule development was noted. These measurements continued until the increases in the seed weights ceased. In the second set of experiments, a further six seed samples were immersed in the salt solutions in petri dishes. Care was taken to maintain the depth of solution in each petri dish at 10 mm at all times. Increases in seed weights were measured 20 hours and 48 hours after immersion. Germination and plumule development was also noted. Seeds were considered germinated when the coleorhiza had appeared. To measure the increases in seed weights after specified times, the samples were drained and the excess solution was removed by quickly drying the seeds between blotting paper before determining their moisture status.

4.3 EXPERIMENT 5: THE DETERMINATION OF EQUILIBRIUM MOISTURE ABSORPTION ISOTHERMS OF KARAMU WHEAT

Objectives

It was clear from the results of experiment 1a and 1b that when grooves were created by the triple disc coulter and covered with loose soil, a large proportion of seeds germinated but did not emerge. Of the germinated seeds a large proportion were found to be viable even at the termination of the experiment at day 18. These results suggested that loose soil cover had maintained a high enough moisture potential (perhaps in the vapour phase) at the seed-soil interface, to sustain the viability of the germinated seeds and seedlings over at least the 18 day period, even if this had not been sufficient to allow the seedlings to emerge.

The purpose of this experiment was firstly to measure the moisture absorption isotherms of wheat seed in equilibrium with salt solutions at a range of molalities at 20^{o}C. This was achieved both by liquid imbibition and through vapour diffusion as described earlier. Secondly the experiment sought to correlate these moisture absorption isotherms with germination counts of wheat seeds in field moisture conditions. Specifications are given in appendix 9 .

Results and discussion

Table 23 shows the equilibrium moisture absorption isotherms of karamu wheat at 20^{o}C, by liquid imbibition, Fig. 13 by vapour imbibition. The initial moisture contents of seeds were 16.5% g/g (d.b.) in both cases. From table 23 it was apparent after 20 hours of imbibition in distilled water the seed moisture contents had increased to 60.6%. At this stage the seed coleorhyza started showing in some seeds. At lower vapour pressure, there was no sign of seed germination after 20 hours.

A second observation was made when 48 hours had elapsed. By this time the moisture contents of the seeds had increased to 77% (d.b.) in distilled water; to 65.2% g/g^{-1} at -11.2 bars and to 61.9% g/g^{-1} at 22.4 bars. Seed germination was visible at these three moisture potentials. There was 100% germination of viable seeds in distilled water and the seed plumules had emerged by an average of 5 mm. Over 50% of viable seeds germinated at -11.2 bar moisture potential and the seed radicles and plumules were visible. At -22.4 bar moisture potential, the seeds appeared to have gained the required amount of moisture and the seed coleorhiza were visible. At lower moisture potentials, however there was no sign of seed germination.

It appeared that the seeds, in contact with soil (and depending upon the area of contact) at approximately -11 bars or more, would be capable of germinating and sustaining the seedling to emergence, provided that the seed radicles were able to penetrate into more moist soil layers within a time interval of approximately 2 to 3 days after sowing. At moisture potentials lower than -11 bars the seeds might germinate but might not be expected to have sufficient vigour to supplement their energy supply through root anchorage, and then to emerge.

TABLE 23

Experiment 5. Equilibrium absorption isotherms of karamu wheat at 20^{o}C in salt solutions (liquid imbibition)

	Increase in seed weight due to moisture Absorption in % (d.b.)					
	Distilled water	0.25 Mol	0.5 Mol	1 Mol	2 Mol	Conc. solution
Moisture Potential (-bars)	0	11.2	22.4	45.5	95.7	387.3
Time in hours	%	%	%	%	%	%
0	16.5	16.5	16.5	16.5	16.5	16.5
20	60.6*	55.9	53.6	50.5	43.3	30.6
48	77.0	65.2	61.9	57.7	50.1	33.6

Initial weight of approximately 200 seeds = 8.0 gm

Initial seed moisture content = 16.5% (d.b.)

* Seed germination was sustained at seed moisture contents of approximately 60% $g.g^{-1}$ and above

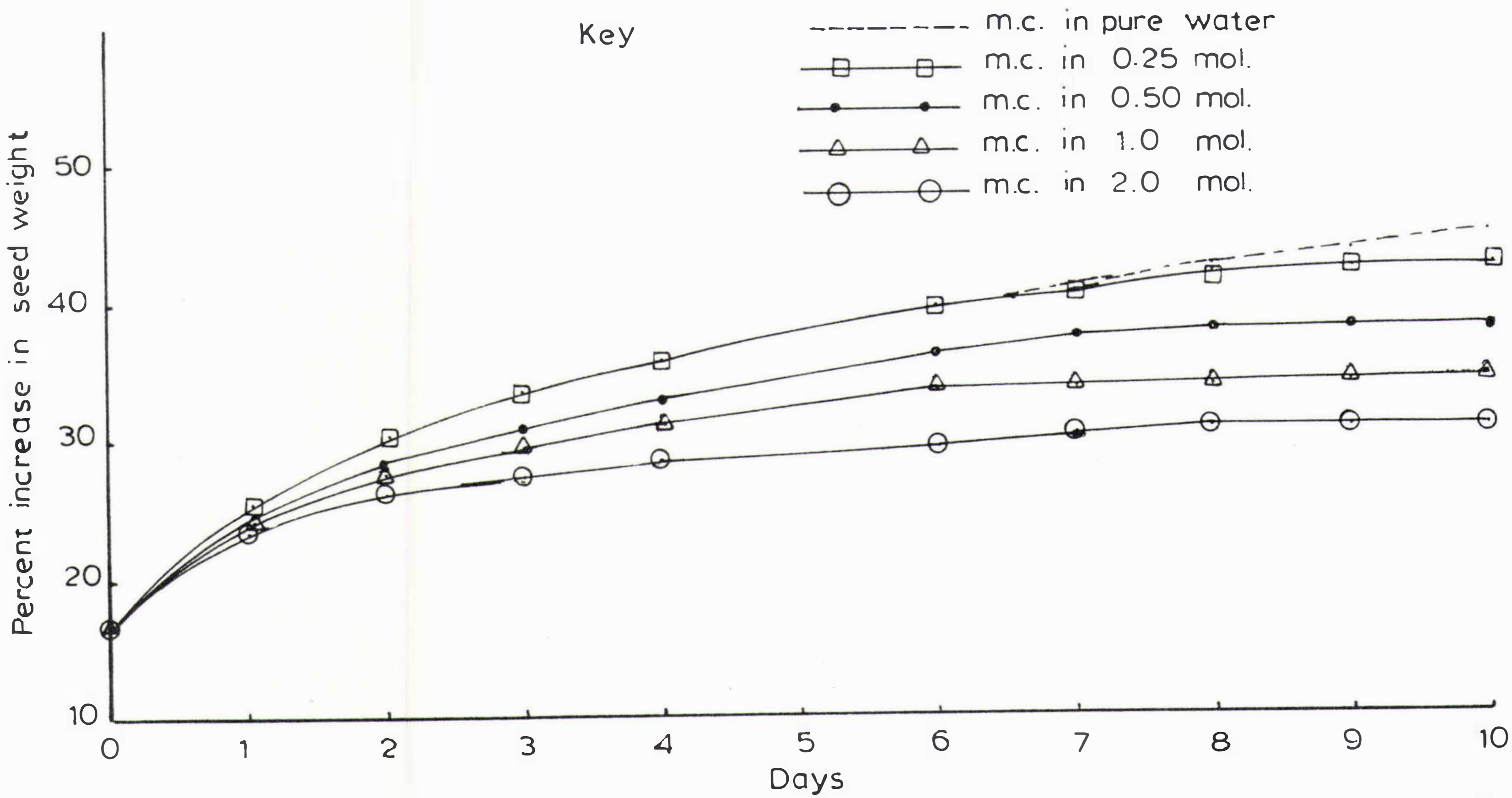


Figure 13. Equilibrium moisture vapour imbibition iso therms of karamu wheat at 20°C.

A further small experiment was then conducted to examine the requirements of germinated seedlings, with 5 mm length of plumules, in a range of moisture potentials. Six groups of 20 germinated seeds each were allowed to grow in six salt solutions corresponding to a wide range of moisture potentials. Plate (13a) shows the fate of the seedlings after 3 days in the salt solutions at 10 mm depth in petri dishes. It is apparent from plate (13a) that the seedlings in distilled water had continued to grow and develop well established root systems. Visual appraisal suggested that the seedlings would grow in the presence of freely available water. The seedling at -11.2 bar moisture potential grew only to approximately 10 mm in lengths and then the growth became stunted. This suggested that at this moisture potential in liquid form the seeds would apparently germinate but the seedlings would not survive long enough to emerge. In the remainder of the 4 salt solutions (which were at lower moisture potentials) the seedlings did not grow, and in many cases died and started decaying.

Fig. 13 shows the equilibrium moisture absorption isotherms of karamu wheat seeds under vapour imbibition. It is apparent from the figure that there was a slow rate of moisture absorption in all situations. Seeds gained a maximum of only 44.6% (d.b.) of moisture by day 10 where the seeds had been held over pure water. There was no seed germination at this time. This also confirmed earlier experiments which had supported the belief that seeds would not germinate until they gained at least 61% (d.b.) weight. At lower moisture potentials, moisture gained by seeds was correspondingly less each sampling time.

It was apparent from this experiment that in the absence of direct seed-soil moisture contact, karamu wheat could not be expected to germinate, even if the ambient humidity was 100%. Projecting these findings to the field conditions in relatively dry soils, it is unlikely that the groove cover alone would be sufficient to initiate germination through water vapour availability *per se*. Some seed-soil contact would be necessary to provide the initial imbibition from the liquid moisture.

Plate 12(g) Typical "germinated but unemerged" seeds from a triple disc coulter groove in initially dry soil.

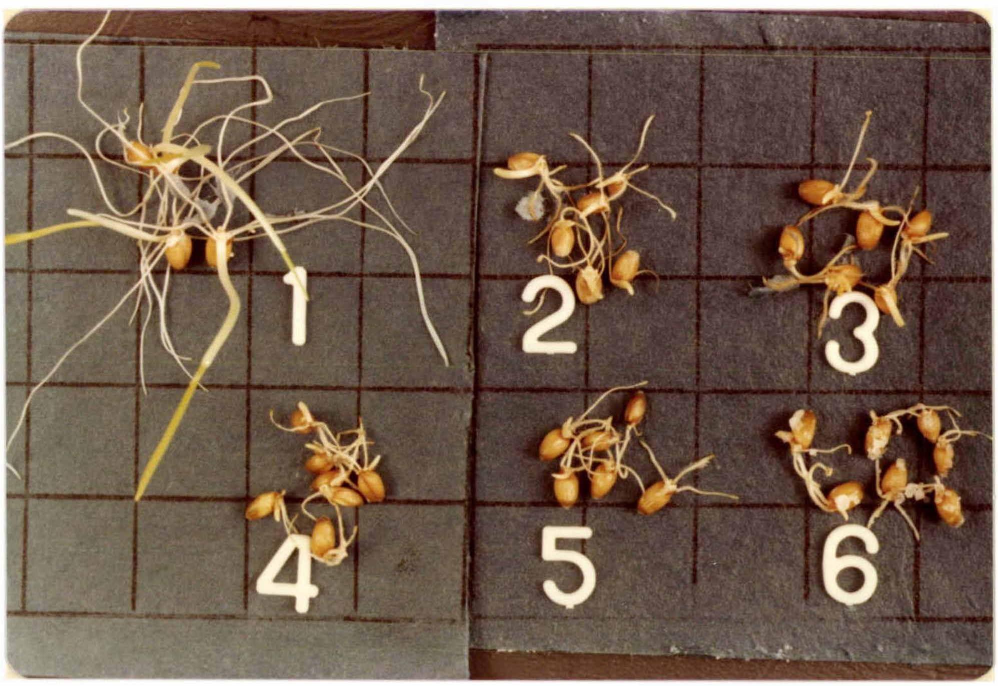


Plate 13(a) Typical seed fate of seeds grown in NaCl solutions; (1) distilled water (2) 0.25 Mol. (3) 0.5 Mol. (4) 1.0 Mol. (5) 2.0 Mol. (6) Concentrated salt solution.

CHAPTER 5

STUDY OF THE IN-GROOVE MICRO-ENVIRONMENT AT THE SEED-SOIL INTERFACE

5.1 METHODS OF MEASUREMENT OF MOISTURE POTENTIAL AT SEED-SOIL INTERFACE

5.1.1 Introduction

The measurement of moisture potential in the micro-environment at the soil-seed interface was expected to be a difficult task, as difficulty had been reported with measurements near the general soil surface(77). In unsaturated and relatively dry soils, discontinuous liquid volume in coexistance with water vapour made it particularly difficult to undertake measurements satisfactorily. It appears from the literature that few, if any attempts have been made to monitor vapour moisture in the vicinity of the seed-soil interface. The temperature gradients near to this interface can be expected to bring rapid and frequent changes in the liquid and gaseous water fluxes which, as stated in Section 2.2.9 was thought to be why temperature dependent moisture measurement methods near the general soil surface were not satisfactory.

An effort was made to evaluate a number of methods of measuring soil moisture potential within the direct drilled grooves. These methods contrasted with those described earlier for determining the liquid soil moisture status, in that they sought to monitor the atmosphere within the groove regardless of the liquid soil moisture status. The methods considered were as follows:

(a) Psychrometers
(b) The use of phosphorus pentaoxide (P_2O_5)
(c) Thin film cells
(d) Dew point hygrometers

(a) Psychrometers:

Psychrometers, as explained earlier were tried and discarded because of the undesirable effects of temperature gradients.

(b) The use of P_2O_5:

The use of P_2O_5 involved taking an air sample in a tube from the in-groove micro-environment. A measured quantity of P_2O_5 was to be introduced in the sealed soil air samples. This was expected to absorb the air moisture. Gravimetric measurements would have revealed the weight of water absorbed. The method was however, considered to be too inaccurate because it needed relatively large air samples which might not be wholly representative of the interface microenvironment. Furthermore the method involved the removal of the samples and errors might be expected due to moisture losses in the sampling tubes and weighing errors (Hardacre, *pers. comm.*)

(c) Thin film cells:

Electro-humidity sensors*are electric hygrometric circuits which sense changes in the relative humidity through changes in impedence. These sensors were considered to be unaffected by environmental conditions that were not detrimental to polystyrene. For example, dust settling on the sensors surface did not affect the performance except possibly to decrease slightly the speed of response (Hardacre, *Pers Com.*)

Two commercial humidity sensors were considered for their possible use in measuring the in-groove relative humidity. Neither of these sensors was found to be suitable however because they were reportedly adversely affected by in-groove liquid moisture (Hardacre, *Pers. Comm.*).

(d) Dew point hygrometer:

Dew point hygrometers employ a technique of withdrawing in-groove soil air samples and measuring the dry bulb and dew point temperatures. The air relative humidity is read directly from psychrometric charts using these temperature data.

* Phys. Chemical Research Corporation PCPC-11 standard electro-humidity sensors, and Honeywell Q464A Gold grid R.H. sensors.

5.1.2 Description of thermo-electric dew point hygrometer

A commercial dew point hygrometer** was used to monitor in-groove relative humidity. The available instrument was an automatic optically sensed, thermoelectrically cooled device. It measured the dew point temperature of the air by presenting a cooled metal surface to the air sample so that the temperature of the latter equilibrated with that of the former. If the metal surface was maintained at a constant temperature below dew point, air moisture condensation continued and an increasing amount of moisture collected on the surface. Alternatively, if the surface was maintained at a higher temperature than dew point, evaporation occurred and resulted in reduced moisture on the surface. A state of dynamic equilibrium occurred only when the surface temperature was exactly at dew point. At this point the amount of moisture on the metal surface remained unchanging and this was reflected in a direct reading of the dew point temperature.

5.1.3 Design of in-groove air sampler

The air in the direct drilled grooves was sampled using a number of open T-shaped 4 mm i.d. transparent nylon tubes. These tubes were embedded 40 mm deep in the soil grooves at the time of drilling, with their perpendicular portion protruding out of the grooves.

The objective was to slowly draw a sample of air from the vicinity of the seed in an effort to correlate the seed-soil interface vapour moisture potential with seedling emergence performance.

5.1.4 Humidity measurement procedure

The dew point hygrometer sensor was connected to the intake part of the air sampler using a clear non-hygroscopic leak-free nylon tube. The in-groove air was drawn at a low flow rate of 5 to 7 cubic centimeters per second. (The hygrometer air pump had the capacity to pump air from 0 to 40 cm^3).

** A EG & G model 880 Thermo-electric Dew Point Hygrometer.

A pilot trial which tested the instrument in the same ambient and groove conditions as were used in the main experiments, indicated that an air flow rate of 5 to 7 cm^3/sec. was optimal. At higher flow rates the accuracy of the instrument was adversely affected by accumulation of fine soil particles which were drawn into the tubes. At lower flow rates the hygrometer tended to be insensitive particularly with air from soil grooves which were overlain by a large amount of cover. No clear explanation can be given for this insensitivity. Results of this pilot trial are given in Appendix 9a.

At each sampling, after initial balancing of the instrument the hygrometer was operated for 3 to 4 minutes during which time the temperature stabilized at the sample dew point. Relative humidity was read from the psychrometer charts using the dry bulb temperature (controlled at 20°C) and dew point temperature for each of the tubes. The r.h. measurements may be converted to moisture potential in bars using the Kelvin equation.

The Kelvin equation for water potential is

$$\psi = \frac{R.T}{W_A} \ln ({}^{P}/Po) . 1000$$

ψ = $J/_{kg}$

1000 $J/_{kg}$ = 1 bar

R = Gas constant, 8.3143 J.deg k^{-1}. $mole^{-1}$

T = Absolute temperature K^{o}

$^{P}/_{Po}$ = Relative vapour pressure in equilibirium with the system

W_A = Molecular weight of water = 18.0016

5.1.5 Experimental design

Initially a pilot experiment was set up to measure the in-groove moisture potential using three types of coulter assemblies. Soil blocks were extracted, treated and drilled (without seed) as explained in Section 2.2.1. The in-groove air sampling tubes were inserted in the groove immediately after drilling took place. The soil samples were moved to the controlled climatic laboratory and subjected to controlled climatic conditions of 20°C and 60% r.h. with day light of 12 hours at 70 kW/m^2. In contrast to the earlier experiments, the ambient conditions were kept constant because diurnal changes were expected to allow dew formation in the air sampler and might therefore have affected the soil atmospheric readings.

In-groove soil moisture potential was measured daily using the dew point hygrometer and air pump until day 17. The results of this pilot experiment are given in Appendix 9. These results justified repetition of this experiment on a more comprehensive scale. These latter experiments took place in two parts.

a. Grooves were drilled and monitored for in-groove relative humidity,
b. Seeds were drilled and both the in-groove relative humidity and seedling emergence was noted.

The purpose of conducting separate seeded and non-seeded experiments was to determine if the presence of the seeds themselves interacted with the environment to affect the in-groove relative humidity. Plate (13b) shows the hygrometer and the connecting tubes for sampling the in-groove air.

Experiment 6(a): In this experiment, 6 treatments, using three coulter types, were randomized in three soil blocks with three replicates each. The treatments were:

(1) Chisel coulter
(2) Hoe coulter
(3) Hoe coulter with 70 kPa pressure applied directly over the seed
(4) Triple disc coulter
(5) Triple disc coulter with 70 kPa pressure applied directly over the seed
(6) Triple disc coulter and groove covered with loose soil followed by 70 kPa pressure over the groove.

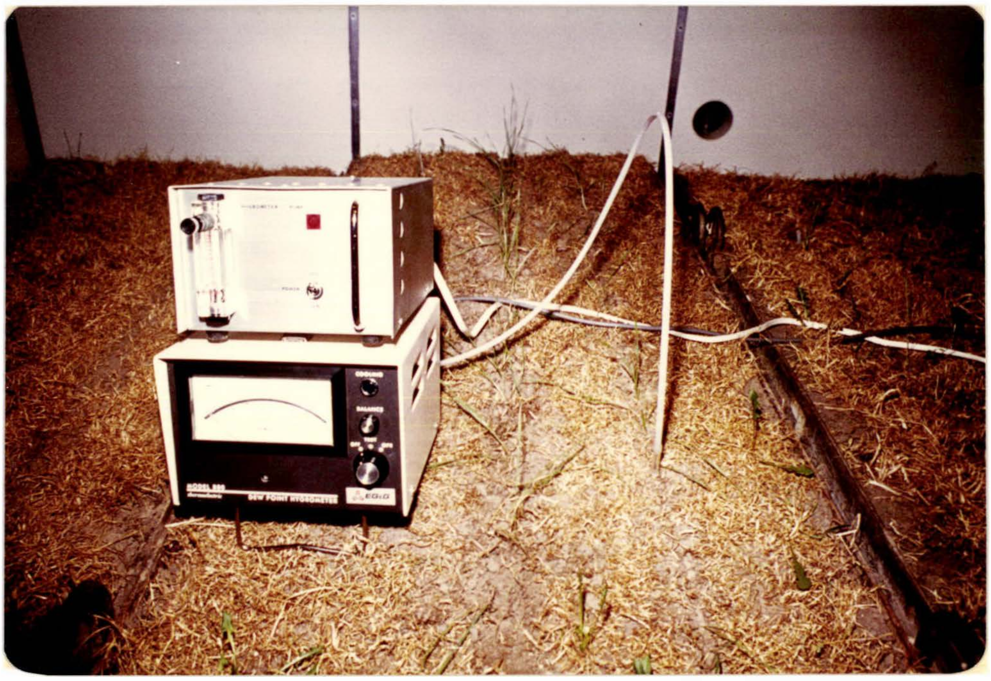


Plate 13(b) A thermo-electric hygrometer in action to measure in-groove soil relative humidity

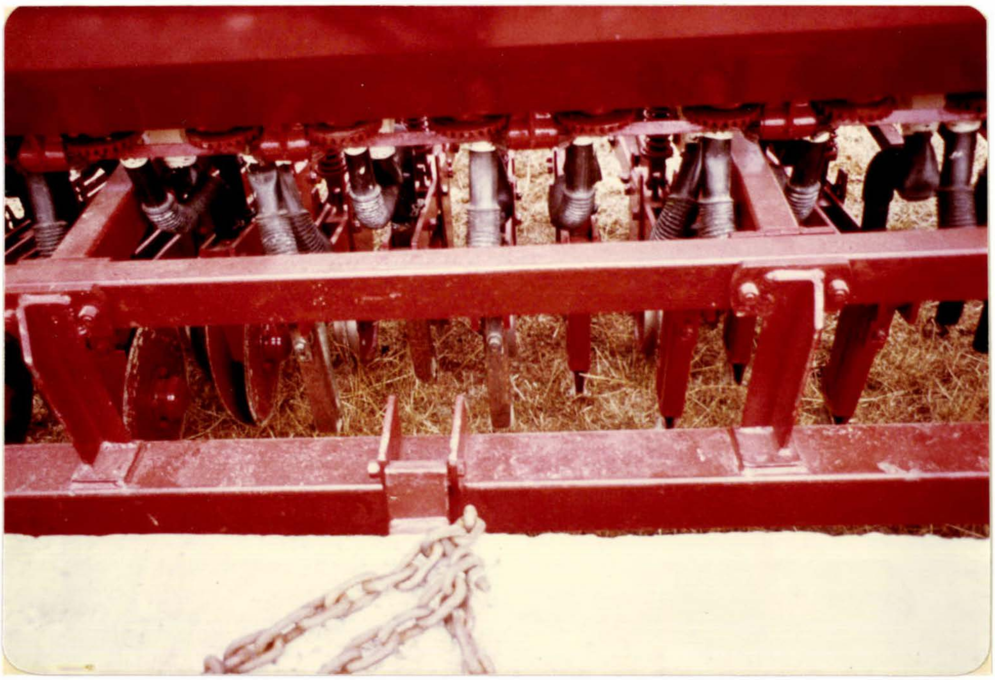


Plate 14. A "Duncan 730 multiseeder" drill equipped with; left, triple disc; centre, hoe; right, chisel coulter assemblies for field drilling.

All treatments were followed by bar harrowing. No seed was drilled in this experiment. In each row of each plot (which was half a bin in length) 2 nylon T-shaped tubes were inserted to measure in-groove relative humidity. Relative humidity was measured daily at midday while the drilled soil blocks remained in controlled climatic conditions similar to those described in the pilot experiment.

Experiment 6(b): Treatments, identical to those in experiment 6(a), were carried out in this experiment, except that in this case seed was drilled at the same time. The six treatments were randomized as full-bin length plots in 6 soil blocks with three replicates. Approximately 100 seeds were drilled in each single row plot. Daily relative humidity measurements were taken using the dew point hygrometer. Seedling emergence counts were taken daily until emergence counts had stabilized. Gravimetric soil moisture samples were taken every 3 days using the core sampler. After day 18, the soil blocks were removed from the climate rooms and terminal seed fate was determined by harvesting the seeds using the hand held scoop.

5.1.6 Data Analyses

The six treatments (being combinations of coulter types and covering techniques) were tested in a completely randomized block design. A one-way analysis of variance was used to test the differences between the means of the in-groove relative humidity of various coulter treatments at a given time after drilling. In experiment 6(b), similar analysis was used to test the differences between in-groove relative humidities, seedling emergence and seed fate.

To establish the vapour moisture drying rates from the grooves, realtive humidity data was plotted against time. A Regression analysis was performed using in-groove relative humidity as dependent variable (Y) and time as independent variable (X). A Burrough's B6700 computer, and Burrough's programme 'Cande' was used for this purpose. Linear regression and a range of transformations were tested to find linear or curvilinear lines of best fit. When more than one line appeared to describe the data, a "best fit" was chosen on the following basis:

To judge the "best fit" of a relationship, accuracy of regression and appropriateness of the resultant curve were the important considerations. Three main criteria were considered concurrently for "best fit".

(a) The higher coefficient of determination R^2. The highest acceptable value however depended on the other criteria as well.

(b) Extrapolations beyond the limit of the data were considered. In this case some bio-physical assumptions were made.

(c) Finally, where an alternate still existed, the simpler equation was chosen.

5.2 EXPERIMENT 6(a): THE EFFECTS OF CONTROLLED CLIMATIC CONDITIONS, COULTER DESIGNS AND COVERING TECHNIQUES ON IN-GROOVE VAPOUR MOISTURE DRYING RATES.

Objectives:

The previous pilot trial had shown that the dew point hygrometer was capable of measuring in-groove relative humidity within an accuracy of ± 3%. It therefore seemed desirable to measure the stability and magnitudes of relative humidity levels in selected coulter grooves. Initially, it was felt to be appropriate to monitor the micro-environment in the grooves in isolation, so no seed was sown.

Additional details of this experiment are given in appendix 9(b & c).

Results and discussion:

Fig. 14a shows the relative humidity readings for the six different coulter design parameters and table 24 lists the day-by-day data and least significant differences between treatment means. The experiment started at an average turf block soil moisture content of 15.5% (d.b.) measured at 0-45 mm depth. Measurement of in-groove relative humidity on day 1 were made after the soil blocks had been stabilized in the climate rooms under a constant ambient relative humidity of 60% and temperature of 20^{o}C.

From the table it appears that there were no significant differences between the treatments in terms of the in-groove r.h. measurements on day 1. On day 4 after drilling, the relative humidity in the triple disc grooves without cover and pressure, and the triple disc groove with pressure directly over the seed were significantly (P = 0.05) lower (80.8% and 83.6% respectively) compared to the chisel coulter (89.4%), the hoe coulter with pressure over seeds (86.1%) and the triple disc coulter groove covered with loose soil and then pressed (88.6%). These differences were maintained thereafter as can be seen in Fig. 14(a)

TABLE 24

The effects of coulter design and covering techniques and time on the soil in-groove relative humidity levels at controlled ambient r.h. of 60%

Treatments	Days from sowing											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Chisel coulter	93.8 a	93.3 a	92.3 a	89.6 a	89.8	89.3	88.3	85.5	82.0	81.1	80.6	80.6
2. Hoe coulter, no cover or pressure	92.3 a	92.0 a	91.1 a	86.5 a	84.3	83.3	81.5	78.6	74.5	73.6	73.3	72.3
3. Hoe coulter, no cover but 70 kPa pressure directly over seed	91.5 a	87.1 b	87.1 ab	86.1 a	85.6	84.8	81.5	77.6	74.6	74.3	73.6	73.5
4. Triple disc coulter, no cover or pressure	91.6 a	88.3 ab	86.6 b	80.8 b	78.0	77.0	76.5	72.8	66.3	63.6	62.1	61.8
5. Triple disc coulter, 70 kPa pressure directly over seed	93.5 a	89.8 ab	88.8 ab	83.6 b	80.3	78.5	77.0	73.3	69.0	67.0	65.6	65.3
6. Triple disc coulter, loose soil cover + 70 kPa pressure over covered seeds	94.5 a	94.4 a	93.3 a	88.6 a	89.3	88.0	86.6	83.3	80.3	80.0	79.6	79.6

Unlike letters in a column show significance differences at (P = 0.05)

Figure 14(b) shows the regression curves (quadratic curvilinear), drawn to fit the in-groove soil relative humidity gradients. For this purpose the soil in-groove r.h. data until day 6 were used, because at this time seedlings started to emerge. The regression curves were differentiated to obtain their slopes in terms of (r.h./day) vapour moisture loss. These vapour moisture drying rates are given in table 25. To determine the significant differences between these rates a t-statistics was used between pair of b_0's, b_1's and b_2's of individual equations. The drying rates in table 25 show that both the triple disc groove without cover and pressure, and the triple disc coulter groove with pressure directly over uncovered seeds had significantly (P = 0.01) more rapid drying rates than all other treatments. The lowest drying rates were achieved with the chisel coulter without pressure application, the hoe coulter with pressure applied directly over the seeds, and the triple disc coulter with the groove covered with loose soil and pressed at 70 kPa. There were no significant differences amongst these last named treatments. Drying rates were significantly (P =0.01) more rapid when the hoe coulter without pressure was employed compared to those of the chisel coulter without pressure, the hoe coulter with 70 kPa pressure, and the triple disc coulter with cover and pressure.

These results appeared to give some support to the hypothesis of the existence of a "moisture potential captivity" between different grooves, which was first discussed in experiments 1 & 4.

From Fig. 14a, it can be seen that the relative humidity levels in the chisel coulter groove, the triple disc coulter groove with loose soil cover and pressure over the covered groove, and in the hoe coulter groove with or without pressure on the uncovered seeds, were maintained at or above 80.0%, 79.6%, 73.0% and 72.0% respectively until day 12. In the other two treatments the r.h. levels were nearing the controlled r.h. levels of 60% by day 12.

To test the effects of changes in ambient r.h. on the in-groove relative humidity, on day 12 the ambient r.h. was increased to 90% relative humidity. Readings in the in-groove situations (fig. 14a) on days 13, 14 and 15 showed that the rate of remoistening was also more rapid in the grooves which had lost moisture vapour rapidly under the drying regime. For example, in the triple disc groove

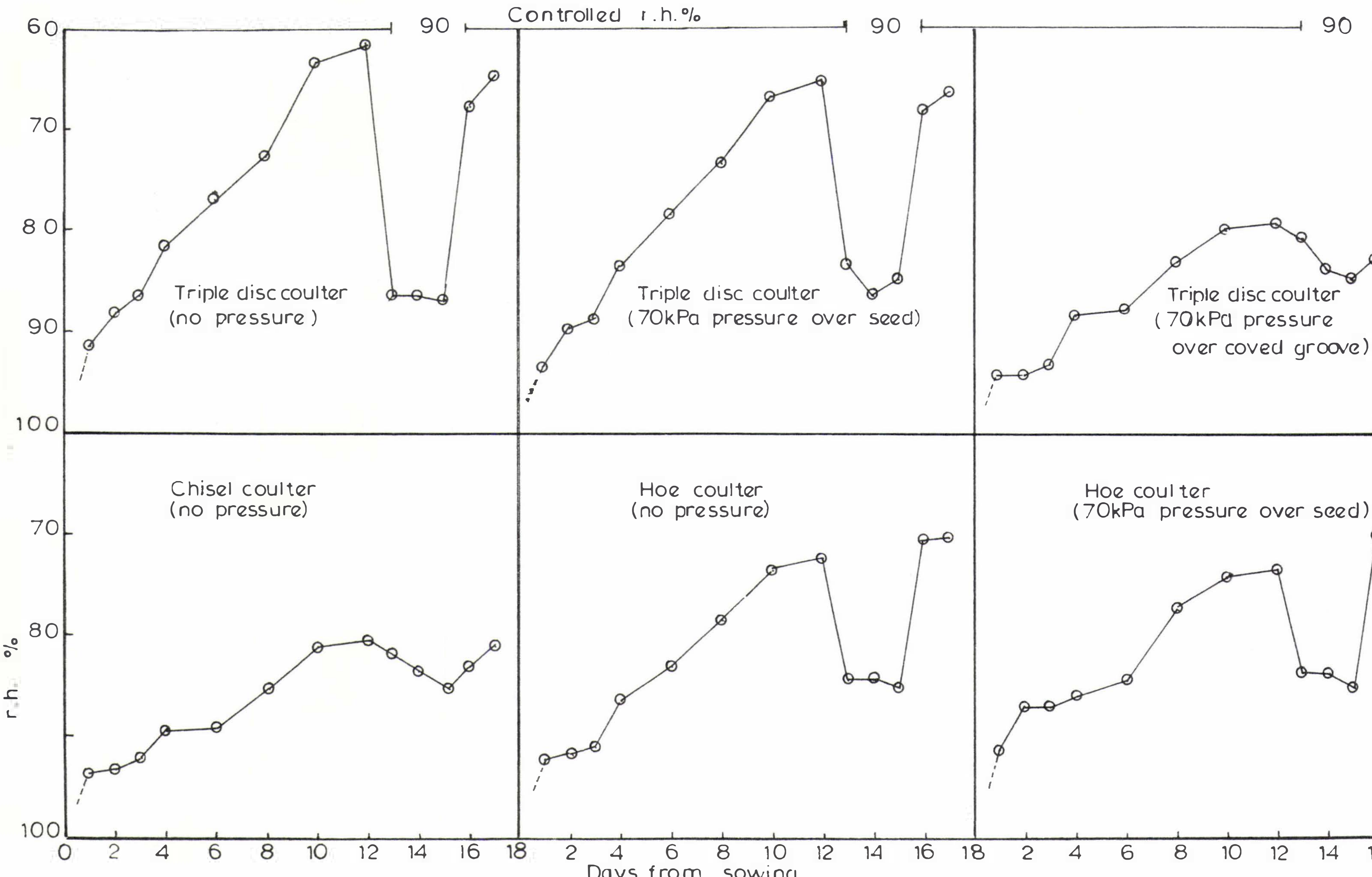


Fig. 14a. The effects of coulter designs and covering techniques, and time on the in-groove relative humidity at 60% controlled ambient relative humidity.

TABLE 25

The effects of selected coulter designs and covering techniques on the in-groove soil drying rates (in r.h.%/day)

Treatments	Mean drying rates - (r.h.%/day)
1. Chisel coulter, no pressure	1.018 C
2. Hoe coulter, no pressure	2.032 B
3. Hoe coulter, 70 kPa pressure over seed	1.122 C
4. Triple disc coulter, no cover or pressure	3.128 A
5. Triple disc coulter, 70 kPa pressure over seed	3.13 A
6. Triple disc coulter, 70 kPa pressure over covered seed	1.328 C

Unlike letters show significant differences at (P = 0.01)

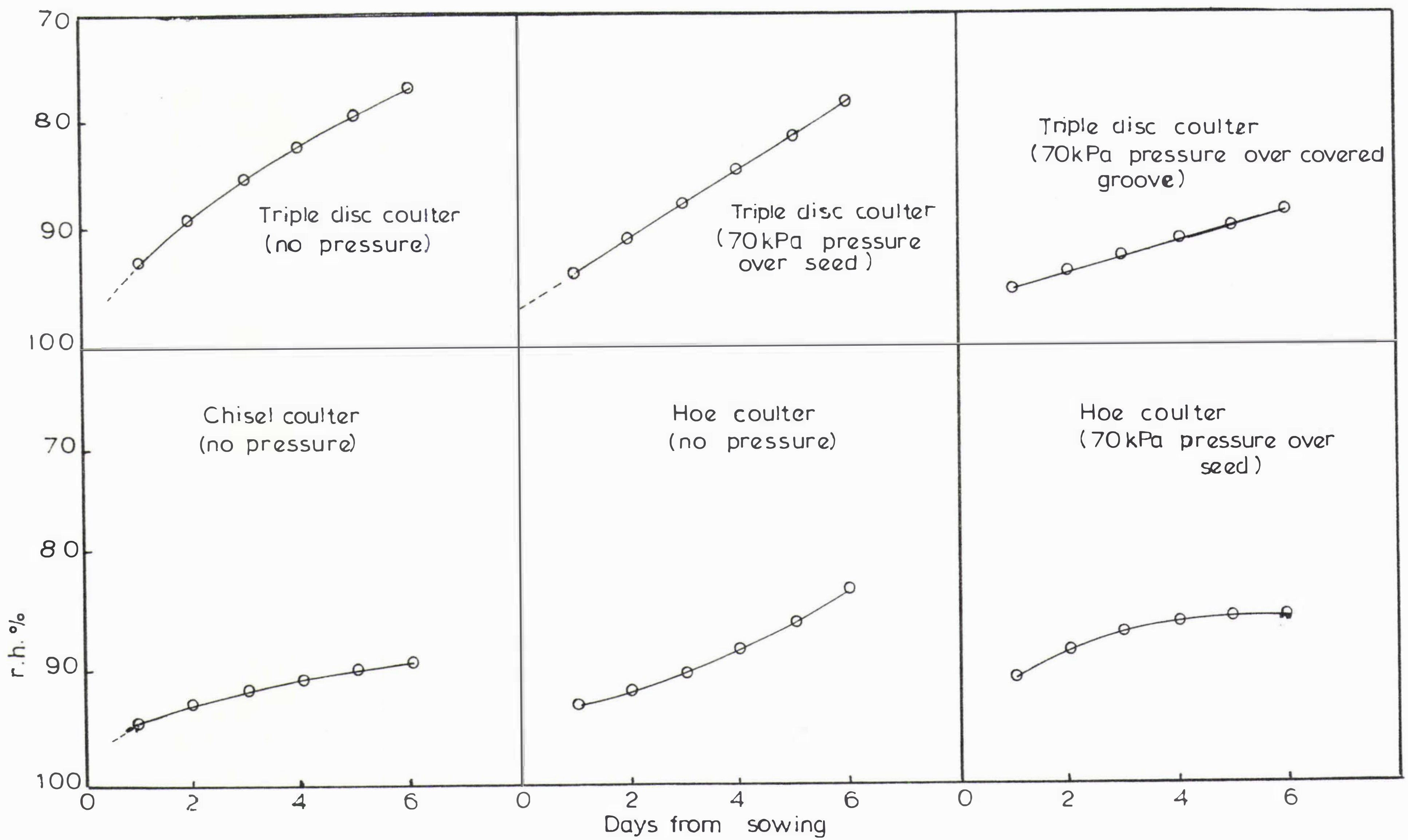


Fig. 14b. The effects of coulter designs and covering techniques, on in-groove soil moisture drying rates at 60% controlled ambient relative humidity (regression curves.)

without cover and pressure, the r.h. increased from 61.8% to 87% within three days, with an average sorption rate of approximately 8% r.h./day. On the other hand, the sorption rate was slowest (at 1% r.h./day) in the chisel coulter grooves. These observations inversely reflected the drying rate trends just after drilling when the grooves were first exposed to the 60% ambient relative humidity.

On day 16, the ambient r.h. was again lowered to 60%. The purpose was to test the repeatability of the drying rates of the in-groove r.h. readings. The continuing in-groove relative humidity readings showed similar trends of drying rates as had been evident at the beginning of the experiment.

Summary

The results of this experiment suggested that:

(a) The slowest loss of moisture potential from the in-groove area was associated with improved seed-soil contact by pressing of the seed, and/or a high grade of seed cover.

(b) Where these groove characteristics were favourable, the moisture vapour in the groove equilibrated more with the seed micro-environment than the ambient air. Although the relative humidity gradient between the in-groove area and the ambient air might have been expected to be a dominant force as earlier suggested by Lemon *et al.*,[70], this was overridden by the dominance of seed-soil contact and/or cover determinants. Thus the steeper relative humidity gradients reacted more slowly to changing ambient conditions (both sorption and desorption) than the flatter gradients. This was clearly because the steepness of the gradient in the first place was determined by the ability of the favourable groove characteristics to buffer the in-groove relative humidity from the ambient condition.

(c) Where the groove characteristics were unfavourable, the in-groove vapour moisture was more inclined to equilibrate with the ambient air than the surrounding soil.

5.3 EXPERIMENT 6(b): CORRELATIONS BETWEEN IN-GROOVE VAPOUR MOISTURE POTENTIAL AND SEEDLING EMERGENCE AS FUNCTION OF COULTER DESIGN AND COVERING TECHNIQUES.

Objectives:

Results from experiment 6(a) had indicated that it was possible to measure significant differences in in-groove relative humidity and rate of change thereof, as a result of the use of different coulter types and covering techniques. It was also clear that the measuring technique used was sufficiently sensitive to measure differences in coulter performance as the relative humidity gradient between soil and ambient was increased or decreased. It was therefore considered desirable to attempt to measure the in-groove relative humidity from the same groove as the sown seeds and thereby permit possible correlations to be examined between, on the one hand, germinating seeds and emerging seedlings, and on the other hand, in-groove vapour moisture loss. Additional details of experiment 6(b) are given in appendix (9 d,e & f).

Results and Discussion:

(a) Seedling emergence and seed fate:

Table 26 shows the seedling emergence and seed fate data of experiment 6b. Seedling emergence appeared to be significantly ($P = 0.01$) higher with a group of three treatments which included the chisel coulter (36.2%), the hoe coulter without pressure (31.1%) and the hoe coulter with 70 kPa pressure directly over seeds (37%); compared to 2.5%, 7.3%, and 8.4% with the three triple disc treatments which were respectively; no cover or pressure, 70 kPa pressure directly over the seed, and loose soil cover followed by pressure over groove at 70 kPa. There was a significantly ($P = 0.01$) larger number of ungerminated seeds found in the grooves of a group of treatments including the hoe coulter without pressure, the hoe coulter with pressure and the triple disc coulter without cover and pressure; compared to the percentage ungerminated seeds in the chisel coulter groove and the triple disc coulter with cover over the seeds followed by pressure.

It appeared that there were ($P = 0.01$) higher numbers of "germinated but unemerged" seeds in the three treatments of the triple disc

TABLE 26

The effects of selected direct drilling coulter types and covering techniques on seedling emergence and seed fate (at the terminal day 18)

Treatments	Seedling emergence %	Ungerminated seeds %	Germinated but unemerged seeds % Dead seedlings		Viable seedling
1. Chisel coulter	36.2 B*	15.2 A	(30.4	+	18.2)48.6 B
2. Hoe coulter, no pressure	31.1 B	38.3 B	(30.6	+	0)30.6 B
3. Hoe coulter, 70 kPa pressure over seed	37.0 B	19.3 B	(43.7	+	0)43.7 B
4. Triple disc coulter, no pressure	2.5 A	29.3 B	(68.2	+	0)68.2 C
5. Triple disc coulter, 70 kPa pressure over seed	7.3 A	3.9 A	(80.8	+	8.0)88.8 C
6. Triple disc coulter, and loose soil cover and 70 kPa pressure over top of groove	8.4 A	0 A	(68.0	+	23.6)91.6 C

Ambient conditions = 60% r.h. and 20^{o}C temp. const.

* Columns with unlike letters denote significant differences (P = 0.01)

coulters compared to the chisel coulter and all the hoe coulter treatments.

Seedling viability tests at the termination of the experiment showed that an average of 18.2% of seeds sown became viable seedlings but had not emerged in the chisel coulter groove compared to 23.6% in the triple disc coulter groove when seeds were covered and pressed. In the triple disc coulter grooves with pressure over the uncovered grooves, there were 8% unemerged viable seedlings. In the remaining treatments, all the seeds in the "germinated but unemerged category, had died.

Since experiment 6(b) started at an abnormally low initial soil moisture content of 14% (d.b.) (which was 3% below PWP for this soil), the low overall seedling emergence levels were not unexpected. The seedling emergence and seed-fate data show very similar patterns to those reported earlier in experiments 1 and 4 in dry soils. The rates of seedling emergence (appendix 9d) showed slightly early seedling emergence when either the chisel coulter or the hoe coulter were used, than when the triple disc coulter was employed. The liquid moisture content of the soil blocks (0 to 45 mm depth) and their rates of drying are shown in table 27. Soil moisture contents declined significantly (P = 0.05) from 14% on the day of drilling to 11.6% on day 16.

(b) <u>In-groove relative humidity measurements</u>

Fig. 15 and Table (28) show the effects of coulter types on the in-groove relative humidity levels with time. From the table it appears that on day 1 after drilling, the in-groove relative humidity was not significantly different amongst all treatments. In-groove relative humidity on day 3 declined significantly (P = 0.05) in the grooves of the hoe coulter without pressure and the triple disc coulter without pressure, compared to a group including the chisel coulter, the hoe coulter groove with pressure over seed, and the triple disc coulter groove with pressure applied over the covered seeds. This trend continued until the termination of experiment on day 17.

From Fig. 15 it is apparent that the initial decline in in-groove r.h. was most rapid in the two unpressed and uncovered grooves (viz.

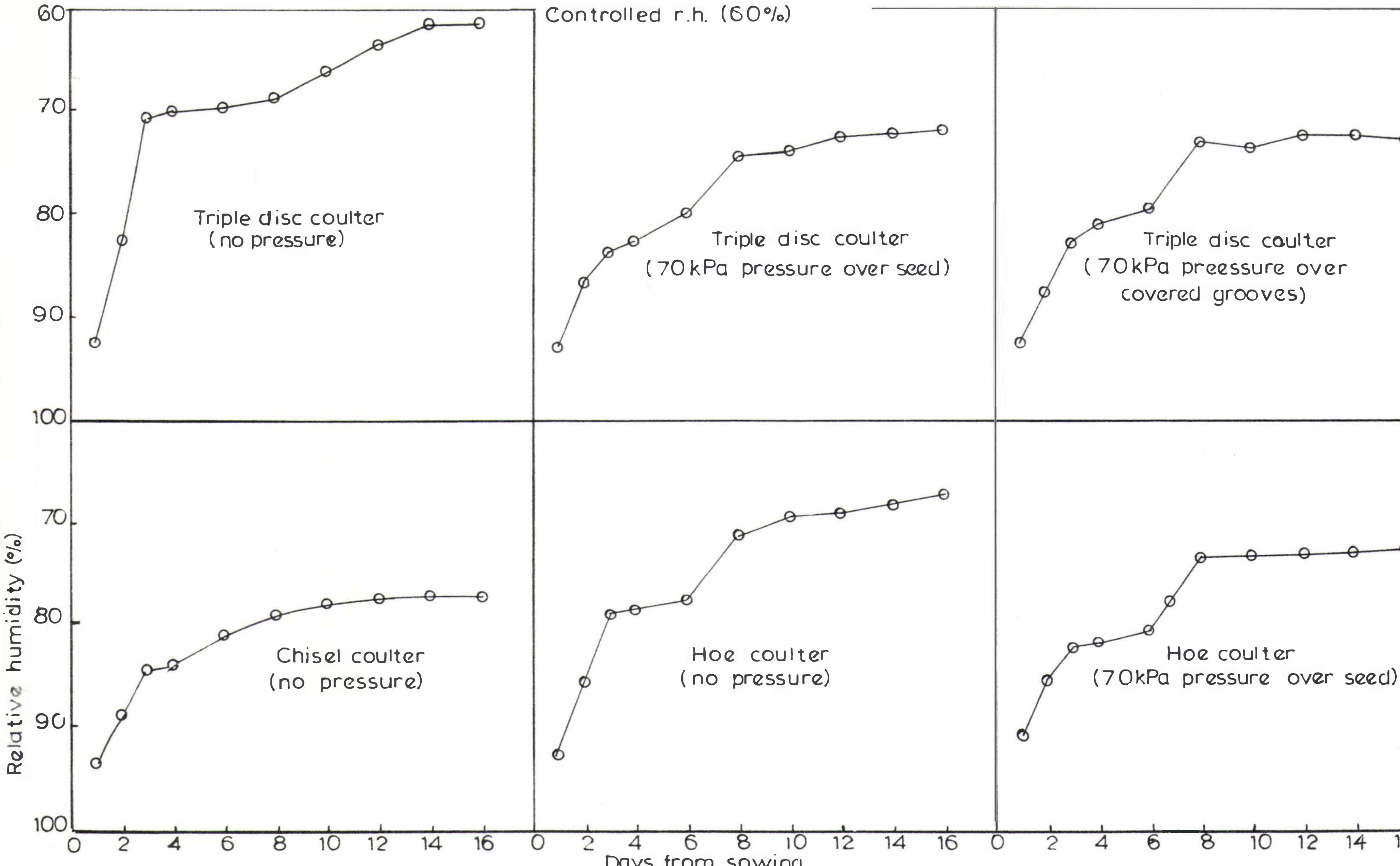


Fig. 15. The effects of coulter design and covering techniques, and time on the in-groove relative humidity at 60% controlled relative humidity

TABLE 27

The effects of ambient conditions on the matrix soil moisture content of turf blocks measured at (0-45mm depth)

Days from sowing	Soil moisture contents % (d.b.)
0	14.0 a
3	12.8 b
6	13.2 b
16	11.6 c
LSD =	0.65

Unlike letters show significant differences at (P = 0.05)

TABLE 28

The effects of coulter types and covering techniques on in-groove r.h. at controlled ambient conditions of 60% and 20°C temperature

Treatments	Days from sowing											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Chisel coulter, no cover or pressure	93.5 a	88.8 a	84.5 a	84.0	82.6	81.0	79.5	79.0	78.8	78.0	77.6	77.6
2. Hoe coulter, no cover or pressure	92.6 a	85.5 a	79.0 b	78.3	78.3	77.6	74.1	71.1	69.6	69.6	69.5	69.1
3. Hoe coulter, 70 kPa pressure directly over seed	91.0 a	85.6 a	82.1 a	81.8	81.1	80.5	77.8	73.6	73.5	73.5	73.1	73.1
4. Triple disc coulter, no cover or pressure	92.3 a	82.6 b	70.8 c	70.8	70.8	69.8	69.1	68.6	66.8	66.0	64.6	63.3
5 Triple disc coulter, 70 kPa pressure over seed	93.0 a	86.8 a	83.8 a	82.8	81.6	80	78.5	74.5	73.5	74.0	72.8	72.8
6. Triple disc coulter, loose soil cover + 70 kPa over covered seeds	92.6 a	87.5 a	83.0 a	82.1	81.1	79.6	77.0	73.0	73.6	73.4	72.4	72.4

Unlike letters in a column show significant difference at (P = 0.05).

Fig. 16. Computational data

Curvilinear regressions

Source	D.F.	R^2	F-value	Slopes (r.h.% /day)
1. Chisel coulter				
$(y = 98.4-5.70X+0.482x^2)$	35	0.92	191.7	2.338
2. Hoe coulter, no pressure				
$(y = 101.4-10.09+1.045x^2)$	35	0.90	153.5	2.776
3. Hoe coulter, 70 kPa Pressure over uncovered seed				
$(y = 96.05-6.148x+0.60x^2)$	35	0.87	111.5	1.92
4. Triple disc coulter, no pressure or cover				
$(y = 106.1-15.48X+1.607x^2)$	35	0.93	237.9	4.232
5. Triple disc coulter, 70 kPa pressure over uncovered seeds				
$(y = 97.82-6.05X+0.532x^2)$	35	0.91	177.7	2.328
6. Triple disc coulter, 70 kPa pressure over covered seeds with loose soil				
$(y = 98.23-6.46X+0.577x^2)$	35	0.90	152.3	2.423

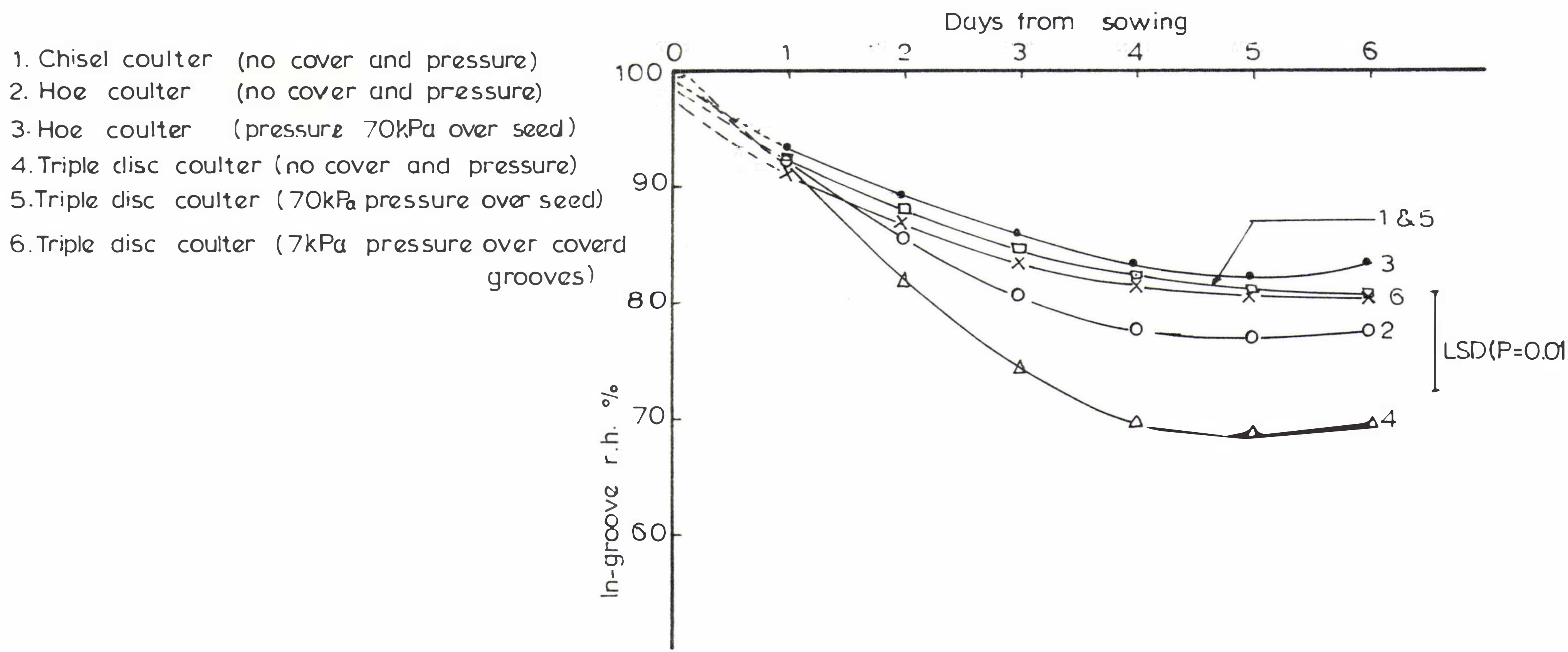


Fig. 16. The effects of coulter types and covering techniques on in-groove relative humidity at controlled ambient relative humidity of 60% (regression curves)

hoe and triple disc).

Fig 16. shows the regression curves of the rates of the in-groove vapour moisture loss of the six treatments. Data of first six days was used as explained in experiment 6(a). The regression equations of all six treatments (from computational data of fig. 16) were differentiated to determine their slopes in terms of r.h.% loss per day. These r.h.% loss rates are shown in table (29). To determine the differences between the mean drying rates of in-groove vapour moisture (r.h.%/day) of all six treatments a t-statistics was used on original data. Table (30) shows the estimated t-statistics for differneces amongst pairs of $\hat{b}_0$'s, $\hat{b}_1$'s and $\hat{b}_2$'s in the quardilinear equations. The differences between each pair of equations were considered to be significant when all or most b-values ($\hat{b}_0$'s, $\hat{b}_1$'s and $\hat{b}_2$'s) of individual equations were significantly different.

From table (29), it appears that the mean drying rate was highly significantly (P = 0.01) more rapid (average 4.231% r.h./day) when the grooves were drawn with the triple disc coulter without any form of cover or pressure application over the seeds after drilling, compared to all other coulter treatments. When the hoe coulter without cover and pressure was used, the in-groove moisture drying rate of 2.775% r.h./day was significantly (P = 0.01) more rapid than the hoe coulter grooves with pressure over the seeds. The vapour moisture drying rate from the hoe coulter grooves without pressure was also significantly (P = 0.01) less rapid than that of the triple disc coulter without cover or pressure. The relationship between in-groove r.h. from day 6 until day 17 and time appeared to be linear. The drying rate treatment differences however remained.

The above results suggest that the chisel coulter was superior in terms of "moisture potential captivity" compared to both the hoe coulter and the triple disc coulter when no covering or pressure was applied. The performances of the both of the hoe coulter treatments were superior to the triple disc without cover or pressure in terms of maintaining a high in-groove vapour moisture. The in-groove vapour moisture drying rates of the triple disc coulter grooves and the hoe coulter grooves were reduced to levels not significantly different to that of the chisel coulter by applying pressure over the covered seeds or directly over the uncovered seeds.

TABLE 29

The effects of selected coulter design and covering methods on the in-groove soil drying rates

Treatments	Mean drying rates (-r.h.%/day)
1. Chisel coulter, no pressure	2.34 C
2. Hoe coulter, no pressure	2.775B
3. Hoe coulter, 70 kPa pressure over seeds	1.92 C
4. Triple disc coulter, no cover or pressure	4.231A
5. Triple disc coulter, no cover 70 kPa pressure over seed	2.328C
6. Triple disc coulter, 70 kPa pressure over covered seeds.	2.423C

Unlike letters show significant differences at (P = 0.01)

TABLE 30

Estimated t-statistics for differences amongst pairs of $\hat{b}_0$'s, $\hat{b}_1$'s and $\hat{b}_2$'s from the curves of vapour moisture drying rates in six coulter treatments

$\hat{b}_0$'s † differences (above) / $\hat{b}_1$'s differences (below)	Chisel coulter	Hoe coulter no pressure	Hoe coulter with pressure on seed	Triple disc coulter no pressure	Triple disc coulter with pressure over seeds	Triple disc cover and pressure over grooves
-Chisel coulter	-	*** 4.87	*** 4.09	*** 11.74	NS 1.06	NS 0.34
-Hoe coulter no pressure	*** 8.33	-	8.52	*** 6.64	*** 5.78	*** 5.0
-Hoe coulter pressure over seed	NS 0.95	*** 7.69	-	*** 15.02	*** 3.09	** 3.34
-Triple disc coulter no pressure	*** 20.0	*** 9.43	*** 17.09	-	*** 12.54	*** 11.66
-Triple disc pressure over seed	NS 0.77	*** 8.81	NS 0.21	*** 17.55	-	NS 0.7
-Triple disc coulter pressure over covered grooves	NS 1.61	*** 6.98	NS 0.62	*** 16.43	NS 0.84	-
$\hat{b}_2$'s differences						
-chisel	-					
-hoe, no pressure	*** 3.04	-				
- hoe pressure	*** 0.98	*** 22.44	-			
- triple disc no pressure	*** 8.85	*** 3.64	*** 7.07	-		
- triple disc pressure over seed	NS 0.42	*** 3.91	NS 0.57	*** 7.57	-	
- triple disc pressure over covered grooves	NS 0.73	*** 3.5	NS 0.24	*** 7.28	NS 0.33	-

NS = Not significant at (P = 0.05)

*** = Significant at (P = 0.005)

† = from equations in fig. 16.

Correlation coefficients of vapour moisture drying rates vs percentage seedling emergence, ungerminated seeds, and seedling survival were computed. A low negative correlation coeff. r = 0.588 existed between the vapour moisture drying rates and the total seedling emergence percentage. Similarly a weak positive correlation coeff. of r = 0.52 was apparent between the vapour moisture drying rates and the ungerminated seeds.

A low negative correlation coeff. between the seedling emergence and the in-groove vapour moisture drying rates may not be wholly unexpected. Results from experiment 5 suggested that seed germination was strongly associated with the liquid soil moisture availability at an early stage. For example, in the triple disc coulter groove, when the seeds were covered, followed by pressure, a relatively high vapour moisture potential (or a low vapour drying rate of 2.423% r.h./ day) was maintained, but this did not result in a correspondingly high seedling emergence, which was only 8.4%. There was however 100% seed germination in this groove, and at the termination of the experiment on day 17, 23.6% of the seeds sown were found to be still viable but had not emerged. This suggests that the improved seed cover had maintained high enough in-groove soil atmospheric relative humidity to have aided the germinated seeds in surviving for a period of a few days. Experiment 5 had also indicated however that moisture potentials as high as 0 bars in the vapour form were not sufficient to permit the seed radicles to elongate, and penetrate into moist soil layers alongside. Consequently the germinated seeds in the triple disc grooves either died or remained viable but were not able to develop to a stage of emergence.

When the triple disc coulter grooves included 70 kPa pressure directly over the uncovered seeds, the in-groove r.h. was again maintained at relatively high level (or a low vapour moisture drying rate of 2.328% r.h./day) but this too did not result in correspondingly more seedling emergence. In this case 96.1% seeds germinated but only 8.0% were found to be still alive. An explanation for this would seem to be that while the seeds initially imbibed enough moisture to germinate due to the favourable seed-soil contact (improved moisture diffusion hypothesis see section 2.3). There was not sufficient seed cover in this case to act as a buffer against the rapid drying of inner groove surfaces. Clearly, from Fig. 15 this resulted in a moisture vapour gradient away from the seed-soil interface towards

Figure (17) Computational data

Curvilinear Regression

$$\sqrt{y} = 10.62 - 2.134 \int_{1.78}^{4.45} x$$

D.F. = 16

R^2 = 58.8%

t-value = -5.02

y = seedling survival in percent

x = soil in-groove relative humidity (r.h.%/day drying rate.

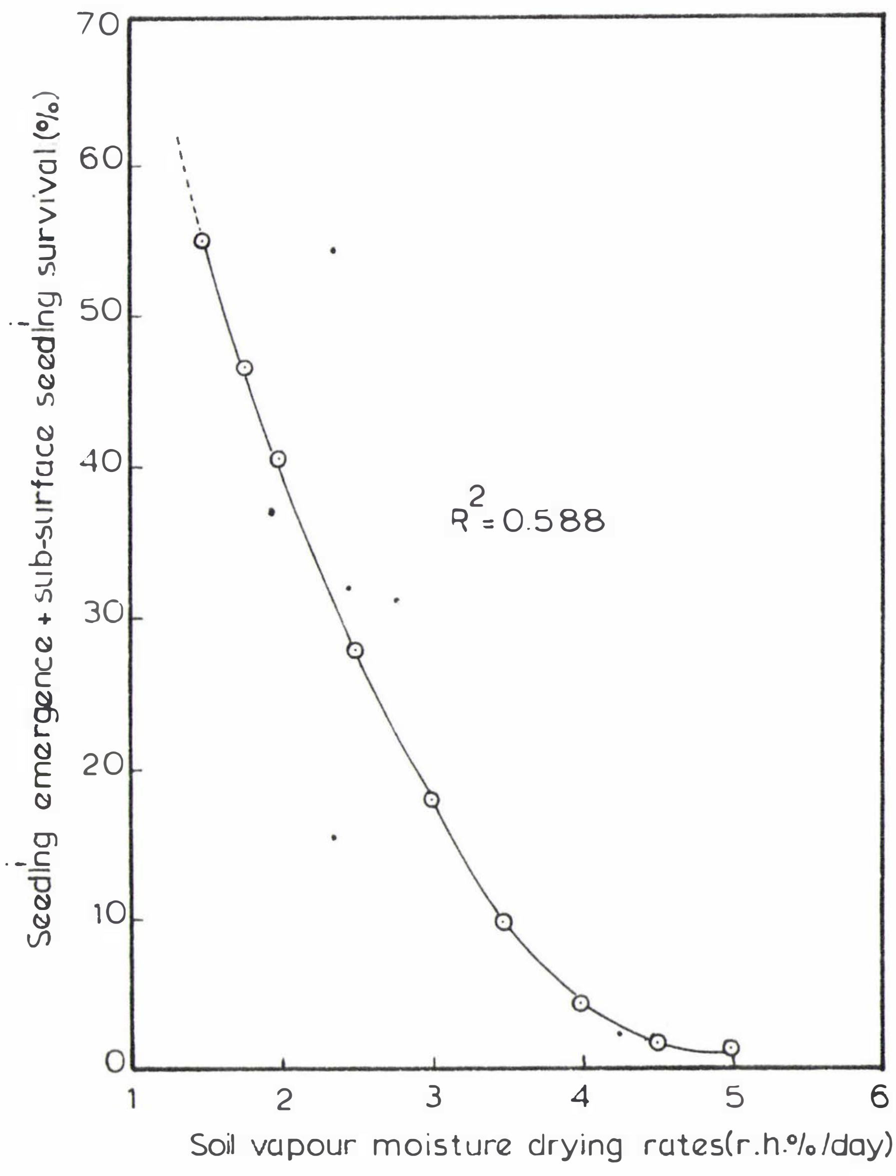


Fig. 17. Correlation curve of (seedling emergence + sub-surface seedling survival) vs in-groove relative humidity loss rate.

the atmosphere. Under these conditions the soil interface was apparently unable to supply sufficient liquid moisture to the seed interface, and seedling mortality occurred.

Since the soil vapour moisture potential (or the lack of it) appeared to be associated at least as much with the sub-surface survival of the germinated seeds as with the proliferation of this to the seedling emergence stage, it seemed logical to examine the correlation between the drying rates of the vapour moisture in the in-groove situations, and the combined percentages of seedling emergence and unemerged viable seedlings. Such a relationship showed a negative correlation coeff. of $r = 0.712$. This might be described as accounting approximately for 51% of seedling emergence and survival performance, in terms of in-groove water vapour drying rates. If this is correct, then the remaining 49% of accountability is as yet unidentified.

Using the data of drying rates from table (29) and seedling emergence from table (26), a curve was fitted which gave a significant fit as shown in the fig. (17). A mathematical model was computed:

$$\sqrt{y} = 10.62 - 2.134 \int_{1.78}^{4.45} x$$

where x = soil in-groove relative humidity (r.h.% /day) loss rate

y = seedling survival in percent.

This model showed a coefficient of determination $R^2 = 0.588$. The model gave a good first hand approximation of the expected combined seedling emergence and sub-surface survival percentages, given the mean drying rate characteristics of the in-groove r.h. for a specified coulter type.

5.4 SUMMARY OF RESULTS AND CONCLUSIONS (Experiments 5,6a,b)

It was apparent from the results of experiment 5 that Karamu wheat seeds would not germinate if moisture availability to the seeds was only in the vapour phase. Initial liquid imbibition (partially or wholly) was necessary for the seeds to germinate. After the seeds had imbibed to at least 60.0% g/g of the seeds, the seed radicles and plumules were able to grow to a few millimetres length under vapour moisture potentials of -20 bars and higher. Under this stress the seedlings would not emerge however unless the seed radicles were able to penetrate quickly into moist soil layers at a higher moisture potential, available in the liquid phase. At vapour moisture potentials less than -20 bars, the germinated seeds were not expected to emerge and sub-surface seedling mortality occurred.

From experiments 6a and 6b it was clear that the chisel coulter, the hoe coulter grooves with pressure over the seeds and the triple disc coulter with pressure over the covered or uncovered seeds were able to maintain significantly high moisture potentials (low vapour drying rates) at the seed-soil interface. Higher moisture potentials in the vapour phase appeared to be an essential component in seedling survival so long as some liquid moisture was also available. In the triple disc coulter grooves, when pressure or seed cover was not provided, there appeared to be greater moisture stress on the seedlings because of the higher initial vapour drying rates which desiccated the germinated seedlings. When seeds in the grooves of the triple disc coulter were covered, the in-groove moisture potential drying rate was generally reduced which aided the survival of some of the germinated seeds. Pressure application directly over the seeds apparently did not significantly increase the total seedling emergence however. There appeared to be a moisture desorption process away from the seed interface probably because of the lack of seed cover under very low ambient r.h. conditions. When the seeds in the triple disc groove were covered with loose soil and then pressed at 70 kPa, there appeared to be a reduction in the in-groove vapour moisture drying rate. This resulted in a higher percentage of seed germination but apparently did not result in a corresponding increase in seedling emergence, although there was an increased percentage of viable seedlings in the "germinated but unemerged" category. This showed that under low liquid moisture availability, pressure over the seeds after covering helped maintain a relatively high vapour moisture potential, and therefore resulted in an increased percentage of seedling survival, if not emergence.

Projecting these findings to field conditions it appears that under critical soil moisture conditions, coulter design parameters must be such that the resultant grooves enable the seeds to be sown at appropriate soil depths where initially, moisture is readily available in the liquid phase. The coulter design must also incorporate facilities to provide optimum seed cover with a view to avoiding the desiccation of the seed-soil interface and the maintenance of in-groove water vapour potential. The desirable seed cover characteristics should:

(a) Allow a low moisture potential diffusion from the seed-soil interface to the soil-ambient interface.

(b) Facilitate the storage of moisture near the soil surface.

(c) Protect the seeds from direct radiation.

(d) Avoid transferring dry surface soil down to the seed-soil interface at a sub-surface level.

This study confirmed the superiority of the chisel coulter over the triple disc coulter, and to a lesser extent, the hoe coulter in terms of creating soil physical conditions suitable for seedling establishment. It has however also highlighted design or technique changes which should improve the suitability of these two latter coulters. A cautious approach is needed however, when interpreting and applying the in-groove r.h. measurements and the in-groove vapour moisture potential drying rate models. Such measuring tools should be considered in relative terms and as general guidelines. For example if the r.h. measurements were taken as absolute, even the maximum r.h. reading of 97%, when converted into moisture potential would equate with -55 bars. This value is too low to allow any vapour dependent seed germination to occur. For future research priorities, therefore it appears to be important:

(i) To further refine the equipment used, and the techniques involved in the measurements of seed-soil interface moisture potential.

(ii) To conduct intensive laboratory research to test the effects of a wider range of coulter grooves on the seed-soil interface moisture potential (both liquid + vapour phase) in an effort to measure quantitatively the interactions between vapour moisture *per se* or in combination with liquid moisture, and seed germination sub-surface survival, and seedling emergence.

CHAPTER 6

FIELD EXPERIMENTS

6.1 EXPERIMENT 7: COMPARISONS OF COULTER PERFORMANCE UNDER A RANGE OF CLIMATIC AND SOIL CONDITIONS

6.1.1 Objectives

Repetitive field drilling aimed at comparing three coulter types and covering techniques was carried out fortnightly over a period of six months during the 1977/78 spring-summer-autumn periods. The purpose of this programme was two-fold.

(a) To test the repeatability in a field situation, of results of coulter performance obtained from the turf blocks studies in the climate laboratory.

(b) To provide information which might be useful in attempting to form meaningful correlations between measured ambient conditions and pre-drilling soil moisture conditions in the seed zone, and seedling emergence of wheat as a function of coulter types and covering techniques.

6.1.2 Experimental design

This experiment was designed to drill wheat seeds fortnightly, irrespective of the weather conditions. Sets of 3 examples of 3 coulter types viz. triple disc, hoe and an experimental chisel coulter were used. Thus a total of 9 test coulters were used. Two rows provided guard rows on either side of the drill. The treatment coulters were assembled on a commercially available seed drill which was followed by a bar harrow. These sets of coulters on drill are shown in plate 14.

Each set of 3 coulter types was fixed in it's position on the drill throughout the experiment. This meant that one set of a given coulter type always remained in the centre. From a statistics point of view, this was undesirable. However, because of practical limitations it was not feasible to continually interchange the position of the coulter types. Although undesirable this arrangement was not felt to have affected the results as every attempt was made to randomise the direction of travel in each plot.

6.1.3 Methods and materials

A flat area of permanent pasture was marked into 4 blocks of 12 plots (4m x 2.6m) each giving a total of 48 plots. At each drilling time 4 plots were selected randomly, sprayed with paraquat and dicamba at the rate of 5.1 l/ha and 1.4 l/ha respectively (which was the same as in the laboratory experiments). Drilling was accomplished 2 days after spraying. The pasture was mown to approximately 40-50mm height one week before spraying.

Ambient conditions

The prevailing weather data was collected from a meteorological station (Massey University) at a distance of 200 metres from the experimental site. This was expected to be representative of the conditions experienced at the site of the field experiment. Over the drilling period, the ambient and soil conditions varied from extremely dry to wet. The average weekly mean temperature and relative humidity % varying from $14^{o}C$ to $20^{o}C$. and 66% to 88% respectively. (see appendix 10d.) It was noted, that this particular summer period was unusually dry compared to the 10 year average (see appendix 10e).

Soil Moisture Measurements

Daily measurement of soil moisture status was considered to be important, to provide data that might be correlated with seed germination and seedling emergence data. It was felt to be of most relevance to measure the soil moisture status at the level of the implanted seed. Accordingly soil moisture was determined at depths of 45 mm using a specially designed core sampler. Core samples, of 12.5 mm diameter were taken from each plot.

Details of rainfall and daily soil moisture content data are given in Appendix 10c.

Seedling Emergence and Seed Fate Counts

Seedling emergence counts were taken weekly from week 1 until 3 weeks after drilling of the wheat seeds. The emergence counts were sampled from 2 m lengths of each treatment row. This represented approximately 90 seeds per row of drilling, or 270 seeds per plot.

The purpose of taking seedling emergence counts over a period of three weeks was for two reasons:

(a) This provided figures from which the plateau of total emergence could be identified.
(b) It was hoped to be able to test the effects on seedling emergence, of water stress as well as possible damage due to insects and pests in the intervening period.

During late November and in December, 1977 damage to the emerged seedlings by slugs and crickets was observed. In the final seedling emergence percentage figures for these two sampling dates an adjustment was made for this damage because the damaged shoots were still visible just below ground level. At the end of the third week after sowing, a metre length of each row was excavated with a hand scoop and seeds and seedlings were harvested for identification (seed fate). It appeared that in experiments where an adequate soil moisture was available and seedling emergence took place, most of the ungerminated and "germinated but unemerged" seeds had decayed by 3rd week. Therefore no reliable data was possible. However, in experiments where no seedling emergence occurred (in dry soil), ungerminated and "germinated but unemerged" seed data was recorded.

Experimental specifications and raw data are given in appendix 10.

6.1.4 Results and discussion

(a) Seedling emergence and seed fate counts:

Table 31 shows the final (week 3) seedling emergence percentages. The week by week data are given in appendix 10b, but only week 3 data were used in the analysis of variance and models discussed below.

TABLE 31

The effects of direct drilling coulter types on seedling emergence of direct drilled wheat (counts as at experiment termination day 21) from 12 drilling dates

	Seedling emergence percent		
Coulter types	Triple disc	Hoe	Chisel
Drilling nos.			
1	71.6 a	66.6 a	67.3 a
2	49.3 b	55.5 b	48.7 b
3	45.0 c	48.1 c	49.3 c
4	59.1 d	51.3 d	64.1 d
5	0 e	0 e	0 e
6	0 e	0 e	0 e
7	0 e	0 e	0 e
8	0 e	0 e	0 e
9	20.5 f	21.1 f	34.6 g
10	40.3 h	57.3 i	54.1 i
11	58.3 j	51.8 j	59.8 j
12	70.5 k	80.9 l	82.6 l

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

Table 32 shows the weekly averaged soil moisture contents at various intervals after drillings took place.

In the first four drillings, the soil moisture contents were high and nearing field capacity. As a result (table 31), there appeared to be generally high seedling emergence counts and there were no significant differences between coulters in this respect.

In the 5th drilling (table 31), there was no seed germination with any coulter, as the soil moisture at the time of drilling was well below wilting point(see appendix 10c). Four millimetres of rain fell 4 days after drilling and as a result increased soil moisture to a temporary peak of 23.8% which promoted 100% seed germination. However this did not result in seedling emergence until the end of the 3rd week by which time emergence counts had ceased. Seed fate samples were taken however at this time and this showed significantly (P = 0.05) higher counts of sub-surface viable seedlings (100%) in the grooves of the chisel coulter compared with 60.6% and 42.4% sub-surface viable seedlings with the hoe and triple disc coulters respectively.

In the sixth drilling (table 31), there again appeared to be no seed germination in any of the coulter grooves, as the soil moisture had again decreased to an average of 6.4%. At the end of the 2nd week, a few millimetres of rain fell, and this promoted some seed germination. This increase in moisture however was not sufficient to maintain seedling vigour to the emergence phase under the unfavourable ambient conditions which prevailed during this time (see appendix 10d).

Similarly, during 7th and 8th drillings (table 31), there was some seed germination but no seedling emergence took place with any of the coulters.

At the time of the 9th drilling (table 31), the field soil moisture content neared to the air dry equilibrium of 5% (d.b.). During the first week after drilling, rain fell and by the end of the 2nd week seeds had germinated although no seedling emergence was evident. The soil moisture content peaked to 22.3% about this time which promoted seedling emergence. The chisel coulter performed significantly (P = 0.05) better in this respect with 34.6% seedling emergence compared with the triple disc coulter (20.5%) and the hoe coulter (21.1%). The average

TABLE 32

The effects of time on soil moisture % measured at 0-45 mm depth

Drilling No.	Soil moisture %(d.b.)			
	1*	2	3	4
1	28.4	23.6	34.8	26.0
2	22.1	32.2	33.1	27.1
3	27.2	23.5	29.7	25.3
4	21.8	17.7	25.5	19.7
5	14.7	11.5	23.4	13.1
6	7.3	5.5	9.1	6.4
7	9.7	7.1	13.5	8.4
8	5.2	6.6	8.5	5.9
9	10.2	14.5	22.3	12.3
10	11.7	15.4	24.4	13.5
11	9.7	28.1	31.0	18.9
12	25.2	30.2	31.3	27.7

* (1) Mean soil moisture contents of week 1 after drilling

(2) " " " " " " 2 " "

(3) Maximum soil moisture stored at any one time within two weeks after drilling

(4) Average soil moisture contents of week 1 and week 2 after drilling

soil moisture content during the 2nd week after drilling was 14.5%.

During the 10th drilling (Table 31), further rain fell and slightly higher seedling emergence resulted overall. Seedling emergence with both the hoe and chisel coulters (57.1% and 54.1%)respectively was significantly (P = 0.05) higher than with the triple disc coulter (40.3%).

During the 11th and 12 drillings (table 31) the soil moisture content had been increased to near field capacity as a result of further rain. Seedling emergence with all coulter types increased and there appeared to be no significant differences between their performances.

The overall data suggest that at lower soil moisture levels, the triple disc coulter was most sensitive and least effective. The chisel coulter generally gave higher seedling emergence in most drillings and in 16.6% of the drillings gave a significantly (P = 0.05) higher seedling emergence performance than the triple disc coulter and in 8% of the drillings, better than the hoe coulter. These figures are possibly conservative as the arbitrary final sampling data (3 weeks) on several occasions (5th, 6th & 7th drillings) prevented a significantly larger sub-surface seedling survival count with the chisel coulter compared to the other two coulters, from being recorded as counts of seedling emergence. This data nevertheless further confirmed the superiority of the chisel coulter grooves compared to the triple disc coulter and to a lesser extent the hoe coulter grooves, in terms of their ability to promote seedling emergence.

Measurements of in-groove vapour moisture potential was not carried out in these experiments as the field experiments were conducted before the results of experiment 6 (section 5) became available. In any case no practical method had yet been devised for measuring in-groove relative humidity in the field.

In practical terms it is apparent that where the soil moisture content at the time of drilling was lower than approximately 15.0% (d.b.), the seeds were not able to germinate with any of the above mentioned coulter types used. In such dry conditions the seeds appeared to remain viable until irrigation or rain was available to germinate them. If rain followed immediately after the seeds were drilled in these dry conditions, the seeds germinated. Some of these seedlings emerged if the soil moisture content over the next 2 weeks was maintained at 15.0% or higher. In such circumstances, the chisel coulter appeared to have performed in a superior manner to either the hoe or triple disc coulters.

Correlations of week 3 seedling emergence counts from the three coulter types were made with the measured soil moisture contents at 0 to 45 mm depth. The correlation coefficient comparing the 3rd week seedling emergence data (table 31) and the second week soil moisture content (table 32) was r = 0.84. The corresponding comparison between week 3 seedling emergence and the mean of weeks 1 & 2 soil moisture content gave a correlation coeff. r = 0.82. The correlation coeff. between the average moisture content during the first week after drilling, and the maximum seedling emergence was r = 0. 60 and the correlation coeff. between the average moisture content during the week before drilling, and maximum seedling emergence at the end of the 3rd week yielded only a weak figure of r = 0.45.

While it must be acknowledged that some limitation was imposed on the data because of the arbitrary limit of three weeks for maximum emergence to take place, the above results suggest that:

(a) If the only soil moisture data available is that at or prior to drilling, the present state of knowledge would not permit accurate seedling emergence data to be predicted.

(b) If soil moisture data is available after drilling the seeds, but before seedling emergence, reasonable predictions of seedling emergence can be made given the characteristics of the coulter types used.

The correlation coefficient comparing the 3rd week seedling emergence data and the 2nd week soil moisture content appeared to be the strongest (r=0.84). However the same emergence data also showed a moderately strong relationship (r = 0.82) with the mean soil moisture data for weeks 1 & 2. The latter data was considered to be of more practical value because of its closeness to the time of drilling. It was, therefore, considered reasonable to base prediction equations, involving seedling emergence and the soil moisture contents of weeks 1 and 2 averaged.

Mathematical models of wheat seedling emergence with each of the coulter types as a function of soil moisture, were constructed for the soil moisture range from 12% to 30%. Forms of polynomial equations were computed which gave significant fits in the observed data for each of three coulter types. Additional computation details are given in fig. 18.

The representative equations are as follows:

(i) chisel coulter

$$\sqrt{Y} = -6.366 + 1.11\,X - 0.02125\,X^2$$

with a coeff. of determination $R^2 = 0.851$

(ii) hoe coulter

$$\sqrt{Y} = -5.764 + 0.9945\,X - 0.01802\,X^2$$

with a coeff. of determination $R^2 = 0.851$

(iii) triple disc coulter

$$\sqrt{Y} = -5.691 + 0.9716\,X - 0.01747\,X^2$$

with a coeff. of determination $R^2 = 0.857$

Where X = mean soil moisture content in percent (d.b.), days 1 to 14 after drilling the seeds.

Y = seedling emergence in percent three weeks after drilling took place.

Fig. 18 illustrates the effects of soil moisture and coulter types on seedling emergence.

Statistical analysis (table 33) of these models demonstrates the significantly (P = 0.01) superior performance of the chisel coulter compared to that of either the hoe or triple disc coulters. There appeared to be no significant difference in the performances of the hoe and triple disc coulters. However, there appeared to be more pronounced differences in the performances of three coulter types at lower soil moisture levels, and the models appeared to be identical at higher soil moisture conditions.

Fig. 18 Computational data

Source	D.F.	R	F-value
(1) Chisel coulter			
$\sqrt{Y} = -6.366 + 1.11X - 0.0212X^2$	45	0.851	130**
(2) Hoe coulter			
$\sqrt{Y} = -5.764 + 0.9945X - 0.0180X^2$	45	0.851	128.1 **
(3) Triple disc coulter			
$\sqrt{Y} = -5.691 + 0.9716X - 0.0174X^2$	45	0.857	134**

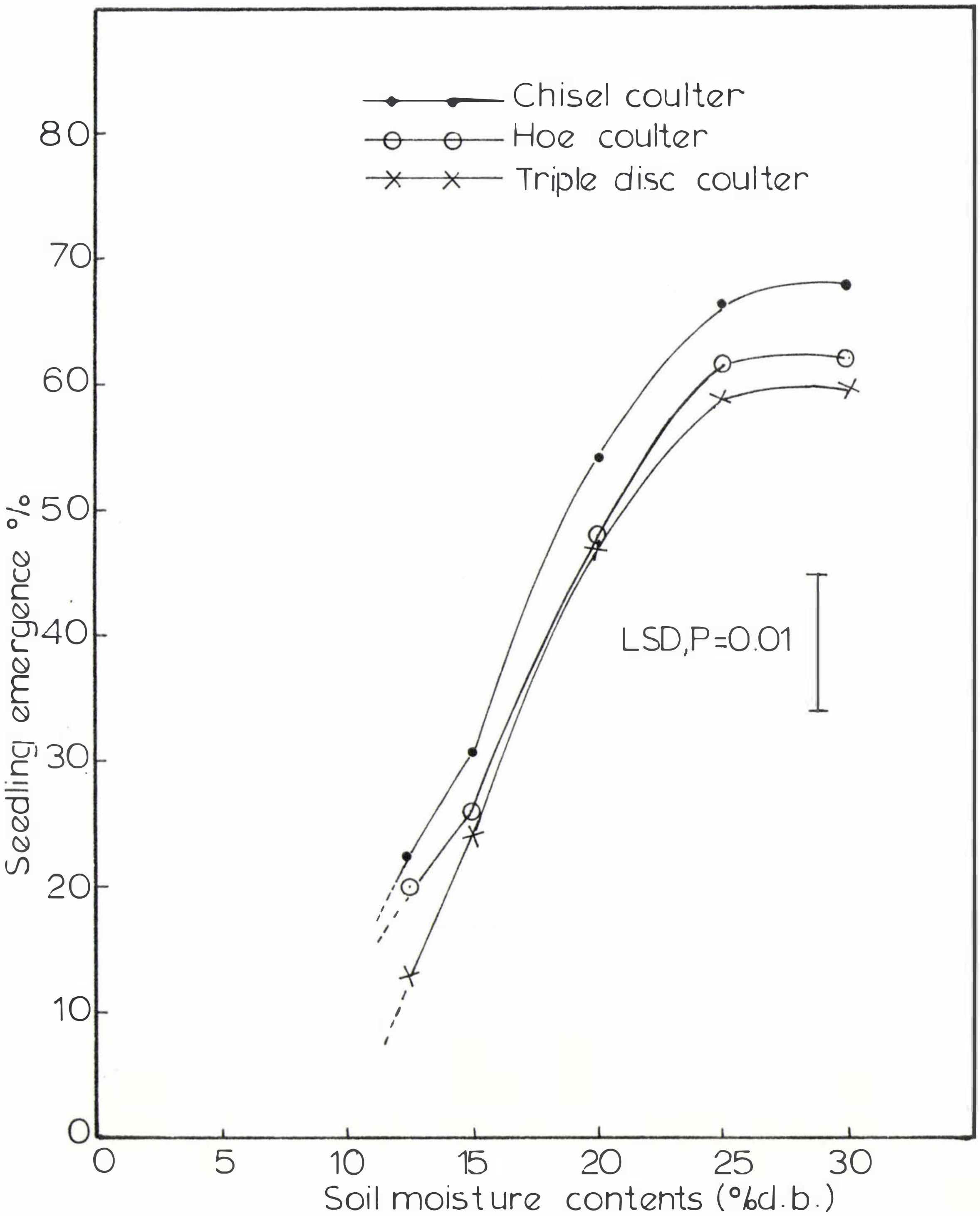


Figure 18. The effects of coulter types, under changing field moisture conditions, on seedling emergence counts.

TABLE 33

Estimated t-statistics for differences amongst pairs of $\hat{b}_0$'s, $\hat{b}_1$'s and $\hat{b}_2$'s from the curves of seedling emergence as affected by coulter type

$\hat{b}_1$'s differences \ $\hat{b}_0$'s differences[1]	Chisel coulter	Hoe coulter	Triple disc coulter
Chisel coulter	-	4.1 **	3.57 **
Hoe coulter	4.62 **	-	0.39 NS
Triple disc coulter	5.69 **	0.94 NS	-
$\hat{b}_2$'s differences			
Chisel coulter	-		
Hoe coulter	5.09 **	-	
Triple disc coulter	11.81 **	0.87 NS	-

NS = Not significant at (P = 0.05)

** = Significant at (P = 0.01)

1 = From regression equations for prediction of seedling emergence with three coulter types.

Soil moisture and ambient conditions varied considerably from extreme wet to extreme dry in the experiments, with a weekly mean day and night ambient temperature range of 14°C to 20°C and ambient relative humidity range from 66% to 88% respectively (see appendix 10a). The extent that the ambient temperature affected the seedling emergence *per se* was not evaluated. It was not possible to correlate directly the ambient temperature data with the seedling emergence data because of the complexity of the indirect effects of temperature which varied also with soil moisture changes (appendix 10a). For example the temperature data suggest that when the temperature increased from 14°C to 20°C over a period of 10 weeks, the corresponding seedling emergence was reduced from approximately 70% to 0%. Clearly such simple comparisons are meaningless in biological terms and insufficient data was collected to attempt to compare the interactions of other factors. Temperatures were, however, within the optimal range for wheat at all times.

(b) Effects of insects and other pests on seedling emergence

It was observed that some of the emerged seedlings were being affected by insects and/or other pests. In the earlier stages of experiment (7) snail and slug attacks on the emerged seedlings were apparent and considerable damage was visible. Slug pellets (3% metaldehide treated) were used at a rate of approximately 100 kg/ha in all subsequent experiments. The slug pellets appeared to be effective against the molluscs, except when it rained, but shoot damage persisted. "Thimat" (20% phorate) was also broadcast over the seed rows 2 days before seedling emergence was expected but this also was not effective in reducing shoot damage.

In the sixth drilling, a bran based diazinon bait was used, and this appeared to be effective in controlling the unidentified insects. All subsequent sowings utilized bran based diazinon as a standard insecticide treatment.

In the first 5 drillings an assessment was made of the percentage seedling emergence damage at the end of week 3 in order to adjust the final seedling emergence data. Table 34 shows the effects insects had had on seedling emergence in these drillings. Damage appeared to be greatest with the hoe and chisel coulter grooves compared with the triple disc coulter grooves. A number of crickets were found in the

TABLE 34

The effect of insects and pests on the seedling emergence percentage in three coulter types

	Mean Percentage Shoot Damage		
	Coulter types		
Drilling No	Chisel	Hoe	Triple Disc
1	-	-	-
2	17	17	10
3	22	19	15
4	15	15	8
Mean	18 a	17 a	11 b

Unlike letters amongst the means show significant differences at (P = 0.05)

grooves of the chisel and hoe coulters, while none were found in the grooves of the triple disc coulter. Apparently, in friable and more moist soils, the relatively loose and even hollow sub-surface of the chisel coulter (and to a lesser extent, the hoe coulter grooves) provided ideal cover for the insects during the day. This problem had been reported earlier, in part by Baker[67].

(c) Effects of herbicides on seedling emergence

During experiment (7) there appeared to be a larger number of emerged seedlings in the unsprayed headlands, compared to the corresponding counts in the sprayed treatment plots (Plate 15a & 15b). These unexpected observations were made only at the later stages in the field experiments, and so were not taken into account in the seedling emergence models presented earlier.

A further experiment was conducted in an attempt to quantify the effects of the herbicides used, on the seedling emergence data. This experiment is presented in section (6.2).

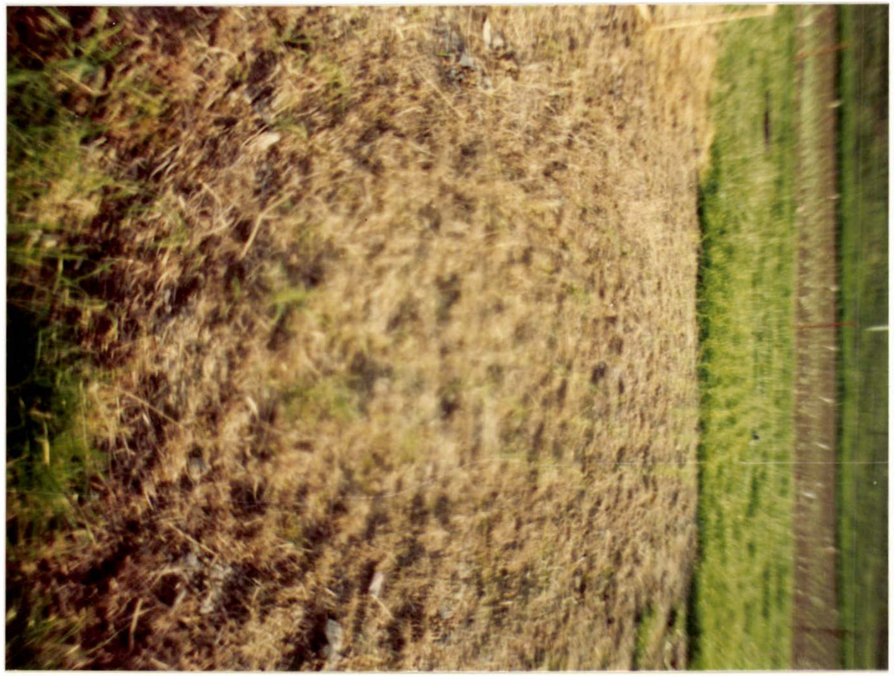


Plate 15. Typical wheat seedling emergence pattern in;

(a) Plots where paraquat + dicamba were used as predrilling herbicides

(b) Headlands where no spray was used (note more vigorous seedling emergence).

6.2 EXPERIMENT 8: ASSESSMENT OF THE EFFECTS OF PRE-DRILLING HERBICIDES USED FOR THE ESTABLISHMENT OF WHEAT SEEDLINGS

6.2.1 Introduction

The herbicides used to kill the resident vegetation in all of the experiments were paraquat and dicamba. The mixtures used were similar to those used earlier by Baker[67] and Mai[56]. The application rates were 5.6 l/ha of paraquat and 1.4 l/ha of dicamba in a single blanket spray. In the latter stages of the experiment 7 it was observed that greater seedling emergence had occurred in the unsprayed headlands through which the drill had passed, than in the sprayed plots (Plates 15a, b). These observations suggested that some effects (direct or indirect) may have arisen from the use of the herbicides.

Earlier evaluation of paraquat as a contact grass killer in combination spray-and-reseeding programmes from pasture, indicated that it was de-activated rapidly in soil but had fast contact action on herbage [91, 92, 93]. O'Toole[94] found, however, that on surface peats, (79% moisture content and approximately 2.5% ash with natural vegetation previously rotavated), paraquat applied at 1.12 kg/ha had prevented the establishment of perennial ryegrass. He suggested that paraquat application prior to sowing or as a pre-emergence herbicide might not be advisable especially on surface peats. Appleby and Brenchley[95] observed that germination of grass seed lying on the soil surface, previously exposed to paraquat sprays, could be markedly reduced. In their experiments the affected seedlings died after green shoots had emerged with paraquat application rates as low as 0.28 kg/ha. They found higher seedling emergence when the seeds were covered with 2.5 cm of soil. They suggested that grass seeds in the early stages of germination might also absorb toxic levels of paraquat from surrounding plant material. Hood *et al.* [96] postulated that in their experiments poor establishment of barley and wheat might have been due to damage from residual paraquat on the dead herbage.

Lynch *et al.*[97] observed that the presence of straw on the soil surface could increase the likelihood of injury to germinating seeds and seedlings in the early stages of development by toxic substances released from decomposing straw. They reported that this was particularly evident when the seed was drilled with the triple disc coulter as the straw was pushed into the slit so that it was close to the seed.

There does not appear to be much published data about the effects of the herbicide dicamba alone, but abundant data exist where dicamba has been used with other herbicides.

The present evidence concerning possible toxic effects of paraquat and dicamba on seed germination and seedling emergence does not appear to be clear. It was, therefore, felt to be important to investigate these effects in the particular conditions of these field experiments.

6.2.2 Experimental objectives

The aim of this experiment was to determine the effects of paraquat by itself, or in combination with dicamba, on field seedling emergence of direct drilled wheat. Application rates and times of application were considered likely to be important criteria in this regard. Three direct drilling coulters and covering methods were tested. These were the triple disc coulter, the hoe coulter, and chisel coulter; each followed by the bar harrow.

6.2.3 Experimental Design (Experiment 8)

An experimental site was chosen on a "Tokomaru silt loam" soil supporting a permanent pasture of approximately 50 mm height. The following treatments were tested:

1. Paraquat sprayed 4 days prior to drilling
2. Paraquat + dicamba sprayed 4 days prior to drilling
3. Paraquat sprayed 4 hours prior to drilling
4. Paraquat + dicamba sprayed 4 hours prior to drilling
5. No spray.

Paraquat and dicamba application rates were 5.6 l/ha and 2 l/ha respectively and were applied with water at approximately 300 l/ha. Dicamba was used at a slightly higher rate than that in the previous experiments to determine the likely affect if the herbicide had been applied at a higher rate in error.

The experimental design was a split-plot randomised block with 4 replicates and the plot size was 4 m x 4 m. The plots were drilled with three rows of each coulter type in an identical manner to the field experiment previously described. A programme pack "XALEMA/ TEDDYBEAR" within 'Cande' was used to compute the data (see appendix 11c). Drilling took place when soil moisture contents were at approximately field capacity. The weekly mean ambient relative humidity and daily average temperature was 85% and 11.5°C respectively (see appendix 10d).

Seedling Emergence Counts and Herbage Dry Matter Yield

The first seedling emergence count was taken one week after drilling, followed by weekly counts until the total number of emerged seedlings had stabilised. Seedling emergence counts were taken randomly from 2 metre lengths of each row. At the end of the 10th week, the dry matter yield of the crop was measured. Specifications and raw data of this experiment are given in appendix 11 a & b).

6.2.4 Results and discussion

Table 35 shows the effects of the type and time of application of herbicides and coulter types on seedling emergence percentages. It appears that there were significant overall differences in seedling emergence between the combination treatments of types of herbicides and times of application. Seedling emergence counts were reduced significantly (P = 0.01) to 63.9% when paraquat + dicamba was applied 4 days before sowing, compared to a count of 75.2% when paraquat alone was applied at the same time. There was however no significant effect on seedling emergence when paraquat + dicamba was applied 4 hours before drilling took place compared with paraquat alone at the same time. There were no significant effects which could be attributable to the time of application of paraquat alone.

When no spray was used, a low seedling emergence count of 64.8% was recorded and this was significantly (P = 0.05) lower than when paraquat alone was applied, but was not significantly different to when dicamba was added to the spray. Reduction in seedling emergence counts, when no spray was applied, was probably linked with competition for water and nutrients, but did not confirm the apparently better establishment in the headlands in experiment 7.

TABLE 35

The effects of type and the time of application of pre-drilling herbicides and coulter types on seedling emergence of the direct drilled wheat.

Treatment factor	Percent seedling emergence
Spray type and time of application	
1. Paraquat application 4 days before drilling	75.2 Aa
2. Paraquat + dicamba application 4 days before drilling	63.9 Bb
3. Paraquat applied 4 hours before drilling	74.3 ABa
4. Paraquat + dicamba applied 4 hours before drilling	70.9 ABab
5. No spray, grass grazed to approx. 50 mm height	64.8 ABb
Coulter types	
Chisel	73.0 a
Hoe	70.5 ab
Triple disc	65.9 b

Spray type and time of application x coulter type interaction NS

Unlike letters show significant differences, capitals (P = 0.01) and small letters (P = 0.05).

Table 35 also shows the effects across spray applications of the three coulter types on seedling emergence. There appeared to be significantly (P = 0.05) a lower seedling emergence count of 65.9% when the triple disc coulter was used than when the chisel coulter was used (73.0%). The seedling emergence count of 70.5%, when the hoe coulter was used, was intermediate between, and not significantly different from either the chisel or triple disc coulters. This confirms earlier data reported herein and may also confirm the results of Lynch *et al.* [97].

The interactions between coulter types and combinations of herbicide and time of application appeared to be insignificant.

Table 36 shows the effects of herbicides on the dry matter yield of the wheat crop at day 70. The herbage dry matter was highest (0.307 gm/per plant), when paraquat was applied alone 4 days before drilling and this was significantly (P = 0.05) higher than when either paraquat + dicamba was used 4 days before drilling (0.133 gm / per plant) or no spray was applied (0.166 gm/per plant) which themselves were not significantly different. There were no significant differences in the herbage dry matter yields when paraquat alone was applied 4 hours before drilling (0.263 gm/per plant) and when paraquat + dicamba was used at the same time (0.234 gm/per plant).

Table 36 also shows the dry matter yield/100 seeds sown. This generally reflected the seedling emergence counts, indicating that no significant interaction between plant vigour and population had occurred.

From the data of herbage dry matter yield and seedling emergence counts it might be concluded that when dicamba was added to the spray mix, this had a detrimental effect on plant establishment, but only when it was applied 4 days before drilling.

TABLE 36

The effects of types of pre-drilling herbicides and their time of application on the dry matter yield of wheat seedlings (10 week old)

Treatments	Herbage Dry Matter Yield	
	gm per plant	gm/2m row length (or 100 seeds sown)
1. Paraquat application 4 days before drilling	0.307 a	23.1 a
2, Paraquat + dicamba 4 days before drilling	0.133 b	8.5 b
3. Paraquat only sprayed 4 hours before drilling	0.263 a	19.6 a
4. Paraquat + dicamba sprayed 4 hours before drilling	0.234 ab	16.6 a
5. No spray (grass grazed to approx. 50 mm height)	0.166 b	10.8 b

Unlike letters in a column show significant differences at ($P = 0.05$)

CHAPTER 7

SUMMARY AND DISCUSSION

The understanding of soil physical factors and their interrelationships with seed germination and seedling emergence was regarded as being fundamental to the functional design of seed drill coulters. This project was initiated against a background of limited published data about the effects of different direct drilling coulter designs on the seed-soil interface micro-environment and the interactions of the latter with seed germination and seedling emergence.

The objective of the study was to identify and investigate the salient soil physical parameters which might have been altered by the actions of different designs of direct drilling coulters and covering methods; and in turn the effects that these might have had on the emergence of wheat seedlings. To the extent that these factors could be influenced by mechanical designs, such information was felt to be a valuable pre-requisite for planter design.

The research work was conducted in three main sections:

(a) Laboratory tillage bin studies of seedling emergence.

(b) Laboratory bin studies of the seed-soil interface micro-environment in direct drilled grooves.

(c) Field experiments comparing coulter performance under a range of climatic and soil conditions.

(a) Laboratory tillage bin study of seedling emergence (experiments 1a, 1b, 2a & 2b)

The common objective of the four tillage bin studies was to investigate the interactions of initial soil moisture content, seed-soil contact (as a function of pressure applied over the covered or uncovered seeds), and two soil drying regimes in controlled climatic conditions with three direct drilling coulters, in terms of seedling emergence and seed fate.

In support of this study a number of measuring devices and techniques were developed and utilized for the instrumentation in these experiments. Initially, studies were conducted to examine appropriate methods of measuring the in-groove liquid soil moisture content in the soil blocks. Psychrometers, resistance blocks and indirect thermogravimetric methods were found to be inappropriate for this particular study. A direct thermogravimetric method was found to be the most accurate and reliable technique to measure soil liquid moisture near to the surface.

A number of presswheels and devices were developed and fabricated for pressure application treatments on and above the sown seeds. A "mechanical seedling" penetrometer was also designed to simulate wheat seedling emergence by penetration from beneath the soil surface. This device was used to measure soil impedence over the seeds in an effort to identify any effects of soil compaction or soil density on seedling emergence performance. All the experiments were carried out in a controlled climatic laboratory under two regimes of ambient conditions (warm dry, and warm moist) in an endeavour to test the effects of such conditions on soil physical characteristics together with any interactions with coulter design.

The results suggested that in initially wet soils, two of the three coulter types tested (viz, chisel coulter, hoe coulter) performed equally in terms of promoting seedling emergence of wheat. The third coulter viz. triple disc coulter, promoted significantly lower seedling emergence compared to the chisel and hoe coulters. The contrasting ambient comditions, dry or humid, did not significantly affect the measured soil physical characteristics, nor seedling emergence. Similarly applied pressures, whether over the covered grooves or directly over the uncovered seeds, did not significantly modify the performance of any of the three coulter types under wet soil conditions.

Significant differences in coulter performance were apparent, however in initially dry soils. The performance of the experimental chisel coulter was significantly ($P = 0.01$) superior to both the hoe and triple disc coulters. The hoe coulter in turn was significantly ($P = 0.01$) superior to the triple disc coulter. Pressures applied over the top of the covered grooves made no significant differences to seedling emergence performance compared to the corresponding treatments without pressures. Significant increases in seedling emergence, however, were measured both with the hoe coulter ($P = 0.01$) and triple disc coulter (P = 0.05) when the seeds were directly pressed into the groove base at 35 kPa before covering compared with when no pressures were applied. Seedling emergence counts further increased with these two coulters when pressures were applied at 70 kPa. No such increases in seedling emergence were noticed with the chisel coulter when seeds were pressed, mainly because seedling emergence had been high without pressure with this coulter.

The change in ambient relative humidity conditions generally resulted in corresponding changes in seedling emergence except with the triple disc coulter. When the hoe coulter was used and seeds were directly pressed at 35 kPa in dry soil, seedling emergence counts were significantly (P = 0.05) higher (66%) in the high relative humidity regime compared to 40% at the lower relative humidity level. The corresponding figures at 70 kPa were 79.9% and 44% respectively and were also significant at the 5% level of probability. Similarly when the chisel coulter was used, seedling emergence increased significantly (P=0.05) from 47.7% in the low r.h. regime to 67.3% in the high r.h. regime. When the seeds were pressed after bar harrowing in the chisel and hoe coulter grooves, there were significant increases (P = 0.05) in seedling emergence in the high r.h. regime compared to those in the low r.h. regime. However in the triple disc grooves the change in ambient relative humidity made no significant difference to seedling emergence performance.

The lower seedling emergence counts with the hoe coulter appeared to be reflected in significantly higher number of ungerminated seeds in dry soils. With the triple disc coulter, in contrast to the hoe coulter, the lower seedling emergence counts appeared to reflect significantly higher percentage of "germinated but unemerged" seeds in similar moisture conditions.

Combined results (see section 2.5) suggested that the triple disc coulter inversely and significantly (P = 0.01) affected the number of unemerged seedlings as percentage of germinated seeds when the initial soil moisture level increased from low to adequate. The chisel coulter appeared to be insensitive in this respect, while the hoe coulter had intermediate sensitivity. Combined results also suggest that the number of unemerged seedlings as a percentage of germinated seeds significantly (P = 0.05) reduced with the hoe coulter, when pressure was applied directly over uncovered seeds compared to that when pressures were applied over covered seeds. No such differences appeared due to the positions of applied pressures, when either the chisel or triple disc coulters were used.

Generally, in the hoe coulter grooves in dry soils, the liquid moisture loss was significantly higher than from the chisel and triple disc coulters. The in-groove liquid soil moisture drying curves, not unexpectedly showed higher drying rates in the lower relative humidity regime compared to those in the higher r.h. regime for all coulters in dry soils.

The "mechanical seedling" penetrometer studies indicated that soil impedence over the top of the sown seeds increased significantly ($P = 0.05$) when the pressure over the covered grooves was increased from 0 kPa to 35 kPa in all coulter types. Impedence was significantly ($P = 0.05$) higher when the hoe coulter was used compared with the chisel coulter and the triple disc coulter. Climatic changes in these experiments had no significant effects on the soil impedence. Soil impedence measurements however appeared to be within an absolute range which could be expected to have little effect on true seedling emergence.

Clearly the effects that the contrasting coulter designs had had on wheat seedling emergence could not be explained in full by liquid soil moisture levels in the grooves. Accordingly further experiments sought to examine the role of vapour soil moisture in this respect. Three general hypotheses were put forward for examination.

(i) "Moisture Potential Captivity"

The hypothesis of "moisture potential captivity" suggested that those direct drilled grooves, which were able to maintain a high moisture potential in the vapour form were capable of promoting a high percentage of survival of germinated seedlings under dry soil conditions. This appeared to be a characteristic displayed by the chisel coulter groove.

(ii) "Moisture Potential Diffusion"

The hypothesis of "moisture potential diffusion" related to the transference of moisture through or from the soil interface to the seed interface. When seeds were directly pressed into the base of the grooves before covering with the hoe coulter (and to a lesser extent with the triple disc coulter), increased seedling emergence occurred.

(iii) The creation or transfer of a thin dry soil layer to the exposed inner surfaces of the grooves was partially responsible for reduced "moisture potential diffusion". This was considered to be a possible cause of the desiccation of some germinated seeds through a moisture desorption process away from the seed interface. This phenomena appeared to be most pronounced in the triple disc coulter grooves, because of dry soil carried down from the surface by the discs.

Experiments were designed to examine the validity of these hypotheses.

(b) Laboratory bin studies of the seed-soil interface micro-environment in direct drilled grooves

Small wooden boxes containing undisturbed soil samples of (450 mm x 304 mm x 100 mm) were utilized in the first of three experiments (expt. 4). It was felt to be most appropriate to attempt to improve the coulter type which had appeared to be least effective in terms of seedling emergence performance in the previous experiment (1a & 1b). This was the triple disc coulter.

A combination of treatments including induced compaction and smearing and covering of the grooves with loose soil and polythene, were tested under a high soil drying regime (55/60% r.h. day/night and 22/18^{o}C day/night temperature) and at a high initial soil moisture stress. The results suggested that compaction and/or smearing, either did not occur, or if they did occur, apparently did not result in any reduction of seedling emergence when the triple disc coulter was employed.

When a loose soil cover was provided over the seeds drilled with the triple disc coulter, no increased seedling emergence was noted. When the seeds were pressed into the base of the grooves there appeared to be a significant (P = 0.05) increase in seedling emergence. These results strengthened the hypothesis of "moisture potential diffusion" evolved as a result of the earlier experiments. Later experiments were not however able to fully explain the mechanism of soil moisture availability to the seeds and its effects on sub-surface seedling survival.

Further laboratory experiments were, therefore, conducted, on the one hand to determine the 'karamu' wheat seed germination isotherms in the presence of liquid and vapour moisture (experiment 5), and on the other hand to measure the soil in-groove vapour moisture potential (experiment 6).

Results from experiment 5 suggested that the seeds, when grown in contact with moisture at -11 bars or above, were capable of germinating and sustaining seedling growth, provided that the seed radicles were able to penetrate into more moist soil layers alongside, within 2 to 3 days after sowing. At moisture potentials drier than -11 bars the seeds might germinate but could not be expected to have sufficient vigour to supplement their energy supply through root anchorage, and therefore to emerge. These results also suggested that when soil moisture availability to seeds was only in the vapour form, karamu wheat seeds could not be expected to germinate.

Experiments were then conducted to test various methods of measuring vapour moisture potential in the direct drilled grooves at the seed-soil interface. A dew point hygrometer was found to be most appropriate for this purpose. An air sampler was designed using 4 mm (inside diameter) transparent nylon tube. Air sampling tubes were embedded in the grooves immediately after the seeds were drilled. Experiment 6(a) indicated that it was possible to measure significant differences in in-groove r.h. levels in a range of soil grooves. Experiment 6(b) clearly indicated that when the triple disc coulter was employed, the in-groove r.h. decreased at a mean rate of 4.231%/day for the first six days after drilling. This rate was significantly ($P = 0.01$) higher than that of the chisel coulter groove (2.34%/day) and the hoe coulter (2.75%/day). Although seedling emergence from the same grooves was correspondingly lower in the triple disc coulter compared to that with the chisel and the hoe coulter, the correlation coefficient between in-groove r.h. drying rates and seedling emergence across all coulters was only $r = 0.588$.

When the seeds in the triple disc grooves were either pressed into the base of the uncovered grooves or when pressure was applied over the covered grooves, the in-groove r.h. mean drying rate was significantly ($P = 0.05$) reduced compared to that in the unpressed triple disc grooves. This improvement in the drying rate however did not result in a corresponding increase in the seedling emergence from these grooves. It did however result in a significant increase in the sub-surface survival of germinated seeds 21 days after drilling. The correlation coefficient between the in-groove r.h. drying rate across all coulters and seedling survival (emergence plus sub-surface survival) was more encouraging at $r \doteqdot 0.712$.

It appeared that the factors responsible for the higher seedling emergence (particularly in dry soil) with the chisel coulter and conversely the low emergence from the unmodified triple disc coulter were attributable to the ability of the former coulter;

(i) To exploit the limited supply of sub-surface soil moisture, and to place the seed initially in a favourable environment.

(ii) To leave the slit closed to the atmosphere in a manner which permitted maintenance of a high "moisture potential captivity" at the soil-seed interface.

(iii) To create minimum surface soil shattering and thus maintain a high incidence of surface mulch in the form of sod and organic matter which in turn apparently assisted in the maintenance of a high "moisture potential captivity" in the vicinity of seeds, and

(iv) To physically loosen and shatter the sub-surface soil to assist in rapid root anchorage and exploitation of soil liquid moisture.

The lesser performance of the triple disc coulter, in terms of seedling emergence, appeared to be mainly because of its inability to create the soil-seed physical environment outlined above. The hoe coulter created seed-soil interface characteristics which permitted significantly superior seedling emergence to that of the triple disc coulter under moisture stress, but significantly lower performance to that of the chisel coulter. However, when the physical characteristics of the hoe coulter grooves were modified using covering and/or pressure applications, the seedling emergence from such grooves was improved to be little different from those of the chisel coulter.

(c) Field experiments comparing coulter performance under a range of climatic and soil conditions

Field experiments were conducted to test the repeatability in a field situation, of results obtained from the turf blocks in the climate laboratory. It was expected that these experiments would give some indication of the frequency and magnitude of treatment differences during one season under a range of climatic conditions, and that such results would be useful in attempting to formulate meaningful correlations between ambient conditions, soil moisture status, and seedling emergence using three designs of coulters.

These experiments on a silt loam soil and using karamu wheat were drilled at fortnightly intervals during spring/summer/autumn 1977/78. A total of 12 drillings were accomplished. The results suggested that seedling emergence was strongly correlated ($r = 0.84$) with the average surface soil moisture, measured at 0 to 45 mm depth, during the second week after drilling. These results also suggested that:

(i) If the only soil moisture data available was that at or prior to drilling, the present state of knowledge would not permit accurate seedling emergence data to be predicted.

(ii) If soil moisture was available after drilling, but before seedling emergence, reasonable predictions of seedling emergence could be made given the characteristics of the coulter types.

From the limited data available example mathematical models of seedling emergence, as a function of soil moisture contents (average of 2nd week after drilling) were constructed for each of the coulters operating in soil with moisture content in the range of 12% to 30% (d.b.)

These models were as follows:

1. Triple disc coulter

$$\sqrt{\text{Seedling emergence \%}} = -5.692 + 0.977\,(\text{m.c.\%}) - 0.0174\,(\text{m.c.\%})^2$$

2. Hoe coulter

$$\sqrt{\text{Seedling emergence \%}} = -5.764 + 0.994\,(\text{m.c.\%}) - 0.018\,(\text{m.c.\%})^2$$

3. Chisel coulter

$$\sqrt{\text{Seedling emergence \%}} = -6.366 + 1.11\ (\text{m.c.\%}) - 0.0212(\text{m.c.\%})^2$$

The field experiments indicated that the chisel coulter had given significantly (P = 0.01) superior seedling emergence compared to the hoe coulter and the triple disc coulter in 8.3% and 16.6% of the drillings respectively in that particular season. The occasions when differences were recorded were climatically dry. The seedling emergence with the hoe coulter was not significantly different to that of the triple disc coulter at any time. At lower soil moisture contents, there might have been a slightly higher seedling emergence from the hoe coulter than the triple disc coulter, but these differences were not significant. The computed mathematical models also suggest that the chisel coulter apparently performed significantly (P = 0.01) better in overall drillings compared with the hoe and triple disc coulters.

Experiments were also conducted to test the effects of the pre-drilling herbicides used, because in the later stages of the field experiments it appeared that the herbicides might have had some detrimental effects on seedling emergence.

Paraquat and dicamba were used in all the experiments. The experiments suggested that when dicamba was sprayed at a rate of 2 l/ha with 5.6 l/ha of paraquat in a mixture of 300 litres of water 4 days before drilling, wheat seedling emergence was significantly reduced compared to that when only paraquat was used (experiment 8). However such effects were not significant when dicamba + paraquat were sprayed only 4 hours before the drilling took place. These effects appeared to be more pronounced (P = 0.05) when the triple disc coulter was used compared to either the hoe or chisel coulters. No attempt was made to fully explain the mechanism of these effects but in the latter situation it is possible that contaminated soil was carried down into the grooves. Clearly further work is justified in this area.

Conclusions and Research Priorities

The results of the tillage bin study under controlled climatic conditions (experiment 1 & 2) have been able to confirm earlier trends reported by Baker [76] who conducted similar experiments under a partially controlled environment. The present study has also been able to test the effects of controlled climatic conditions on the performance of three different coulter types under two initial soil moisture conditions. Using a combination of covering and pressure applications over the seeds the study has demonstrated that in dry soils the in-groove "moisture potential captivity" at the seed-soil interface and the "moisture potential diffusion" between the soil-interface and the seed interface were dynamic processes and that the magnitudes and rates of changes of the parameters were correlated with the types of coulter and covering techniques used to form the grooves (experiment 6).

Field experimental data was used to form mathematical models to predict seedling emergence, given specified soil moisture and ambient conditions. Though based on limited data, these prediction equations appear promising for further refinement. This study suggests strongly that under soil moisture stress and unfavourable ambient conditions, the design characteristics of the groove openers are of major importance.

It is suggested that further research work should be conducted in the following directions"

(i) Refine the equipment used, and the techniques involved in the measurement of the in-groove seed-soil interface moisture potential in an effort to measure more precisely the interactions of liquid and/or vapour moisture potentials with seed germination and seedling emergence as a function of coulter design parameters.

(ii) Conduct further field experiments to improve the reliability of seedling emergence mathematical models, for use with given coulter types, crop species, weather and soil conditions.

(iii) Devise simple instrumentation to test the suitability of direct drilling systems for given on-farm conditions.

CHAPTER 3

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ACKNOWLEDGEMENTS

I wish to express my thanks to my chief supervisor, Dr C.J. Baker, Reader in agricultural mechanisation, for his continuous interest and advice and for his patience in reading the manuscript of this thesis. Similarly, thanks are due to my co-supervisors, Dr D.R. Scotter and Prof B.R. Watkin, who offered advice on aspects of the soil physical studies of this investigation and agronomic aspects and general advice respectively.

Grateful acknowledgement is made to Grassland Division, D.S.I.R. for financial assistance and to Plant Physiology Division, D.S.I.R. (and in particular to Mr A.K. Hardacre and Mr I.J. Warrington) for assistance with growth room facilities.

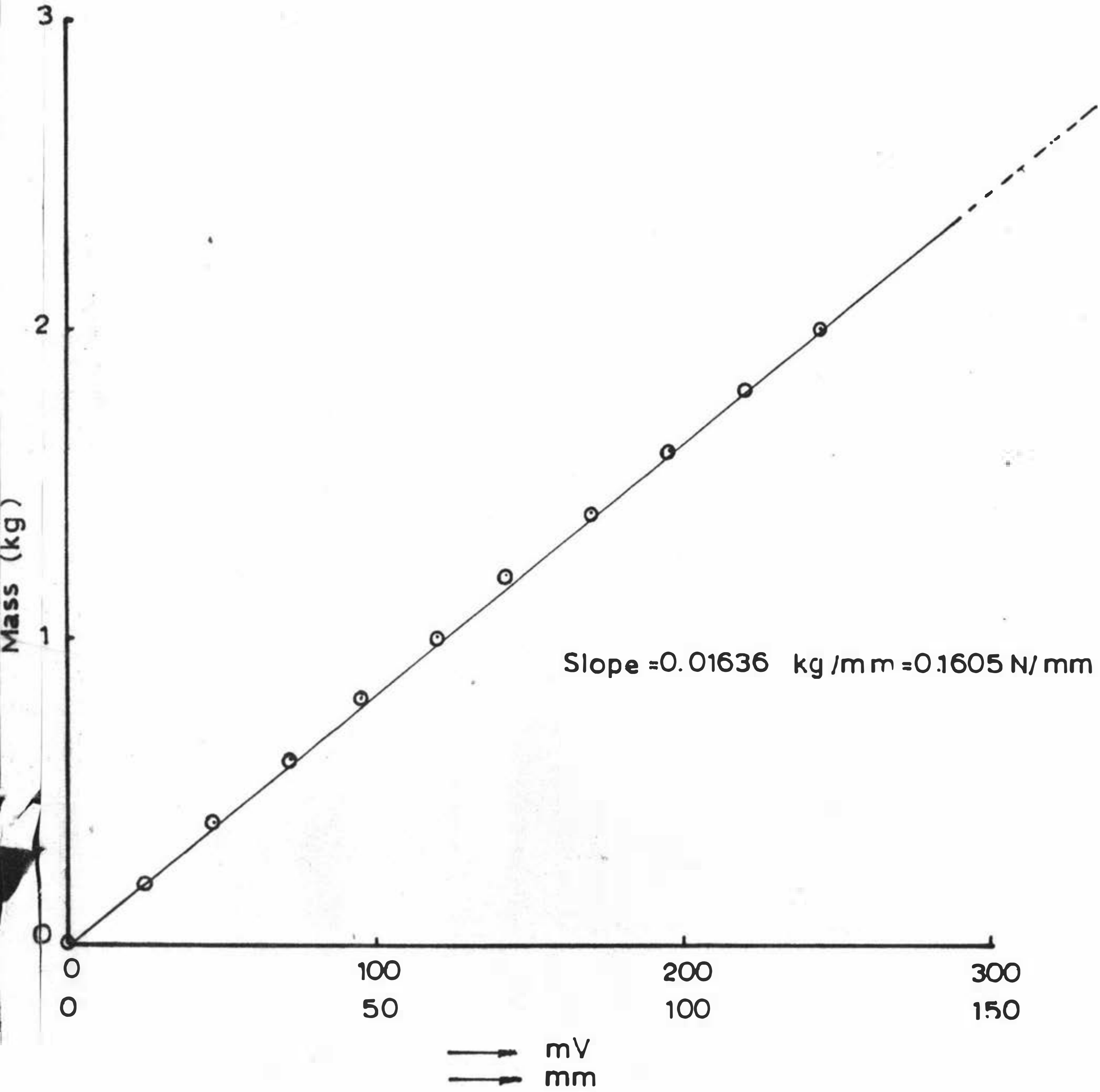
Special thanks are due to Messrs E.M. Badger and J.H. MacDonald for construction of the equipment used in this study and also for their continuous assistance during experimental work. Thanks are also due to many other staff members in the Agronomy Department (and especially those in the agricultural mechanisation section) who assisted in numerous ways towards the accomplishment of this project.

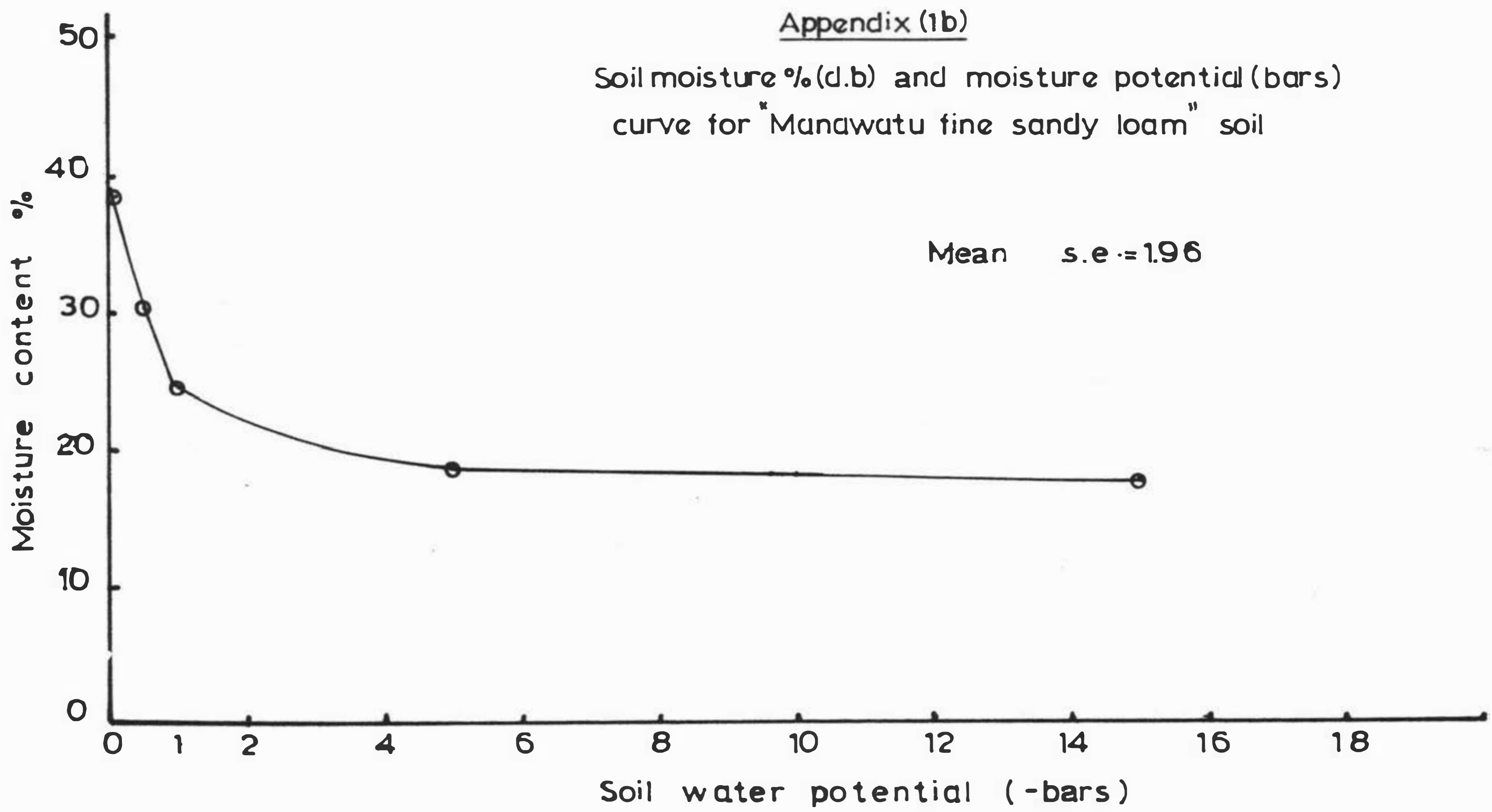
Finally, thanks are due to Mrs J. Humphries for typing this thesis.

APPENDICES

Appendix (1 a)

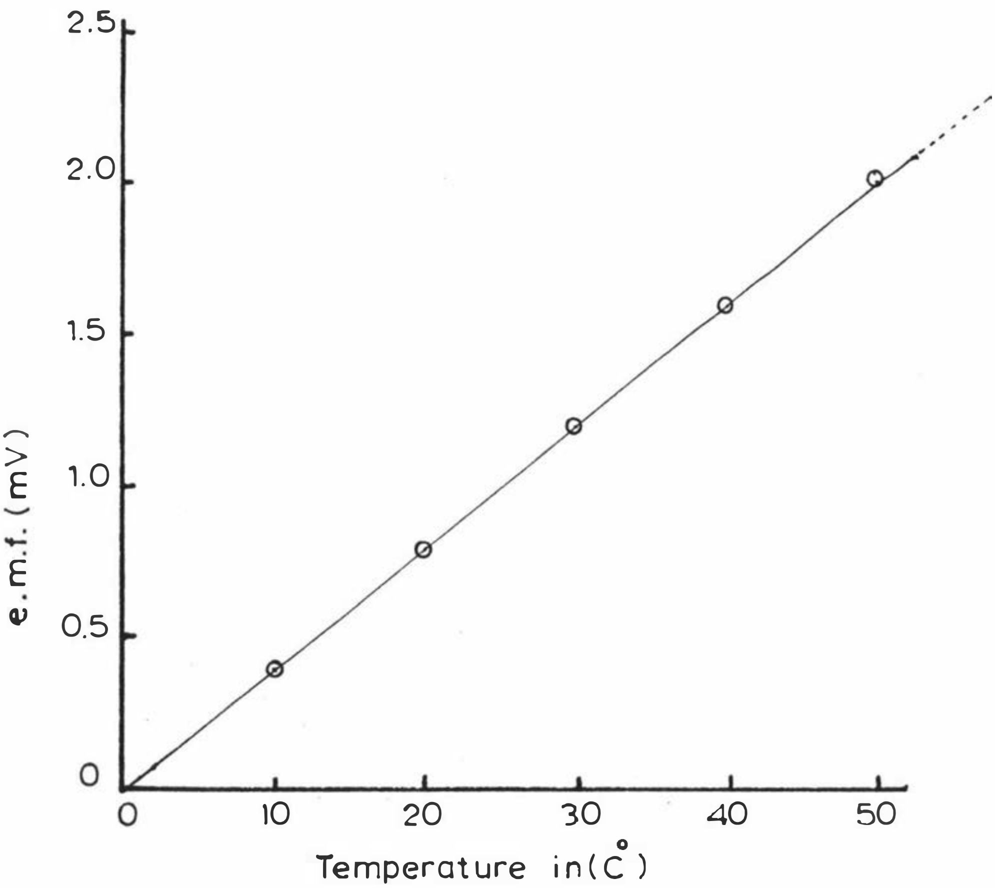
Pressure transducer calibration for penetrometer




Appendix (1b)
Soil moisture % (d.b) and moisture potential (bars)
curve for "Manawatu fine sandy loam" soil
Mean s.e = 1.96
Moisture content %
50
40
30
20
10
0
0
1
2
4
6
8
10
12
14
16
18
Soil water potential (-bars)

Appendix (1c)

Thermocouple calibration curve



APPENDIX 2

Calibration of soil moisture measuring techniques

Specification of climatic conditions in climate laboratory

Experiment date	29.11.1976	
	Day	Night
r.h.	47.2%	71%
Light (P.A.R.)	5 hours	
V.P.D.	9 mb	
Temperature	$25^{o}C$	$15^{o}C$
Dew pt.	19.5	3.8

Soil moisture measuring techniques tested

1. Psychrometers
2. Gypsum blocks
3. Gypsum beads
4. Glass fibre paper
5. Gravimetric method

Apparatus requirements: Micro volt meter, moisture meter (a.c. wheatstone bridge), Psychrometers and different size of gypsum blocks.

APPENDIX 2a

Testing and calibration of three types of gypsum blocks

Date: 10.12.1976

Gypsum blocks: 3 types x 8 = 24.

Resistance in kΩ

Time Days	Soil Moisture % (d.b.)	6 mm φ								7.5 mm φ								15 mm φ							
		1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
1	26.4	1.2	1.2	0.9	0.97	1.43	0.82	0.7	4.7	1.2	0.66	0.84	1.0	1.16	2.16	1.35	1.0	1.04	1.06	1.0	1.1	0.8	1.25	1.3	1.3
2	23.2	2.2	3.1	1.05	1.05	1.53	0.84	0.78	5.6	1.95	0.73	0.9	1.0	1.2	2.3	1.5	1.2	1.45	1.45	1.05	1.3	0.85	1.6	1.8	1.45
3	21.9	1.0	32	1.3	1.7	0.9	0.88	6.0	6	0.7	1.0	1.0	1.0	1.3	2.5	1.85	1.5	2.9	2.5	1.25	1.6	0.9	2.4	3.3	1.85
4	18.5	63	108	1.7	1.7	2.0	1.0	1.1	11.0	95	0.8	1.2	1.0	1.4	2.9	2.4	2.0	12.3	6.3	1.5	2.35	1.0	4.7	6.2	2.8
5	18.6	82	180	2.4	2.4	2.3	1.4	1.4	27	400	0.9	1.5	1.1	1.7	3.4	3.3	3.1	55	17	2	4.4	1.24	13	21	4.5
6	16.8	150	300	3.5	3.9	2.6	2.1	2.1	93	750	1.1	2.1	1.3	2.4	3.5	4.7	5.5	75	47	2.8	11.6	1.5	46	33	7.4
7	20.9	280	550	5.4	6.7	2.9	3.5	3.4	220	800	1.5	3.7	1.6	5.0	4.3	6	10.5	105	62	43	35	2.2	68	38	18.4
8	14.2	600	700	7	14.2	3.5	16	5.7	370	1000	2.7	7	2.3	2.1	5.5	10	24	150	90	5.4	50	3.5	92	46	34
9	9.6	700	800	9.6	26	4.4	42	11	400	1200	5.7	16.5	3.9	63	5.9	24	39	190	85	9	59	6	110	50	46

APPENDIX 2b

Date 29 November, 1976

Testing of Gypsum blocks in two soil moisture conditions

Soil moisture % (d.b.)	Time	Resistance in Ohms							
	Block no.	1	2	3	4	5	6	7	8
Low moisture	Resistance under Vaccuum	450	600	520	450	520	450	520	450
15.7	0 hr	840	710	700	760	800	1000	720	750
14.9	4 hr	720	600	640	710	740	900	670	690
14.5	1 day	720	660	650	750	750	930	700	720
14.1	2	850	780	740	800	800	1040	720	800
14.0	3	860	780	740	850	800	1050	650	840
13.4	4	1000	950	900	980	850	1650	750	2100
Higher moisture									
	Resistance under Vacuum	520	450	520	450	600	600	550	450
33.2	0 hr	500	600	520	500	750	750	800	450
32.9	4 hr	500	450	550	450	710	700	770	410
31.5	1 day	600	450	570	450	710	700	770	400
30.0	3	550	500	550	550	750	700	800	400
29.1	4	600	500	550	500	800	700	840	450

APPENDIX 2c

Testing of Gypsum blocks in three coulter type grooves

Time After drilling days	Gravimetric moisture content % (d.b.) (mean)	Chisel coulter 1	2	3	Mean	Hoe coulter 1	2	3	Mean	Triple disc coulter 1	2	3	Mean
		k ohms				k ohms				k ohms			
1		1.25	0.7	1.0	0.98	0.85	1.2	1.1	1.05	1.78	1.05	0.99	1.27
2		1.3	0.7	1.0	1.0	1.0	1.2	1.2	1.1	1.8	1.1	1.1	1.3
3		1.35	0.7	1.05	1.03	1.05	1.25	1.25	1.18	1.8	1.15	1.1	1.35
4	19.9	1.5	0.73	1.2	1.14	1.26	1.38	1.41	1.41	1.83	1.2	1.22	1.41
5	19.3	1.76	0.73	1.56	1.66	1.77	1.50	1.72	1.66	1.92	1.46	1.43	1.6
6	15.9	2.15	-	2.27	2.22	2.5	1.75	2.2	2.15	2.1	1.63	1.71	1.81
7	15.8	3.0	-	4.5	3.75	3.7	2.1	3.2	3.0	2.35	1.90	2.2	2.15
8	15.4	4.7	-	8.7	6.7	6.3	2.8	5.7	4.93	2.8	2.2	2.9	2.63
9	14.5	7.0	-	30.0	18.5	5.8	4.3	10.0	7.7	3.6	2.7	3.7	3.33
10	-	-	-	-	-	-	-	-	-	-	-	-	-
11	11.5	20	-	37.0	28.5	75	37	90	67.3	15.0	6.0	7.7	9.56
12	11.5	70	-	71	70.5	120	64	140	108	28	8.3	11.5	15.9
13	12.3	110	-	120	115	240	88	210	179.3	43	12.5	16.5	24
14	13.5	160	-	105	132.5	300	145	330	258.3	60	20	24	34.6
15	11.1	170	-	120	145	450	190	500	380	66	28	27	40.3
16	12.6	190	-	115	152.5	500	210	750	486	75	36	34.5	48.5
17	11.9	190	-	145	167	550	240	800	530	90	47	38	58.3

$r_c^2 = 0.68$ $r_h^2 = 0.2$ $r_t^2 = 0.36$

APPENDIX 2d

Determination of correlation of moisture metering techniques with gravimetric soil moisture sampling

Time (days) After planting	Gravimetric Soil Moisture (d.b) % Coulter types			Gypsum blocks resistance (' Ω) Coulter types			Gypsum beads % (d.b.) Coulter types			Glass fibre filter paper % (d.b.) Coulter types		
	Chisel	Hoe	Triple Disc	Chisel	Hoe	Triple Disc	Chisel	Hoe	Triple Disc	Chisel	Hoe	Triple Disc
1												
2												
3												
4	18.0	21.2	21.3	1.14	1.42	1.42	40.3	39.3	34			
5	17.1	20.2	20.7	1.66	1.66	1.60	50.3	39.0	36.3	80.9	8.5	87.8
6	17.2	13.0	17.7	2.22	2.15	1.80	33.0	28.4	30.8			
7	13.9	17.5	15.3	3.75	3.0	2.15	32.8	32.9	33.9	10.5	31.1	9.8
8	13.5	15.3	17.3	4.7	4.93	2.63	33.8	30.1	30.9			
9	16.3	11.2	16.2	7.0	7.7	3.33	33.6	32.2	32.2	45.9	59.2	14.3
10	15.0	12.0	14.1	28.5	27.6	5.5						
11	13.1	13.0	12.3	51.5	67.3	9.56						
12	12.6	14.0	12.7	70.5	108	15.9	r_c^2=0.4	r_h^2=0.71	r_t^2=0.27			
13	13.9	12.0	11.0	115	179	24						
14	11.7	13.8	15.2	132	258	34.6						
15	10.8	9.4	13.3	145	380	40.3						
16	11.3	13.1	13.6	152	486	48.5						
17	11.2	12.7	11.7	167	530	58.3						

APPENDIX 3

(a) Specifications of Experiment 1(a)

Date of experiment	December 1976
Type of experiment	Large soil blocks in laboratory
Coulter types used	Chisel (experimental), hoe and triple disc coulters.
Species sown	"Kapora" wheat
Seed germination potential	98.4% (Massey Uni, Seed Tech Centre)
Nominal sowing depth	38-40 mm
Nominal sowing spacing	20 mm
Drilling speed	60 m/hour
Groove covering treatments	Drilled grooves bar harrowed and then pressed at 0,35, 70 kPa respectively.
Soil type	"Manawatu fine sandy loam"
Initial soil moisture stress	Stabilized to an average of 17% (d.b.) approximately at -15 bars.
Condition of parent vegetation	Ryegrass, mown to ground level and then sprayed.
Herbicides used, rate and time of application	Paraquat at 5.1 l/ha + dicamba 1.4 l/ha in one blanket spray 3 days prior to drilling.
Experimental design	Randomised complete blocks with 4 replicates (split-plot)
Duration of lapse time between drilling and termination of experiment	3 weeks
Climatic conditions during experiment	Controlled climatic conditions (climate laboratory, PPD, DSIR) at 90/93% r.h. and 22/18^{o}C day/night and 55/60% r.h. and 22/18^{o}C temp. day/night in each of two rooms respectively.
Seedling emergence counts	Daily seedling emergence counts until the termination of experiment.

APPENDIX 3b

LRH Regime

Chisel coulter

Rate of seedling emergence percentage

Pressure intensity in kPa	Reps	5	6	7	8	9	10	11	12	13	14	15	16	17
		Days from sowing												
	1		18.1	44.4	48.4	52.5	54.5	54.5	56.5	58.5	58.5	58.5	58.5	58.5
0	2		2	12.1	16.1	16.1	16.1	18.1	20.2	20.2	20.2	20.2	20.2	20.2
	3		12.1	32.3	46.4	54.5	56.5	60.6	60.6	60.6	60.6	60.6	60.6	60.6
	4		22.2	32.3	54.5	58.5	62.6	66.6	70.7	70.7	70.7	70.7	70.7	70.7
Mean			13.6	30.2	41.3	45.4	47.4	49.9	52	52.5	52.5	52.5	52.5	52.5
	1		16.1	30.3	34.3	36.3	38.3	44.4	44.4	52.5	52.5	52.5	52.5	52.5
35	2		12.1	24.2	28.2	28.2	30.3	30.3	30.3	30.3	30.3	30.3	30.3	30.3
	3		18.1	34.3	34.3	40.4	44.4	50.5	50.5	50	50.5	50.5	50.5	50.5
	4		8	34.3	60.6	60.6	62.6	64.6	66.6	66.6	66.6	66.6	66.6	66.6
Mean			13.5	30.7	39.3	41.3	43.9	47.4	47.9	49.9	49.9	49.9	49.9	49.9
	1		38.3	48.4	66.6	68.6	68.6	72.7	74.7	74.7	74.7	74.7	74.7	74.7
70	2		14.1	26.2	32.3	32.3	32.3	34.3	34.3	38.4	38.4	38.4	38.4	38.4
	3		16.1	58.5	68.6	78.7	78.7	80.8	80.8	82.8	82.8	82.8	82.8	82.8
	4		14.1	40.4	44.4	44.4	44.4	46.4	46.4	48.4	50.5	50.5	50.5	82.8
Mean			20.6	43.3	52.9	56	56	58.5	60.0	61.0	61.6	61.6	61.6	61.6

Contd.

Appendix 3b contd

Hoe coulter

Pressure intensity in kPa	Reps 5	6	7	8	9	10	11	12	13	14	15	16	17
	1	0	0	0	0	0	0	0	0	0	0	0	0
0	2	0	0	0	0	0	0	2	2	2	2	2	2
	3	8	14.1	14.1	18.1	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2
	4	4	4	4	4	4	6	6	8	8	8	8	8
Mean		3	4.5	4.5	4.5	6.0	6.5	7.0	7.5	7.5	7.5	7.5	7.5
	1	0	0	4	4	4	4	4	4	4	4	4	4
35	2	2	6	14.1	16.1	20.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2
	3	12.1	18.1	22.2	24.2	26.2	26.2	28.1	32.3	32.3	32.3	32.3	32.3
	4	0	0	0	0	0	0	0	0	0	0	0	0
Mean		3.5	6	10	11	12.6	13	13.5	14.6	19.6	14.6	14.6	14.6
	1	0	0	2	2	2	2	2	2	2	2	2	2
	2	0	0	0	0	0	0	0	0	0	0	0	0
70	3	12.1	16.1	16.1	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2
	4	2	4	4	4	4	4	4	4	4	4	4	4
		3.5	5	5.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5

Appendix 3b contd

Triple disc coulter

Pressure intensity in kPa	Reps 5	6	7	8	9	10	11	12	13	14	15	16	17
	1	0	0	0	0	0	0	0	0	0	0	0	0
0	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	2	2	2	2	2	2	2	2	2	2	2	2
	4	0	0	0	0	0	2	2	2	2	2	2	2
Mean		0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1	1
	1	0	0	2	2	2	2	2	2	2	2	2	2
35	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	2	4	6	6	6	6	6	6	6
	4	0	0	0	0	0	0	0	0	0	0	0	0
Mean		0	0	0.5	1	1.5	2	2	2	2	2	2	2
	1	0	0	0	0	0	0	0	0	0	0	0	0
75	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	2	2	2	4	4	4	4	4	4	4	4
	4	0	2	2	2	2	2	2	2	2	2	2	2
Mean		0	1	1	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5

Appendix 3b contd

HRH Regime

Chisel coulter

Pressure intensity in kPa	Reps 5	6	7	8	9	10	11	12	13	14	15	16	17
	1	26.2	40.4	44.4	52.5	62.6	68.6	74.7	74.7	74.7	74.7	74.7	74.7
0	2	14.1	36.3	44.4	50.5	54.5	56.5	56.5	56.5	56.5	56.5	56.5	56.5
	3	38.3	48.4	50.5	56.5	56.5	58.5	58.5	60.6	60.6	60.6	60.6	60.6
	4	44.4	60.6	66.6	66.6	66.6	70.7	70.7	70.7	70.7	70.7	70.7	70.7
Mean		30.7	46.4	51.5	56.5	60.0	63.5	65.1	65.6	65.6	65.6	65.6	65.6
	1	52.5	58.5	66.6	66.6	68.6	68.6	68.6	70.7	72.7	72.7	72.7	72.7
35	2	42.4	46.4	52.5	52.5	54.5	54.5	56.5	56.5	56.5	58.6	58.6	58.6
	3	44.4	60.6	70.7	72.7	72.7	76.7	76.7	78.7	78.8	78.8	78.8	78.8
	4	28.2	36.3	48.4	52.5	52.5	52.5	52.6	62.6	62.6	62.6	62.2	62.6
Mean		41.8	50.4	59.5	61	62	63	63.5	67.1	67.6	68.1	68.1	68.1
	1	10.1	16.1	26.2	28.2	28.2	34.3	34.3	36.3	36.3	36.3	46.3	36.3
70	2	18.1	38.3	50.5	58.5	66.6	66.6	66.6	66.6	66.6	66.6	66.6	66.6
	3	36.3	52.5	54.5	56.5	62.6	66.6	66.6	68.6	68.6	68.6	68.6	68.6
	4	14.1	28.2	40.4	50.5	50.5	56.5	56.5	60.6	60.6	62.6	62.6	62.6
Mean		19.6	33.7	42.9	47.9	51.9	56	56	58	58	58.5	58.5	58.5

Appendix 3b contd

Hoe coulter

Pressure intensity in kPa	Reps	5	6	7	8	9	10	11	12	13	14	15	16	17
	1		0	2	2	2	2	2	2	2	4	4	4	4
0	2		0	0	2	2	4	4	8	8	8	8	8	8
	3		10.1	16.1	20.2	22.2	34.3	40.4	40.4	40.4	40.4	40.4	40.4	40.4
	4		14.1	18.1	24.2	24.2	42.4	46.4	46.4	48.4	48.4	48.4	48.4	48.4
Mean			6	9.0	12.1	12.6	20.6	23.2	24.2	25.2	25.2	25.2	25.2	25.2
	1		10.1	12.1	22.2	30.3	30.3	30.3	30.3	30.3	32.3	32.3	32.3	32.3
35	2		20.2	24.2	30.3	30.3	36.3	36.3	40.4	40.4	40.4	40.4	40.4	40.4
	3		0	0	4	4	4	4	4	4	4	4	4	4
	4		0	0	0	0	0	0	0	0	0	0	0	0
Mean			7.5	9.0	14.1	16.6	17.6	17.6	18.6	18.6	19.1	19.1	19.1	19.1
	1		0	0	0	0	0	2	2	2	2	2	2	2
70	2		2	2	2	2	2	2	2	4	4	6	6	6
	3		20.2	30.3	34.3	38.3	48.4	48.4	52.5	52.5	54.5	54.5	54.5	54.5
	4		8	22.2	26.2	32.3	32.3	32.3	34.3	34.3	34.3	34.3	34.3	34.3
Mean			7	13.6	15.6	18.1	20.6	21.1	22.7	23.2	23.7	24.2	24.2	24.2

<u>Appendix 3b contd</u>

<u>Triple disc coulter</u>

Pressure intensity in kPa	Reps	5	6	7	8	9	10	11	12	13	14	15	16	17
	1		0	0	0	4	4	4	4	4	4	4	4	4
0	2		0	0	0	0	0	0	0	0	0	0	0	0
	3		0	0	0	0	0	0	0	0	0	0	0	0
	4		0	0	0	0	0	0	0	0	0	0	0	0
Mean			0	0	0	1	1	1	1	1	1	1	1	1
	1		0	0	0	0	0	0	0	0	0	0	0	0
35	2		0	0	0	0	2	2	2	2	2	2	2	2
	3		0	0	2	2	2	2	2	2	2	2	2	2
	4		0	0	0	0	0	0	0	0	0	0	0	0
Mean			0	0	0.5	0.5	1	1	1	1	1	1	1	1
	1		0	0	0	0	0	0	0	0	0	0	0	0
70	2		0	0	0	0	0	0	0	0	0	0	0	0
	3		0	0	0	0	0	0	0	0	0	0	0	0
Mean	4		0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 3b

Seed Fate % (in the LRH regime)

Coulter types	Pressure intensity = 0 kPa		= 35 kPa		= 70 kPa	
	Germinated but unemerged seeds	Ungerminated seeds	Germinated but unemerged seeds	Ungerminated seeds	Germinated but unemerged seeds	Ungerminated seeds
	14.1	16.1	16.1	34.3	4	46.6
Chisel	8	32.3	8	26.2	2	16.1
	19.5	60.3	12.1	38.4	24.2	38.3
	30.3	10.0	22.2	48	8	14
Mean	17.9	29.6	14.6	36.7	9.5	28.7
	21.9	70.1	18.4	81.5	36.9	42.5
Hoe	14.7	65.2	39.6	28.3	21.8	74.2
	18.1	80.8	22.2	74.7	19.2	80.8
	16.0	84.8	28.3	50	32	66
Mean	17.6	75.2	27.1	58.6	27.4	65.8
	81.6	16.3	90	10	66.3	29.7
Triple disc	75.7	22.3	40.6	58.4	84.7	13.3
	38	40	70	30	68	32
	68	30	64	30	80	20
Mean	65.8	27.1	66.1	32.1	74.7	23.7

Appendix 3a contd. Seed Fate % (in the HRH regime)

Coulter types	Pressure intensity = 0 kPa		= 35 kPa		= 70 kPa	
	Germinated but unemerged seeds	Ungerminated seed	Germinated but unemerged seeds	Ungerminated seeds	Germinated but unemerged seeds	Ungerminated seeds
	8.5	17.3	22.4	5.6	32	32
Chisel	14.6	29.3	19	19.5	14	18
	21.7	17.8	9.9	31.6	21.7	11.8
	19.8	9.9	21.7	0	35.6	1.9
Mean	16.1	18.5	18.2	14.1	25.8	15.9
	46.8	5.2	46.5	23.3	35.7	10.2
Hoe	22.2	37.7	37.8	22.1	66.0	0
	13.7	82.2	15.9	79.9	8.9	89.1
	14.8	77.1	15.7	84.2	12.2	81.7
Mean	24.3	50.5	28.9	52.3	30.7	45.2
	55.7	40.2	75	25	39.1	60.8
Triple disc	82.5	17.5	77.1	22.9	54.5	45.5
	94	6	80	20	82	18
	74	26	82.0	16	80	20
Mean	76.5	22.4	78.5	20.9	63.9	36.0

APPENDIX 3c

The effects of coulter types and ambient relative humidity on the in-groove soil moisture contents in percent (d.b.).

Coulter types	Pressure intensity in kPa	LRH regime Days from sowing 3	6	9	12	15	HRH regime Days from sowing 3	6	9	12	15
		13.7	15.3	11.0	11.7	8.4	14.7	15.3	12.7	13.8	12.9
Chisel	0	15.4	14.7	11.4	13.9	11.6	15.5	15.7	16.4	16.8	16.9
		14.7	13.1	14.0	14.7	13.7	17.1	17.3	16.2	17.7	16.2
		10.6	13.8	12.2	7.4	10.5	13.9	14.3	12.5	14.4	15.5
	35	14.5	15.9	14.1	11.6	15.0	15.6	17.0	16.5	16.6	9.7
		13.3	17.1	17.3	13.1	14.9	16.9	15.4	16.0	17.7	14.8
		10.5	8.7	12.5	8.24	8.2	16.0	11.7	10.2	15.3	10.0
	70	15.2	14.6	14.4	10.9	12.5	12.7	14.4	15.8	20.0	13.0
		14.2	13.6	15.7	13.6	13.6	14.5	16.8	16.8	20.6	16.8
Soil Block		13.8	13.7	18.0	16.5	12.1	19.6	13.1	19.2	9.7	9.3
		13.8	12.3	10.5	11.74	12.1	19.6	19.6	19.3	20.6	9.3
Coulter type		12.7	10.1	9.6	8.4	8.5	16.6	15.2	16.4	13.8	10.5
Hoe	0	15.7	13.0	12.1	12.5	10.4	16.6	17.2	19.8	16.5	11.5
		13.8	12.7	13.9	13.7	12.3	17.6	18.1	19.7	16.8	12.5
	35	12.7	11.0	13.3	11.6	9.6	16.5	17.1	18.1	13.5	12.7
		16.4	13.0	15.5	15.0	10.7	17.5	17.7	21.4	18.1	14.6
		13.0	13.6	16.1	15.6	11.8	16.5	17.6	20.0	19.1	16.9
		12.0	8.5	9.9	10.0	10.0	18.6	15.6	15.1	16.6	11.7
	70	12.8	11.7	11.9	13.3	11.0	16.0	19.0	17.4	18.3	11.6
		11.9	11.3	14.6	12.5	12.0	18.7	18.3	17.1	17.7	11.5
Soil Block		18.3	14.3	14.3	13.1	10.2	16.9	19.5	19.3	19.8	14.9

Appendix 3c contd

Coulter type	Pressure intensity in kPa	L R H regime Days from sowing 3	6	9	12	15	HRH regime Days from sowing 3	6	9	12	15
Triple Disc		21.4	25.5	17.0	18.0	12.8	18.3	19.2	20.8	17.2	21.1
	0	19.1	16.8	19.5	19.2	12.6	21.9	19.4	23.9	19.2	22.1
		21.1	18.9	21.2	18.0	12.4	17.4	22.4	24.8	19.9	23.1
		19.5	12.1	16.3	15.7	13.1	19.7	19.2	17.8	17.6	15.6
	35	20.5	18.4	20.9	19.7	15.2	19.8	20.2	20.9	20.7	16.7
		19.3	14.9	20.7	19.9	17.3	21.4	21.2	20.8	19.9	18.8
		19.4	14.5	17.5	12.9	11.8	18.5	23.8	22.6	12.9	17.0
	70	20.5	18.1	19.1	17.2	14.9	19.4	26.2	23.9	17.0	19.0
		17.9	17.7	20.5	18.8	18.0	17.7	24.2	23.0	16.2	18.0
Soil Block		11.9	14.9	14.6	14.7	14.2	19.7	19.6	20.2	17.8	13.5

APPENDIX 4

Soil Impedence Measurement

Definitions:

Shear Point:

A location at which the soil shears when the "mechanical seedling" passes through the soil surface. Shear point is assumed to be occurring when the "mechanical seedling" encounters maximum penetration force.

Distance of Shear Point:

The distance from the soil surface to the shear point or at the maximum penetration force.

Mechanical Seedling Diameter: 1.11 mm

Conversion factor of graph sheet scale on the chart recorder to actual travel of "mechanical seedling" is 2.5.

Calibration factor = 0.1605 $N/_{mm}$

Area on chart = Distance of penetrometer travel mm x force (mm)

Energy expended = Area x conversion factor x calibration factor

= Area x 2.5 x 0.1605 x 10^{-3} Nm.

Maximum force = Distance of shear point from soil surface x calibration factor.

APPENDIX 4a

(a) Soil impedence measurement data (pre emergence)

Coulter type	Pressure Intensity kPa	Reps	Energy expended Nm x 10^{-3}	Maximum force of emergence (N)	Distance of shear point (mm)
Chisel	0	1	71.6	3.7	18.1
		2	69.6	3.9	18.3
		3	82.5	4.8	20.0
		4	58.7	2.8	16.4
	35	1	50.5	2.0	22.6
		2	42.5	2.3	27.5
		3	47.3	2.6	22.4
		4	45.7	1.6	17.5
	70	1	114.8	4.0	17.0
		2	114.8	4.4	11.0
		3	120.9	6.2	15.1
		4	108.7	4.2	12.9
Hoe	0	1	109.4	4.7	5.6
		2	105.8	5.1	4.4
		3	127.6	5.9	5.3
		4	87.6	3.9	4.7
	35	1	120.5	4.1	8.5
		2	114.7	4.3	9.7
		3	118.6	5.0	8.9
		4	119.6	3.4	7.7
	70	1	190.1	5.7	4.3
		2	180.3	6.1	4.0
		3	183.0	5.9	4.3
		4	187.4	5.9	4.6
Triple Disc	0	1	128	4.3	23.0
		2	128	4.3	23.4
		3	135.5	5.5	28.0
		4	120.5	3.1	18.4
	35	1	90.5	3.6	32.2
		2	88.7	3.4	25.8

Appendix 4a Contd

Coulter type	Pressure Intensity kPa	Reps	Energy expended (Nmm)	Maximum force of emergence (N)	Distance of shear point (mm)
		3	98.6	4.0	28.9
		4	80.6	3.0	29.1
	70	1	148	6.0	20.5
		2	136	6.4	19.5
		3	141.5	5.1	17.6
		4	142.5	7.3	22.4

APPENDIX 4b

(b) Soil impedence measurement data: (post emergence)

LRH

Coulter Type	Pressure Intensity kPa		Energy Expended Nm x 10^{-3}	Maximum Penetration force (N)	Distance of shear (mm)
Chisel	0	1	132.6	10.1	32.5
		2	128.2	2.3	22.5
		3	135.1	5.2	38.3
		4	125.7	7.2	16.7
	35	1	83.3	4.5	33.9
		2	71.9	4.3	33.5
		3	78.6	5.4	38.7
		4	76.6	3.4	28.7
	70	1	116.4	4.8	23.0
		2	125.3	4.1	19.4
		3	116.4	5.5	20.1
		4	107.5	4.8	22.3
Hoe	0	1	134.8	9.1	16.5
		2	100.7	13.3	16.7
		3	94.8	10.0	18.3
		4	128.9	12.4	14.9
	35	1	79.6	5.3	19.7
		2	100.1	3.5	17.7
		3	79.6	3.1	18.5
		4	58.7	1.3	18.9
	70	1	99.3	6.8	18.7
		2	79.1	0.4	18.7
		3	121.0	1.4	19.2
		4	57.4	2.6	18.2
Triple disc	0	1	78.5	4.0	20.0
		2	40.7	4.2	10.0
		3	69.4	5.0	7.5
		4	49.8	3.2	22.5

Appendix 4b contd

Coulter Type	Pressure Intensity kPa		Energy Expended Nm x 10^{-3}	Maximum Penetration force (N)	Distance of shear (mm)
	35	1	110.6	4.3	36.2
		2	80.5	4.3	26.2
		3	48.6	6.0	33.0
		4	78.7	2.6	29.4
	70	1	93.1	2.6	16.0
		2	49.3	3.0	12.2
		3	76.0	4.8	14.5
		4	66.4	0.8	13.7
			HRH		
Chisel	0	1	125.0	4.3	5.1
		2	121.4	5.1	4.9
		3	128.1	3.7	6.0
		4	118.3	5.7	4.0
	35	1	130.0	3.6	2.4
		2	134.0	4.0	2.6
		3	137.2	1.8	3.5
		4	126.8	5.8	1.5
	70	1	147.9	4.7	1.9
		2	145.1	2.6	3.1
		3	150.3	4.7	2.7
		4	142.5	6.8	2.3
Hoe	0	1	130.5	7.1	16.3
		2	109.5	2.9	12.3
		3	95.0	6.5	15.1
		4	145.0	3.5	13.5
	35	1	91.0	5.0	1.9
		2	91.4	6.2	3.1
		3	101.1	5.3	2.9
		4	81.3	5.9	2.1

Appendix 4b contd.

Coulter Type	Pressure Intensity kPa		Energy Expended Nm x 10^{-3}	Maximum Penetration force (N)	Distance of shear (mm)
	70	1	116.5	12.0	5.1
		2	110.7	10.0	4.9
		3	122.6	11.5	6.5
		4	104.6	10.5	3.5
Triple Disc	0	1	62.6	2.5	6.1
		2	41.4	2.1	6.3
		3	53.0	1.3	5.0
		4	51.0	3.3	7.4
	35	1	83.2	4.5	20.0
		2	83.2	4.1	21.4
		3	94.1	5.3	21.7
		4	72.3	3.3	19.7
	70	1	105.9	5.6	2.0
		2	99.1	6.0	3.0
		3	123.3	4.7	1.0
		4	82.3	6.9	2.0

APPENDIX 4c

The effect of coulter types, pressure application and ambient relative humidity on the in-groove soil temperature at ambient day and night temperatures of 22^{o}C and 18^{o}C respectively.

Coulter types	Pressure Intensity kPa	4	9	12	15	Mean	4	9	12	15	Mean
		Days from Sowing					Days from sowing				
		Day Temperature C^{o} HRH					Day Temperature C^{o} LRH				
Chisel coulter	0	24.3	24.43	24.68	24.68	24.5	22.15	22.5	22.53	22.65	22.4
	35	24.3	24.17	24.43	24.55	24.3	22.78	23.16	23.03	23.03	23.0
	70	24.05	24.43	24.55	24.68	24.3	22.15	22.78	23.16	23.03	22.7
Hoe	0	24.3	24.81	25.06	25.19	24.8	22.91	23.16	22.91	22.78	22.9
	35	24.3	24.43	34.81	24.81	24.5	22.53	22.4	22.53	22.78	22.5
	70	24.43	24.81	25.06	25.19	24.8	22.15	22.27	22.53	22.65	22.4
Triple disc	0	24.05	24.3	24.55	24.81	24.4	24.68	24.81	25.06	25.19	24.9
	35	24.55	24.68	24.81	25.06	24.7	23.29	24.05	24.3	24.43	23.9
	70	24.05	24.3	24.43	24.43	24.3	23.54	24.17	24.55	24.81	24.9
						Night Temperature					
Chsel coulter	0	21.89	22.27	22.02	22.65	22.1	21.01	21.26	20.76	21.77	21.1
	35	21.77	22.27	22.15	22.78	22.2	20.63	21.01	20.5	21.64	20.9
	70	22.02	22.4	22.02	22.65	22.2	20.88	21.14	20.63	21.77	21.0
Hoe	0	22.27	22.4	22.27	22.78	22.4	20.5	21.14	20.88	21.39	20.9

Appendix 4c contd

Coulter types	Pressure Intensity kPa	Days from Sowing 4	9	12	15	Mean	Days from sowing 4	9	12	15	Mean
		HRH					LRH				
	35	22.27	22.53	22.4	23.16	22.5	20.88	21.14	21.01	21.39	21.2
	70	22.65	22.4	22.15	23.03	22.5	21.39	21.52	21.26	22.02	21.5
Triple Disc	0	21.89	22.15	21.77	22.65	22.0	21.01	21.39	21.14	21.64	22.2
	35	22.15	22.02	21.77	22.53	22.0	21.01	21.52	21.14	21.89	21.4
	70	21.77	22.27	21.89	22.78	22.1	20.88	21.39	21.01	21.64	21.2

APPENDIX 5.

(a)

Specifications of experiment I(b)

Date of experiment	23.11.77
Type of experiment	Large soil blocks in laboratory
Coulter type used	Chisel (experimental), hoe and triple disc coulters
Species sown	"Kapora" wheat
Seed germination potential	98.4% (Massey University, Seed Tech. Centre)
Nominal sowing depth	38 - 40 mm
Nominal sowing spacing	20 mm
Drilling speed	60 m/hour
Groove covering treatments	Drilled seeds pressed directly at 0, 35 and 70 kPa before bar harrowing
Soil type	"Manawatu fine sandy loam"
Initial soil moisture stress	Stabilized to an average of 17% (d.b.) approximately at -15 bars
Condition of parent vegetation	Rye grass, mown to ground level and then sprayed
Herbicides used, rate and time of application	Paraquat at 5.1 l/ha + dicamba 1.4 l/ha in one blanket spray 3 days prior to drilling
Experimental design	Randomised, complete blocks with 4 replicates (split-plot)
Duration of lapse time between drilling and termination of experiment	3 weeks
Climatic conditions during experiment	Controlled climatic conditions (climate laboratory, PPD, D.S.I.R.) at 90/93% r.h. and 22/18^{o}C temp. day/night and 55/60% r.h. and 22/18^{o}C temp. day/night in each of two rooms respectively.
Seedling emergence counts	Daily seedling emergence until the termination of experiment.

APPENDIX 5

(b) SEEDLING EMERGENCE RATE PERCENTAGE

LRH regime

Coulter Type	Pressure Intensity in kP	Reps	Days from sowing 5	6	7	8	9	10	11	12	13	14	15	16	17
Chisel coulter	0	1	-	2.2	2.2	15.4	24.2	26.4	28.6	30.8	30.8	30.8	30.8	30.8	30.8
		2	-	-	24.2	41.8	54.8	62.0	66.0	70.4	75.8	75.8	75.8	75.8	75.8
		3	-	-	26.4	26.4	28.5	55.0	59.4	59.4	62.2	62.2	62.2	62.2	62.2
		4	2.2	15.4	17.6	33.0	37.4	39.6	39.6	39.6	42.2	42.2	42.2	42.2	42.2
	Mean		0.55	4.4	17.6	29.15	36.25	45.75	48.4	50.05	52.75	52.75	52.75	52.75	52.75
	35	1	-	-	6.6	8.8	13.2	13.2	15.4	15.4	17.6	17.6	17.6	17.6	17.6
		2	-	2.2	8.8	26.4	33.0	44.0	44.0	46.2	50.6	50.6	50.6	50.6	50.6
		3	6.6	14.4	24.2	31.1	37.4	44.0	55.0	55.0	50.50	60.6	60.0	60.0	60.0
		4	-	11,0	17,6	26.4	33.0	35.2	39.6	42.8	46.2	46.2	48.8	48.8	48.8
	mean		1.65	6.9	14.3	23.17	29.15	34.1	38.5	39.85	43.75	43.75	44.25	44.25	44.2
	70	1	-	-	6.6	8.8	15.4	15.4	15.4	15.4	17.6	17.6	17.6	17.6	17.6
		2	-	6.6	19.8	40.4	55.0	64.8	66.0	66.0	71.0	71.0	71.0	71.0	71.0
		3	6.6	19.8	28.6	33.0	33.0	37.6	39.6	44.4	44.4	44.4	44.4	44.4	44.4
		4	-	22.2	33.3	33.3	35.2	39.6	39.6	44.4	44.4	46.6	51.1	51.1	51.1
	Mean		1.65	12.1	22.07	28.87	34.65	39.3	40.15	41.35	44.35	44.9	46.02	46.02	46.0

Appendix 5b

Hoe coulter	Pressure intensity in kP	Reps	Days from sowing												
			5	6	7	8	9	10	11	12	13	14	15	16	17
	0	1	-	2.2	8.8	13.3	19.9	19.9	22.2	22.2	22.2	22.2	22.2	22.2	22.2
		2	-	4.4	11.1	15.5	17.7	19.9	22.2	22.2	24.4	24.4	24.4	24.4	24.4
		3	-	6.6	8.8	8.8	8.8	15.5	17.7	17.2	20.0	20.0	20.0	20.0	20.0
		4	-	2.2	6.6	8.8	11.1	13.3	13.3	17.7	20.0	20.0	20.0	20.0	20.0
	Mean		-	3.85	0.82	11.6	14.37	17.15	18.85	19.95	21.65	21.65	21.65	21.65	21.65
	35	1	-	-	11.1	19.9	19.9	22.2	26.6	28.8	31.1	35.5	35.5	35.5	35.5
		2	-	6.6	13.3	24.4	24.4	33.3	35.5	37.7	37.7	37.7	37.7	37.7	37.7
		3	-	-	8.8	13.3	22.2	24.4	33.3	33.3	39.9	39.9	39.9	39.9	39.9
		4	6.6	8.8	13.3	22.2	37.7	42.2	44.4	44.4	44.4	44.4	44.4	44.4	44.4
	Mean		1.65	3.85	11.62	19.4	26.05	30.52	34.95	36.05	38.27	39.37	39.37	39.37	39.3
	70	1	-	6.6	24.4	44.4	59.9	66.6	77.7	79.9	79.9	80.0	80.0	80.0	80.0
		2	-	2.2	8.8	15.5	17.7	24.4	26.6	28.8	31.1	31.1	33.3	33.3	33.3
		3	-	2.2	4.4	17.7	19.9	22.2	22.2	22.2	24.4	24.4	26.6	26.6	26.6
		4	2.2	4.4	15.5	19.9	31.1	33.3	33.3	35.5	35.5	35.5	35.5	35.5	35.5
			0.55	3.85	13.27	24.37	32.15	36.62	39.95	41.6	42.72	42.72	43.85	43.85	43.85

Appendix 5b

Triple Disc Coulter	Pressure intensity in kP	Reps	Days from sowing 5	6	7	8	9	10	11	12	13	14	15	16	17
	0	1	-	-	-	-	-	-	-	-	-	-	2.2	2.2	2.2
		2	-	-	4.4	8.8	8.8	8.8	13.3	13.3	13.3	17.7	17.7	17.7	17.7
		3	-	-	-	2.2	2.2	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
		4	-	-	2.0	2.2	2.2	2.2	2.2	2.2	2.2	4.4	4.4	4.4	4.4
		Mean	-	-	1.6	3.3	3.3	3.85	4.97	4.97	4.97	6.62	7.17	7.1	7.1
	35	1	4.4	4.4	13.3	17.7	24.4	39.9	44.4	46.6	51.1	51.1	51.1	51.1	51.1
		2	-	-	4.4	8.8	8.8	8.8	13.3	17.7	19.9	20.0	20.0	20.0	20.0
		3	-	2.2	2.2	8.8	13.3	15.5	19.9	20.0	20.0	20.0	20.0	20.0	20.0
		4	-	-	2.2	8.8	11.1	11.1	11.1	11.1	13.3	13.3	13.3	13.3	13.3
			1.1	1.65	5.52	11.02	14.4	18.82	22.17	23.85	26.07	26.1	26.1	26.1	26.1
	70	1	-	-	6.6	11.1	13.3	22.2	28.8	31.1	35.5	35.5	35.5	35.5	35.5
		2	-	-	2.2	4.4	8.8	11.1	13.3	24.4	37.7	42.2	42.2	42.2	42.2
		3	-	-	2.2	6.6	6.6	8.8	8.8	8.8	11.1	11.1	11.1	11.1	11.1
		4	-	-	2.2	6.6	8.8	13.3	13.3	17.7	22.2	22.2	24.4	24.4	24.4
			-	-	3.3	7.17	9.37	13.85	16.05	20.5	26.62	27.75	28.3	28.3	28.3

Appendix 5b

HRH regime

Chisel coulter

Pressure Intensity in kP	Reps	Days from sowing 5	6	7	8	9	10	11	12	13	14	15	16	17
0	1	-	37.7	59.9	79.9	82.2	88.8	88.8	88.8	88.8	88.8	88.8	88.8	88.8
	2	-	15.5	17.7	28.8	28.8	33.3	35.5	39.9	39.9	40.0	40.0	40.0	40.0
	3	-	2.2	28.8	35.5	44.4	66.6	66.6	68.8	68.8	68.8	68.8	68.8	68.8
	4	2.2	11.1	24.4	26.6	51.5	55.5	55.5	55.5	55.5	57.7	57.7	57.7	57.7
	Mean	0.55	41.6	32.7	42.7	51.72	61.05	61.6	62.7	63.25	63.82	63.82	63.82	63.82
35	1	-	15.5	22.2	31.1	35.5	39.9	41.1	41.1	41.1	41.1	41.1	41.1	41.1
	2	-	44.4	72,2	72,2	72,2	72.2	88.8	93.93	95.5	95.5	95.5	95.5	95.5
	3	6.6	17.7	28.8	39.9	48.8	59.9	62.6	66.6	66.6	66.6	66.6	66.6	66.6
	4	-	4.4	22.2	28.8	31.1	35.5	37.7	37.7	39.9	39.9	42.2	42.2	42.2
	Mean	1.65	20.5	31.35	43.0	46.9	51.87	57.27	59.83	60.77	60.77	61.35	61.35	61.3
70	1	-	24.4	39.9	88.8	91.1	93.3	93.3	97.7	97.7	97.7	97.7	97.7	97.7
	2	-	24.4	48.8	62.2	72.2	75.5	75.5	75.5	75.5	77.7	77.7	77.7	77.7
	3	2.2	4.4	33.3	37.7	44.4	48.8	53.3	79.9	79.9	81.1	84.4	84.4	84.4
	4	11.1	15.5	31.1	31.1	33.3	35.5	37.7	39.9	44.4	46.6	46.6	46.6	46.6
	Mean	3.27	17.17	38.27	54.95	60.25	63.27	64.95	73.25	74.37	75.77	76.6	76.6	76.6

Appendix 5b

Hoe coulter	Pressure intensity in kP	Reps	Days from sowing												
			5	6	7	8	9	10	11	12	13	14	15	16	17
	0	1	-	6.6	17.7	22.2	24.4	28.8	28.8	31.1	35.5	35.5	35.5	35.5	35.5
		2	-	6.6	6.6	8.8	17.7	22.2	33.3	33.3	33.3	33.3	33.3	33.3	33.3
		3	2.2	6.6	8.8	8.8	8.8	15.5	15.5	17.7	17.7	20.0	20.0	20.0	20.0
		4	4.4	4.4	17.7	17.7	17.7	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2
			1.65	6.05	12.7	14.37	17.15	22,17	24.95	26.07	27.17	27.75	27.75	27.75	27.7
	35	1	-	11.1	19.9	28.8	35.5	44.4	51.0	53.3	59.9	62.2	62.2	62.2	62.2
		2	-	6.6	26.6	55.5	64.4	66.6	66.6	68.8	77.7	77.7	77.7	77.7	77.7
		3	11.1	19.9	31.1	35.5	46.6	44.4	57.7	62.2	62.2	62.2	62.2	62.2	62.2
		4	8.8	13.3	15.5	31.1	44.4	51.0	53.3	62.2	62.2	62.2	62.2	62.2	62.2
			4.97	12.72	23.27	37.72	47.72	51.6	57.15	61.62	65.5	66.07	66.07	66.07	66.0
	70	1	-	11.1	31.1	51.0	59.9	64.4	77.7	79.9	82.2	82.2	82.2	82.2	82.2
		2	-	6.6	22.2	39.9	57.7	64.4	66.6	68.8	71.1	75.5	80.0	80.0	80.0
		3	15.5	31.1	42.2	51.0	55.5	59.9	77.7	84.4	84.4	84.4	84.4	84.4	84.4
		4	13.3	26.6	33.3	44.4	46.6	62.2	62.2	62.2	62.2	62.2	62.2	62.2	62.2
			7.2	18.85	22.7	46.57	54.92	62.72	71.05	73.82	74.97	76.02	77.2	77.2	77.2

<u>Appendix 5b</u>

Triple Disc Coulter	Pressure intensity in kP	Reps	Days from sowing 5	6	7	8	9	10	11	12	13	14	15	16	17
	0	1	-	-	-	-	2.2	6.6	8.8	8.8	8.8	8.8	8.8	8.8	8.8
		2	-	-	-	-	2.2	6.6	8.8	11.1	11.1	11.1	11.1	11.1	11.1
		3	-	-	-	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
		4	-	-	-	-	-	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
			-	-	-	0.55	1.65	4.95	6.05	6.62	6.62	6.62	6.62	6.62	6.6
	35	1	-	6.6	15.5	13.3	15.5	17.7	28.8	38.3	37.7	37.7	37.7	37.7	37.7
		2	-	2.2	4.4	4.4	6.6	6.6	8.8	8.8	8.8	11.1	11.1	11.1	11.1
		3	-	4.4	11.1	11.1	13.3	22.2	22.2	33.3	35.5	35.5	37.7	37.7	37.7
		4	-	-	-	-	2.2	4.4	4.4	6.6	6.6	6.6	6.6	6.6	6.6
			-	3.3	7.75	7.75	9.4	12.72	16.05	20.5	22.15	22.72	23.25	23.25	23.2
	70	1	-	4.4	15.5	24.4	31.1	33.3	35.5	39.9	39.9	40.0	40.0	40.0	40.0
		2	-	2.2	8.8	22.2	31.1	35.5	37.7	42.2	42.2	42.2	42.2	42.2	42.2
		3	-	-	2.2	4.4	4.4	6.6	6.6	6.6	6.6	8.8	8.8	8.8	8.8
		4	-	-	-	-	-	2.2	11.1	15.5	15.5	17.7	17.7	20.0	20.0
			-	1.65	6.62	12.75	16.65	10.4	22.72	26.05	26.05	27.17	27.17	27.75	27.7

APPENDIX 5(c)

Temperature measurement in direct drilled grooves (C^o)

Relative humidity regimes	Coulter types	Reps	Days from drilling 3 Day	3 Night	6 Day	6 Night	9 Day	9 Night
LRH	Chisel	1	22.5	19.7	23.5	22.5	25.0	22.7
		2	22.7	19.5	25.0	22.7	25.0	22.7
		3	21.8	19.7	25.7	22.5	25.7	22.7
	Hoe	1	22.0	19.9	24.9	22.7	25.0	24.0
		2	21.5	19.7	23.7	22.7	25.0	24.0
		3	22.7	19.9	25.0	25.0	25.5	24.0
	Triple Disc	1	22.7	19.2	25.3	22.0	25.0	25.0
		2	22.7	19.5	25.0	22.5	25.7	25.0
		3	22.7	19.7	25.0	22.5	25.0	22.5
HRH	Chisel	1	24.5	19.5	26.6	19.9	25.5	21.5
		2	24.7	19.5	25.7	20.2	24.0	22.0
		3	24.2	19.2	25.5	19.7	26.3	21.7
	Hoe	1	24.0	19.4	24.0	20.8	25.0	21.0
		2	24.0	19.2	24.0	21.0	25.0	20.8
		3	24.7	19.4	24.0	20.8	25.7	21.0

Appendix 5(c)

Relative humidity regimes	Coulter types	Reps	Days from drilling					
			3		6		9	
			Day	Night	Day	Night	Day	Night
	Triple disc	1	22.7	19.2	25.3	19.9	25.0	21.5
		2	25.3	18.7	26.0	19.9	25.7	21.5
		3	24.0	18.9	25.2	20.2	25.7	21.0

APPENDIX 6

(a) Specifications of Experiment 2(a)

Date of experiment	1.7.1977
Type of experiment	Large soil blocks in laboratory
Coulter types used	Chisel (experimental), hoe and triple disc coulter
Species sown	"Kapora" wheat
Seed germination potential	98.4% (Massey University Seed Tech. Centre)
Nominal sowing depth	38 - 40 mm
Drilling speed	60 m/hour
Groove covering treatments	Drilled seeds pressed over the grooves at 0, 35, 70 kPa respectively after bar harrowing
Soil type	"Manawatu fine sandy loam"
Initial soil moisture stress	Stabilized to an average of 45% (d.b.) approximately at -0.2 bars
Condition of parent vegetation	Rye grass, mown to ground level and then sprayed
Herbicides used, rate and time of application	Paraquat at 5.1 l/ha + dicamba 1.4/ha in one blanket spray 3 days prior to drilling
Experimental design	Randomised blocks with 4 replicates (split plot)
Duration of lapse time between drilling and termination of experiment	3 weeks
Climatic conditions during experiment	Controlled climatic conditions (climate laboratory, PPD, D.S.I.R.) at 90/93% r.h. and 22/18^{o}C temp. day/night and 55/60% r.h. and 22/18^{o}C temp. day/night in each of two rooms respectively.
Seedling emergence counts	Daily seedling emergence counts until the termination of experiment.

APPENDIX 6(b)

Seedling emergence percentage

LRH	Pressure Intensity kPa	Reps	Days from sowing 4	5	6	7	8	9	10	11	12	13	14	15	16
Chisel	0	1	-	17.7	33.3	43.3	53.3	57.7	65.5	67.7	67.7	70	70	70	70
coulter		2	2.2	19.9	37.7	49.9	53.3	61.2	65.5	69.9	69.9	72	72	72	72
		3	-	0	4.0	8.8	14.4	14.4	16.6	19.9	31.1	31.1	31.1	31.1	31.1
		4	-	4.4	11.1	13.3	22.2	41.0	51.1	51.1	53.3	57.7	57.7	57.7	57.7
		Mean	0.55	10.5	21.52	28.82	35.8	38.87	49.67	52.15	55.5	57.7	57.7	57.7	57.7
	35	1	-	31.0	78.8	86.6	92.1	92.2	90	90	90	90	90	90	90
		2	-	8.8	37.7	45.5	59.9	63.2	65.5	65.5	68	68	68	68	68
		3	-	4.4	14.4	22.2	35.5	37.7	39.9	43.43	53.3	53.3	53.3	53.3	53.3
		4	-	6.6	16.6	16.6	31.1	35.5	43.3	53.3	55.5	60	60	60	60
		Mean	-	12.7	36.87	42.72	54.65	57.15	59.67	63.05	66.7	67.82	67.82	67.82	67.8
	70	1	0	20.2	41.1	65.5	78.8	78.8	84	84	84	84	84	84	84
		2	4.4	20.2	31.1	43.3	47.7	55.5	58	58	58	58	58	58	58
		3	-	-	2.2	6.6	11.0	24.4	24.4	24.4	24.4	24.4	24.4	24.4	24.4
		4	-	4.4	11.0	22.2	29.9	31.1	39.9	43.3	46.6	46.6	46.6	46.6	46.6
		Mean	1.1	11.2	21.35	34.4	41.85	47.45	51.57	52.42	53.25	53.25	53.25	53.25	53.25

Appendix 6(b) contd

LRH	Pressure Intensity kPa	Reps	Days from sowing 4	5	6	7	8	9	10	11	12	13	14	15	16
Hoe	0	1	-	-	18.8	37.7	45.5	51.	59	69.9	69.9	82.2	82.2	82.2	82.2
coulter		2	-	6.6	12.2	18.8	33.3	41.1	45.5	47.7	49.9	53.3	53.3	53.3	53.3
		3	-	4.4	37.7	61.1	69.5	74.4	77.7	78.8	82.0	82.0	82.0	82.0	82.0
		4	2.2	18.8	57.7	69.9	74.7	82.2	84.4	86	86	86	86	86	86
		Mean	0.55	7.45	31.6	46.87	55.85	62.17	66.65	70.6	71.95	71.95	75.87	75.87	75.8
	35	1	-	6.6	20.2	43.3	59.9	61.0	65.5	67.7	75.5	75.5	75.5	75.5	75.5
		2	-	4.4	4.4	6.6	20.2	33.3	49.9	49.9	55.5	60.0	60	60	60
		3	4.4	24.4	49.9	72.0	80	80	80	80	80	80	80	80	80
		Mean	1.1	14.95	30	46.3	58.87	64.57	69.85	70.4	73.75	74.87	74.87	74.87	74.8
	70	1	-	2.2	16.6	39.9	47.7	53.3	55.5	61.1	67.7	73.3	73.3	73.3	73.3
		2	-	2.2	12.2	18.8	26.6	41.1	55.5	69.9	69.9	75.5	75.5	75.5	75.5
		3	12.2	41.1	53.3	72.1	80.8	80	80	80	80	80	80	80	80
		Mean	3.05	19.15	34.95	50.75	59.32	64.7	69.4	74.25	75.9	78.7	78.7	78.7	78.7

Appendix 6(b) cont

LRH	Pressure Intensity kPa	Reps	Days from sowing 4	5	6	7	8	9	10	11	12	13	14	15	16	17
Triple	0	1	-	2.2	4.4	10	18.8	18	20.2	20.2	24	24	24	24	24	24
Disc		2	-	-	2.2	8.8	16.6	20	20.2	22.2	22.2	24	24	24	24	24
Coulter		3	-	10	12.2	16.6	35.5	41.0	49.9	55.5	55.5	60	60	60	60	60
		4	-	-	4.4	8.8	10.1	18.0	22.2	35.5	37.7	40	40	40	40	40
		Mean	-	3.05	5.8	11.05	20.25	24.25	28.12	33.35	34.3	34.3	37.0	37.0	37.0	37.0
	35	1	-	2.2	10.1	20.2	35.5	37.7	49.9	51.1	51.1	51.1	51.1	51.1	51.1	51.1
		2	-	-	8.8	8.8	14.4	14.9	19.9	18.0	20	24	24	24	24	24
		3	-	2.2	4.4	6.6	10	24.4	37.7	41.1	47	48	48	48	48	48
		4	-	6.6	14.4	31.1	37.7	39.9	43.3	55.5	55.5	55.5	60	60	60	60
		Mean	-	9.42	16.67	24.4	29.22	37.7	41.42	43.4	44.65	45.77	45.77	45.77	45.77	45.77
	70	1	-	-	18.8	37.7	53.3	61.1	67.7	69.9	69.9	70	70	70	70	70
		2	-	4.4	12.2	22.2	30	30	30	30	30	30	30	40	30	30
		3	-	-	4.4	10.0	16.6	20.2	31.1	37.7	40	40	40	40	40	40
		4	-	2.2	4.4	8.8	14.4	22.2	31.1	31.1	35.5	37.7	37.7	37.7	37.7	37.7
		Mean	-	1.65	9.95	19.67	28.57	33.37	39.97	42.17	43.85	44.42	44.42	44.42	44.42	44.4

Appendix 6(b) contd

HRH	Pressure Intensity kPa	Reps	Days from sowing 4	5	6	7	8	9	10	11	12	13	14	15	16
Chisel	0	1	-	4.4	10.1	22.2	31.1	39.9	41.1	42.2	42.2	42.2	42.2	42.2	42.2
coulter		2	-	4.4	6.6	16.6	26.6	35.5	37.7	37.7	42.2	48.8	48.8	48.8	48.8
		3	-	4.4	20.2	35.5	41.0	41.0	55.5	59.9	60	60	60	60	60
		4	-	12.3	26.6	31.1	35.5	43.2	53.3	55.5	64	64	64	64	64
		Mean	-	6.37	15.87	26.35	33.55	37.97	46.9	48.82	52.1	53.75	53.75	53.75	53.7
	35	1	6.6	45.5	51.0	65.5	84.4	88.8	88.8	88.8	88.8	88.8	88.8	88.0	88.0
		2	-	8.8	8.8	18.8	35.5	41.1	47.7	47.7	57.7	57.7	57.7	57.7	57.7
		3	-	12.2	12.2	20.2	35.5	39.9	49.9	57.7	57.7	57.7	57.7	57.7	57.7
		4	-	22.2	37.7	47.7	57.7	69.9	72	72	72	72	72	72	72
		Mean	1.65	22.17	27.42	38.05	53.27	59.92	4.6	66.55	69.05	69.05	69.05	69.05	69.05
	70	1	-	2.2	6.6	14.4	22.2	33.3	37.7	41.1	46.6	46.6	46.6	46.6	46.6
		2	-	4.4	4.4	16.6	24.4	31.1	41.1	53.3	57.7	57.7	57.7	57.7	57.7
		3	-	16.7	29.9	45.5	57.7	63.2	63.2	64	64	64	64	64	64
		4	10	26.6	41.0	47.7	72.7	80.0	78.0	78	78	78	78	78	78
		Mean	2.5	12.47	20.47	31.05	44.25	51.9	55	59.1	61.57	61.57	61.57	61.57	61.6

Appendix 6(b) contd

HRH	Pressure Intensity kPa	Reps	Days from sowing 4	5	6	7	8	9	10	11	12	13	14	15	16
Hoe	0	1	-	22.2	37.7	53.3	61.1	65.5	67.7	69.9	72	72	72	72	72
coulter		2	-	10.1	20.2	37.7	55.5	55.5	65.5	69.9	80	80	80	80	80
		3	-	4.4	14.4	18.8	31.1	41.0	43.3	49.9	55.5	60	60	60	60
		4	-	2.2	4.4	8.8	22.2	35.5	37.7	49.9	49.9	57.7	57.7	57.7	57.7
		Mean	-	9.72	19.17	29.65	42.47	49.37	53.55	59.9	64.35	67.42	67.42	67.42	67.4
	35	1	2.2	18.8	35.5	49.9	55.5	61.0	61.0	61.1	64.4	64.4	64.4	64.4	64.4
		2	-	6.6	6.6	18.8	35.5	47.7	51.1	53.3	53.3	53.3	53.3	53.3	53.3
		3	-	-	12.2	22.2	37.7	41.1	51.1	59.9	59.9	62	62	62	62
		4	-	4.4	10.1	18.8	26.6	33.3	47.7	49.9	49.9	52	52	52	52
		Mean	0.55	7.45	16.1	27.42	38.82	45.77	52.72	56.02	56.87	57.92	57.92	57.92	57.9
	70	1	2.2	22.2	31.1	45.5	61.1	61.1	61.0	64	64	64	64	64	64
		2	4.4	14.4	26.6	43.3	55.5	61.1	63.0	67	67	68	68	68	68
		3	-	16.6	26.6	37.7	55.5	61.0	65.0	67	77.7	77.7	77.7	77.7	77.7
		4	-	2.2	6.6	10.1	29.9	39.9	43.3	46.6	46.6	46.6	46.6	46.6	46.6
		Mean	1.65	13.85	22.72	34.15	50.5	55.77	58.07	61.15	63.82	64.07	64.07	64.07	64

Appendix 6(b) contd.

HRH	Pressure Intensity kPa	Reps	Days from sowing 4	5	6	7	8	9	10	11	12	13	14	15	16	17
Triple	0	1	-	10.0	12.2	16.6	35.5	41.1	49.9	51.0	55.5	54.0	54	54	54	54
disc		2	-	-	4.4	8.8	10	18.8	22.2	27.7	26.6	26.6	26.6	26.6	26.6	26.6
		3	2.2	24.4	33.3	41.0	53.3	53.3	61.1	65.5	68	68	68	68	68	68
		4	10	35.5	59.9	67.7	72.2	78.8	78.8	78.8	78.8	80	80	80	80	80
		Mean	3.05	17.47	27.45	33.52	42.75	48	60.5	55.75	57.22	57.15	57.15	57.15	57.15	57.1
	35	1	-	2.2	4.4	6.6	10	24.4	27.7	28.8	28.8	28.8	28.8	28.8	28.8	28.8
		2	-	6.6	14.4	31.1	27.7	27.7	27.7	28.8	28.8	28.8	28.8	28.8	28.8	28.8
		3	-	26.6	49.9	59.9	65.5	67.7	68	68	68	68	68	68	68	68
		4	-	28.8	53.3	67.7	80	86	90	90	90	90	90	90	90	90
		Mean	-	16.05	30.5	41.32	45.8	51.45	53.35	53.90	53.90	53.90	53.90	53.90	53.90	53.90
	70	1	-	-	4.4	10.0	16.6	20.2	31.1	37.7	37.7	46.6	46.6	46.6	46.6	46.6
		2	-	2.2	4.4	6.6	14.4	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2
		3	6.6	20.0	47.7	55.5	72.2	74.4	76	76	76	76	76	76	76	76
		4	4.4	24.4	35.5	63.0	65.5	59.9	74	74	74	74	74	74	74	74
		Mean	2.75	11.65	23	33.77	42.17	46.67	50.82	52.47	52.47	54.7	54.7	54.7	54.7	54.7

APPENDIX 6(c)

In-Groove Moisture Content Measurement in % (d.b.)

LRH Regime	Pressure intensity in kPa	Reps	Days from sowing 3	6	9	12	15
Coulter types							
Chisel coulter	0	1	35.5	33.3	34.6	31.9	28.9
		2	48.2	44.5	44.8	34.5	37.1
	35	1	39.9	37.7	36.5	32.1	33.6
		2	51.1	45.0	43.4	45.1	39.7
	70	1	40.0	38.9	37.8	33.1	32.8
		2	48.6	47.1	42.8	42.2	39.6
Triple disc	0	1	44.9	44.0	42.5	37.1	38.5
		2	47.4	46.7	40.6	39.3	35.7
	35	1	45.9	47.9	43.4	41.5	37.2
		2	48.6	45.0	39.4	45.9	33.9
	70	1	39.5	43.5	39.3	40.2	32.8
		2	53.0	46.7	43.2	44.6	35.6
Hoe	0	1	41.5	39.4	38.9	35.8	29.9
		2	43.5	40.5	43.2	35.1	36.9
	35	1	42.4	28.7	42.6	33.3	27.8
		2	42.2	38.8	40.5	39.6	39.4
	70	1	45.3	38.7	37.3	35.6	35.9
		2	43.1	45.1	41.9	43.8	35.4

Appendix 6c contd

HRH

	Pressure intensity in kPa	Reps	Days from sowing 3	6	9	12	15
Chisel coulter	0	1	48.8	44.3	43.6	43.1	37.7
		2	46.3	46.0	41.7	40.2	39.8
	35	1	45.5	48.8	42.8	43.0	41.2
		2	42.7	47.5	47.7	43.5	40.7
	70	1	47.9	46.7	46.3	46.9	43.5
		2	45.9	53.2	47.1	42.0	44.1
Triple disc	0	1	46.4	48.1	44.1	43.9	39.5
		2	36.5	44.6	46.2	38.7	40.5
	35	1	48.4	50.6	48.3	46.9	40.8
		2	38.8	44.3	41.2	36.5	36.5
	70	1	52.9	48.4	47.9	44.5	41.4
		2	39.8	38.4	35.9	36.7	34.6
Hoe coulter	0	1	44.3	46.2	44.4	42	40.4
		2	37.9	37.9	39.7	38.2	37.8
	35	1	45.7	45.3	43.3	41.1	39.8
		2	39.6	44.2	38.7	8.6	36.1
	70	1	46.7	47.4	47.8	43.2	39.9
		2	40.1	39.2	39.4	39.6	37.7

APPENDIX 6(d)

The effect of coulter types and ambient conditions on the in-groove soil temperature

LRH regime

Coulter types	Reps	4 Day	Mean	4 Night	Mean	7 Day	Mean	7 Night	Mean	10 Day	Mean	10 Night	Mean	13 Day	Mean	13 Night	Mean
		Days from drilling															
Chisel coulter groove	1	17.7		17.2		19.2		17.5		18.9		17.2		18.9		17.0	
	2	18.0		17.0		18.7		17.0		18.0		16.7		18.5		16.7	
	3	18.0		16.7		18.7		16.7		18.7		17.0		18.5		16.9	
	4	18.0	18.0	17.0	17.0	18.0	19.0	17.2	17.1	18.5	18.6	17.2	17.1	18.5	18.6	17.0	17.0
	5	18.5		17.0		19.2		17.2		18.5		17.2		18.3		17.0	
	6																
Triple disc coulter	1	18.3		18.0		19.4		18.0		19.2		17.5		18.7		17.5	
	2	18.7		17.7		19.5		18.0		19.4		17.0		18.7		17.0	
	3	18.9		17.7		19.4		18.0		19.4		17.2		18.5		17.0	
	4	18.0	18.6	17.7	17.5	19.5	19.5	18.0	17.9	19.4	19.3	17.2	17.1	18.9	18.9	17.0	17.1
	5	18.7		17.0		19.7		17.5		19.2		17.0		19.2		17.0	
	6	18.9		17.0		19.7		17.7		19.4		17.0		19.2		17.0	
Hoe coulter	1	18.0		18.0		19.4		18.0		19.4		18.0		18.9		17.0	
	2	18.5		17.0		19.4		17.2		19.4		17.0		19.2		17.7	
	3	18.0		17.7		18.9		17.7		18.9		17.5		18.9		17.2	
	4	18.0	18.3	16.7	17.4	19.2	19.2	17.2	17.5	18.9	19.2	17.0	17.5	19.2	19.1	17.5	17.4
	5	18.7		17.7		18.9		17.7		19.4		18.0		19.2		17.5	
	6	18.3		17.2		19.4		17.5		19.2		17.5		19.2		17.5	

Ambient Day = 22^{o}C Night = 18.0^{o}C

Appendix 6(d) contd

HRH regime

Coulter types	Reps	4 Day	Mean	4 Night	Mean	7 Day	Mean	7 Night	Mean	10 Day	Mean	10 Night	Mean	13 Day	Mean	13 Night	Mean
Chisel coulter	1	20.2		18.5		20.2		18.5		20.2		18.5		21.0		18.3	
	2	19.7		18.0		20.8		18.0		20.2		18.0		21.0		17.7	
	3	19.4	19.6	18.5	18.4	19.9	20.3	18.5	18.2	19.0	20.0	18.5	18.3	20.5	20.9	18.0	18.0
	4	19.4		18.5		20.2		18.0		20.2		18.2		20.8		18.3	
	5	19.4		18.7		19.9		18.5		20.2		18.5		20.8		18.0	
	6	19.4		18.0		20.5		17.7		20.2		18.0		21.0		17.7	
Triple disc	1	19.7		18.0		21.0		18.3		20.2		18.0		21.0		17.9	
	2	19.5		17.5		21.0		17.7		20.5		17.5		21.0		17.9	
	3	19.2	19.7	17.7	18.0	20.8	21.0	18.3	18.2	20.5	20.4	17.5	17.9	20.8	20.9	18.0	18.0
	4	19.5		18.0		20.8		18.3		20.2		18.2		20.5		18.0	
	5	19.5		18.0		21.0		18.3		20.2		18.0		20.8		18.0	
	6	19.9		17.5		21.0		18.0		20.5		18.0		21.0		17.9	
Hoe coulter	1	19.5		18.0		20.2		18.3		19.9		18.0		20.2		17.9	
	2	19.9		18.0		20.5		17.7		20.2		18.0		20.5		18.0	
	3	20.5	19.9	17.7	18.1	21.0	20.5	18.3	18.1	20.5	20.1	18.0	18.0	21.0	20.5	17.7	17.9
	4	19.9		18.3		20.8		18.0		19.9		17.5		20.8		18.0	
	5	19.4		18.3		19.9		18.0		19.9		18.2		19.9		18.0	
	6	20.2		18.0		20.5				20.2		18.0		20.5		17.9	

(Column headings: Days from drilling 4, 7, 10, 13; Day / Night)

Ambient Day = 22°C Night = 18°C

APPENDIX 7

(a) Specifications of experiment 2(b)

Date of experiment	6.1.78
Type of experiment	Large soil blocks in laboratory
Coulter type used	Chisel (experimental), hoe, and triple disc coulters
Species sown	"Kapora" wheat
Seed germination potential	98.4% (Massey University, Seed Tech. Centre)
Nominal sowing depth	38-40 mm
Nominal sowing spacing	20 mm
Drilling speed	60 m/hour
Groove covering treatments	Drilled seeds pressed directly at 0,35 and 70 kPa before bar harrowing
Soil type	"Manawatu fine sandy loam"
Initial soil moisture stress	Stabilized to an average of 45% (d.b.) approximately -0.2 bars
Condition of parent vegetation	Ryegrass, mown to ground level and then sprayed
Herbicides used, rate and time of application	Paraquat at 5.1 l/ha + dicamba 1.4 l/ha in one blanket spray 3 days prior to drilling
Experimental design	Randomised complete blocks with 4 replicates (split-plot)
Duration of lapse time between drilling and termination of experiment	3 weeks
Climatic conditions during experiment	Controlled climatic condition (climate laboratory, PPD, DSIR) at 90/93% r.h and 22/18^{o}C temp. day/night and 55/60% r.h. and 22/18^{o}C Temp. day/night in each of two rooms respectively.
Seedling emergence counts	Daily seedling emergence counts until the end of experiments.

APPENDIX 7

(b) Seedling Emergence Rate Percentage

LRH Regime

Coulter types	Pressure Intensity (kPa)	Reps	Days from Sowing 5	6	7	8	9	10	11	12	13	14	15	16	17
Chisel coulter	0	1	6.6	26.6	39.9	46.6	51.1	55.5	55.5	55.5	64.4	66.6	71.1	71.1	71.1
		2	2.2	13.3	24.2	41.1	53.3	55.5	57.7	62.2	66.6	68.8	73.3	73.3	73.3
		3	-	11.1	17.7	26.6	35.5	39.9	48.8	66.6	79.9	79.9	82.2	82.2	82.2
		4	22.2	26.6	28.8	51.1	55.5	62.2	66.6	79.9	88.8	88.8	91.1	81.1	81.1
		Mean	7.75	19.4	27.65	41.35	48.85	53.27	57.15	66.05	74.92	76.02	79.42	79.42	79.42
	35	0	4.4	17.7	22.2	28.8	33.3	71.0	93.3	93.3	93.3	95.5	95.5	95.5	95.5
		2	11.1	19.9	24.4	35.5	39.9	46.6	68.8	71.1	71.1	71.1	77.7	77.7	77.7
		3	19.9	26.6	28.8	33.3	39.9	44.4	55.5	66.6	86.6	86.6	88.8	88.8	88.8
		4	6.6	13.3	44.4	48.8	53.3	53.3	64.4	64.4	66.6	66.6	66.6	66.6	66.6
		Mean	10.5	19.37	29.95	36.6	41.6	53.82	70.5	73.85	79.4	79.95	82.15	82.15	82.15
		1	6.6	24.4	37.7	53.3	53.3	57.7	64.4	64.4	68.8	68.8	73.3	73.3	73.3
		2	13.3	24.4	31.1	35.5	37.7	39.9	44.4	44.4	53.3	57.7	60	60	60
		3	26.6	26.6	53.3	53.3	64.4	64.4	64.4	64.4	64.4	66.6	68.8	58.8	68.8
		4	-	28.8	33.3	37.7	42.2	48.8	73.3	73.3	73.3	81.1	84.4	84.4	84.4
		Mean	11.62	26.05	38.85	44.95	49.4	52.7	61.62	61.62	64.95	68.55	71.62	71.62	71.62

Appendix 7(b)

Coulter types	Pressure Intensity (kPa)	Reps	Days from Sowing 5	6	7	8	9	10	11	12	13	14	15	16	17
Hoe coulter	0	1	11.1	26.6	31.1	39.9	44.4	55.5	53.3	57.7	62.2	62.2	62.2	62.2	62.2
		2	13.3	26.6	44.4	51.1	53.3	57.7	57.7	57.7	66.6	68.8	68.8	68.8	68.8
		3	-	4.4	11.1	37.7	42.1	44.4	48.8	48.8	73.3	73.3	75.5	75.5	75.5
		4	-	26.6	26.6	26.6	48.8	51.0	53.2	75.5	75.5	75.5	75.5	75.5	75.5
		Mean	6.1	21.05	28.3	38.82	47.15	52.15	53.25	59.92	69.4	69.95	70.5	70.5	70.5
	35	1	4.4	19.9	22.2	35.5	37.7	59.9	62.2	66.6	71.1	71.1	71.1	71.1	71.1
		2	11.1	28.8	42.2	53.3	59.9	62.2	62.2	66.6	75.5	77.7	77.7	77.7	77.7
		3	11.1	22.2	33.3	42.1	42.1	44.4	48.8	48.8	62.1	64.3	64.3	66.6	66.6
		4	26.6	51.0	53.2	55.5	59.9	62.1	62.1	62.1	62.1	62.1	62.1	62.2	62.2
		Mean	13.3	30.47	37.72	46.6	49.9	57.15	58.82	61.02	67.7	68.8	68.8	69.4	69.4
	70	1	6.6	26.6	31.1	44.4	48.8	50.0	55.5	62.1	68.8	75.5	75.5	75.5	75.5
		2	6.6	15.5	22.2	26.6	31.1	35.5	37.7	39.9	42.1	44.4	44.4	44.4	44.4
		3	34.4	55.5	62.1	66.6	73.2	77.7	82.1	82.2	82.2	84.4	84.4	86.6	86.6
		4	6.6	17.7	22.2	55.5	57.7	64.3	68.8	68.8	71.0	71.0	75.5	75.5	75.5
		Mean	11.05	28.82	34.4	48.27	52.7	56.87	61.02	63.25	66.02	68.82	69.95	70.5	70.5

Appendix 7(b)

Coulter types	Pressure Intensity (kPa)	Reps	Days from sowing 5	6	7	8	9	10	11	12	13	14	15	16	17
Triple disc coulter	0	1	-	-	4.4	6.6	11.1	13.3	11.1	15.5	17.7	17.7	20	20	20
		2	-	2.2	8.8	17.7	22.2	24.4	26.6	26.6	26.6	26.6	26.6	26.6	26.6
		3	-	17.7	22.2	24.4	26.6	26.6	25.5	28.8	28.8	28.8	33.3	33.3	33.3
		4	-	22.2	48.8	48.8	48.8	51.0	51	51	53.2	53.2	57.7	57.7	57.7
		Mean	-	10.52	21.05	24.37	27.17	28.27	28.82	30.47	31.57	31.57	34.4	34.4	34.4
	35	1	-	4.4	11.1	22.2	26.6	28.8	31.1	31.1	33.3	33.3	35.5	35.5	35.5
		2	-	-	2.2	2.2	4.4	8.8	13.3	13.3	20	20	20	20	20
		3	-	19.9	33.3	33.3	39.9	46.6	46.6	46.6	46.6	46.6	48.8	48.8	48.8
		4	-	15.5	22.2	22.2	31.1	35.5	37.7	37.7	37.7	39.9	42.1	42.2	42.2
		Mean	-	9.95	17.2	19.97	25.5	29.92	32.17	32.17	34.4	34.95	36.6	36.62	36.62
	70	1	-	6.6	15.5	22.2	22.2	22.2	22.2	22.2	24.4	26.6	26.6	26.6	26.6
		2	-	2.2	4.4	6.6	11.1	13.3	13.3	13.3	17.7	22.2	22.2	22.2	22.2
		3	-	22.2	28.8	31.1	33.3	57.7	57.7	57.7	59.9	66.6	66.6	66.6	66.6
		4	-	-	2.2	4.4	6.6	11.1	13.3	19.9	22.2	26.6	28.8	28.8	28.8
		Mean	-	7.75	12.72	16.07	18.3	26.07	26.62	28.27	31.05	35.5	36.05	36.05	36.05

Appendix 7(b)

HRH regime

Coulter types	Pressure Intensity (kPa)	Reps	Days from Sowing 5	6	7	8	9	10	11	12	13	14	15	16	17
Chisel coulter	0	1	35.5	44.4	48.8	51.0	51.0	53.2	55.5	55.5	68.8	68.8	68.8	68.8	68.8
		2	19.9	28.8	42.1	51.0	53.2	53.2	53.2	64.3	68.8	68.8	73.3	73.3	73.3
		3	26.6	33.3	37.7	44.4	48.8	51.0	57.7	79.9	82.2	82.2	82.2	82.2	82.2
		4	6.6	13.3	22.2	33.3	39.9	42.2	44.4	46.6	64.3	64.3	66.6	66.6	66.6
		Mean	22.15	29.95	37.7	44.92	48.22	49.9	52.7	61.57	71.02	71.02	72.72	72.72	72.72
	35	1	22.2	31.1	44.4	51.0	53.2	53.2	51.0	53.2	62.1	66.6	71.1	71.1	71.1
		2	33.3	46.6	57.7	73.2	75.5	79.9	79.9	79.9	88.8	91.1	91.1	91.1	91.1
		3	4.4	8.8	13.3	17.7	26.6	33.3	37.7	46.6	68.8	68.8	68.8	68.8	68.8
		4	2.2	28.8	55.5	62.2	64.4	66.6	68.8	93.3	93.3	95.5	95.5	95.5	95.5
		Mean	15.52	28.82	42.72	51.02	54.92	58.25	59.35	68.25	78.25	80.5	81.62	81.62	81.62
	70	1	15.5	31.1	39.9	42.1	42.1	42.1	44.4	53.3	55.5	57.7	57.7	57.7	57.7
		2	13.3	26.6	39.9	48.8	53.2	57.7	62.2	62.2	66.6	66.6	68.8	68.8	68.8
		3	4.4	31.1	39.9	66.6	73.3	73.3	73.3	75.5	75.5	75.5	75.5	75.5	75.5
		4	24.4	26.6	53.2	57.7	68.8	68.8	68.8	91.1	88.8	88.8	88.8	88.8	88.8
		Mean	14.4	28.85	43.22	53.8	59.35	60.47	62.17	70.52	71.6	72.15	72.7	72.7	72.7

Appendix 7(b)

Coulter types	Pressure Intensity (kPa)	Reps	Days from Sowing												
			5	6	7	8	9	10	11	12	13	14	15	16	17
Hoe coulter	0	1	15.5	31.1	42.1	51.0	51.0	51.0	51.0	64.4	64.4	64.4	64.4	64.4	64.4
		2	26.6	46.6	59.9	64.3	66.6	68.8	68.8	79.9	79.9	82.2	82.2	82.2	82.2
		3	-	11.1	22.2	28.8	31.1	31.1	31.1	31.1	33.3	33.3	40	40	40
		4	2.2	33.3	39.9	44.4	57.7	59.9	62.2	62.2	68.8	68.8	68.8	68.8	68.8
		Mean	11.07	30.52	41.02	47.12	51.6	52.7	53.27	59.4	59.95	62.17	63.85	63.85	63.85
	35	1	37.7	57.7	59.9	68.8	68.8	71.0	71.0	73.2	73.3	75.5	75.5	75.5	75.5
		2	19.9	42.2	55.5	66.6	66.6	66.6	66.6	71.0	71.0	71.1	71.1	71.1	71.1
		3	11.1	17.7	26.6	31.1	44.4	44.4	62.2	62.2	62.2	52.2	62.2	62.2	62.2
		4	-	22.2	24.4	26.6	35.5	44.4	48.8	48.8	73.3	73.3	73.3	73.3	73.3
		Mean	17.17	34.95	41.6	48.27	53.82	56.6	62.15	63.8	69.95	70.52	70.52	70.52	70.52
	70	1	26.6	48.8	55.5	59.9	62.2	66.6	66.6	86.6	86.6	88.8	88.8	88.8	88.8
		2	24.4	33.3	42.2	46.6	46.6	48.8	48.8	55.5	57.7	57.7	57.7	57.7	57.7
		3	13.3	24.4	35.5	39.9	40	46.6	46.6	46.6	55.5	57.7	60	60	60
		4	24.4	33.3	42.2	44.4	71.0	73.3	73.3	73.3	84.4	87.7	88.8	88.8	88.8
		Mean	22.17	34.95	43.85	47.7	54.95	58.82	58.82	61.5	71.05	72.97	73.82	73.82	73.82

Appendix 7(b)

Coulter types	Pressure Intensity (kPa)	Reps	Days from sowing 5	6	7	8	9	10	11	12	13	14	15	16	17
Triple disc	0	1	13.3	17.7	22.2	24.4	31.1	33.3	33.3	33.3	35.5	35.5	35.5	35.5	35.5
		2	-	8.8	13.3	13.3	22.2	22.2	22.2	22.2	26.6	26.6	28.8	28.8	28.8
		3	4.4	15.5	15.5	24.4	26.6	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
		4	2.2	11.1	17.7	22.2	24.4	26.6	26.6	28.8	28.8	35.5	35.5	35.5	35.5
		Mean	4.97	13.27	17.7	21.07	26.07	27.72	27.72	28.72	29.92	31.6	32.15	32.15	32.15
	35	1	-	4.4	4.4	4.4	15.5	15.5	15.5	17.7	20	20	20	20	20
		2	26.6	26.6	28.8	35.5	37.7	42.2	46.6	53.3	53.3	53.3	55.5	55.5	55.5
		3	11.1	13.3	26.6	28.8	31.1	35.5	37.7	37.7	39.9	39.9	42.2	42.2	42.2
		4	6.6	42.2	46.6	48.8	51.0	48.8	48.8	48.8	48.8	51.1	51.1	51.1	51.1
		Mean	10.92	21.62	26.6	29.37	33.82	35.5	37.15	39.37	40.5	41.07	42.2	42.2	42.2
	70	1	-	15.5	24.4	24.4	28.8	28.8	28.8	33.3	33.3	37.7	37.7	37.7	37.7
		2	17.7	19.9	22.2	26.6	26.6	26.6	35.5	37.7	42.2	44.4	44.4	44.4	44.4
		3	2.2	26.6	31.1	33.3	35.5	39.9	42.2	42.2	44.4	46.6	46.6	46.6	44.4
		4	13.3	22.2	28.8	31.1	42.2	42.2	44.4	44.4	53.3	53.3	53.3	53.3	53.3
		Mean	8.3	21.05	26.62	28.85	33.27	34.37	37.72	39.4	43.3	45.5	45.5	45.5	45.5

Appendix 7(c)

The effect of coulter types and ambient relative humidity regimes on the in-groove soil moisture content in % (d.b.)

Coulter types / HRH Regime	Reps	Days from sowing 3	6	9	12
Chisel	1	40.6	45.5	34.1	40.3
	2	44.4	45.8	36.2	41.9
	3	42.6	42.9	38.5	40.7
	4	43.7	36.8	35.7	35.5
	5	45.1	37.7	39.6	35.4
	6	46.3	35.8	41.7	36.1
	Mean	43.7	40.7	37.6	38.3
Hoe					
	1	46.8	41.0	46.1	45.4
	2	47.4	43.7	38.2	44.4
	3	46.5	43.1	39.8	40.0
	4	45.3	44.5	35.6	37.6
	5	41.5	36.9	38.8	36.2
	6	40.9	41.6	41.4	41.1
	Mean	44.7	41.8	39.9	40.7
Triple disc	1	35.7	35.3	31.4	38.5
	2	37.7	35.7	33.2	40.9
	3	40.7	38.9	29.0	34.6
	4	40.5	40.6	43.0	36.7
	5	41.2	41.8	44.0	39.9
	6	43.6	40.8	44.7	43.7
	Mean	39.9	38.8	37.5	39.0

Appendix 7(c)

LRH Regime

Coulter types	Reps	Days from sowing 3	6	9	12
Chisel	1	49.4	41.4	32.4	33.4
	2	48.5	41.5	30.8	37.2
	3	42.8	37.58	28.9	29.9
	4	40.1	37.2	21.7	30.9
	5	39.4	26.2	27.8	25.0
	6	42.6	30.2	27.5	24.36
	Mean	43.8	35.6	28.1	30.1
Hoe	1	36.9	36.2	28.3	25.1
	2	32.6	29.7	23.8	22.3
	3	30.4	29.4	27.5	26.2
	4	35.5	27.1	34.6	25.6
	5	37.5	32.3	33.0	24.4
	6	39.1	27.7	32.0	21.0
	Mean	35.3	30.4	29.8	24.1
Triple disc	1	38.5	45.0	35.7	40.7
	2	35.9	45.3	28.1	40.0
	3	40.7	42.3	31.9	36.0
	4	41.3	39.1	36.9	33.3
	5	46.9	37.4	34.5	33.0
	6	43.7	36.7	35.6	28.3
	Mean	41.1	40.9	33.7	35.2

APPENDIX 7

(d) Combined analysis of variance of seed fate in experiments 1 and 2.

Treatment source	Levels of treatments
Initial soil moisture regimes (M)	2 (low, adequate)
Positions of applied pressures (I)	2 (over covered seeds, over uncovered seeds)
Relative humidity regimes (H)	2 (high, low)
Coulter types (T)	3 (chisel, hoe and triple disc coulters)
Pressures intensities (P)	3 (0, 35 and 70 kPa)

Experimental design = split-split-plot.

Analysis of Variance

Main plot		Seedling emergence		Ungerminated seeds		"Germinated but unemerged" seeds	
Source	D.F.	F-value	Level of Significance	F-value	Level of Significance	F-value	Level of significance
M	1	52.41	**	833.79	**	0.11	NS
I	1	6.22	NS	86.79	**	0.01	NS
M x I	1	3.22	NS	80.89	**	5.29	NS
Error 1	4						
Total 1	7						
CV			46.98%		41.10%		9.91%

Appendix 7(d) contd

Sub-plot

Source	D.F.	F-Value	Level of significance	F-Value	Level of significance	F-value	Level of Significance
H	1	2.83	NS	186.37	**	2.04	NS
T	2	51.9	**	691.49	**	5755.8	**
MxH	1	3.26	NS	164.36	**	0.45	NS
MxT	2	8.62	**	648.46	**	542.02	**
IxH	1	0.6	NS	5.42	*	58.9	**
IxT	2	1.02	NS	25.31	**	66.1	**
HxT	2	0.21	NS	27.46	**	17.51	**
MxIxH	1	0.09	NS	2.24	NS	44.4	**
MxIxT	2	6.77	**	19.20	**	384.52	**
MxHxT	2	2.51	NS	22.25	**	112.2	**
IxHxT	2	0.39	NS	4.4	*	83.6	**
MxIxHxT	2	0.11	NS	2.78	NS	18.4	**
Error 2	20						
Total	40						
CV		38.58%		15.93%		5.04%	

Sub-sub-plot

P	2	8.56	**	108.35	**	5.92	**
MxP	2	2.03	NS	88.19	**	30.08	**
IxP	2	3.03	*	66.08	**	12.29	**
HxP	2	1.7	NS	3.06	*	28.73	**

Appendix 7(d) contd

Source	D.F	F-Value	Level of significance	F-value	Level of significance	F-value	Level of significance
TxP	4	1.60	NS	27.27	**	14.88	**
MxIxP	2	5.08	**	83.67	**	8.47	**
MxHxP	2	0.09	NS	1.13	NS	1.65	NS
MxTxP	4	2.85	*	19.1	**	15.53	**
IxHxP	2	1.93	NS	5.56	**	33.76	**
IxTxP	4	2.70	*	14.77	**	27.00	**
HxTxP	4	0.20	NS	9.87	**	8.11	**
MxIxHxP	2	0.66	NS	4.32	**	1.63	NS
MxIxTxP	4	0.47	NS	15.79	**	11.23	**
MxHxTxP	4	0.69	NS	11.63	**	7.46	**
IxHxTxP	4	0.81	NS	23.93	**	3.95	**
MxIxHxTxP	4	0.55	NS	17.38	**	22.75	**
Error 3	48						
Total	96						
CV		19.35%		13.00%		5.48%	

Total of all plots

Error	72						
Total	143						
CV		28.03%		16.64%		5.7%	

APPENDIX 8

(a) Specification of experiment 3, 4a,b

Experiment date	23.9.77 to 21.11.77
Type of experiment	Soil blocks in boxes
Coulter types used	Triple disc coulter, a kitchen knife (both hand-drawn)
Species	"Kapora" wheat
Seed germination potential	98.4% (Massey University, Seed Tech. Centre)
Nominal sowing depth	38-40 mm
Nominal sowing spaces	20 mm
Groove covering treatments	A combination of various covering and pressing techniques.
Soil type	"Rangitikei sandy loam"
Initial soil moisture stress	Experiment 4(a) at 15.5% and Experiment 4(b) at 21.5%
Herbicides used, their rates & time of application	Paraquat 5.1 l/ha + dicamba 1.4 l/ha in one blanket spray 3 days prior to drilling
Experimental design	Completely randomised blocks with 3 replicates in experiment 4(a) and 4 replicates in experiment 4(b)
Duration of experiment time	3 weeks
Climatic condition	Controlled in climate lab. (DSIR) at 55/60% r.h. day/night and temp at $22^{o}/18^{o}C$ day/night.
Seedling emergence counts	Daily seedling emergence counts until the end of experiment.

APPENDIX 8

(b) Seedling emergence rate in percentage

Treatments	Reps	5	6	7	8	9	10	11	12	13	14	15	16	Mean (day 16)
(A) Knife cut grooves														
(i) No cover	1	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	0
	3	-	-	-	-	-	-	-	-	-	-	-	-	
	4	-	-	-	-	-	-	-	-	-	-	-	-	
(ii) seed covered with loose soil	1	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	2.5
	3	-	-	-	-	-	-	-	-	-	-	-	-	
	4	-	-	-	-	-	-	-	5	10	10	10	10	
(iii) Seed pressed at 70kPa	1	20	35	40	45	50	50	50	60	50	50	50	50	
	2	-	-	5	5	5	5	5	5	5	10	10	10	35
	3	-	10	15	15	25	30	35	40	40	40	40	40	
	4	-	5	5	10	15	20	30	35	35	40	40	40	
(iv) Polythene cover over the ground surface	1	-	-	5	20	25	30	30	30	30	30	30	30	
	2	-	-	5	5	5	5	5	5	5	10	10	10	
	3	-	-	-	-	-	5	5	5	5	10	10	10	
	4	-	5	15	25	30	40	50	50	50	50	50	50	24.3
	5	-	-	-	20	20	20	30	30	30	30	30	30	
	6	-	5	5	10	15	20	30	30	30	35	35	35	
	7	-	-	-	5	5	5	5	5	5	5	5	5	
	8	-	-	-	10	15	20	20	20	20	25	25	25	

Treatments	Reps	5	6	7	8	9	10	11	12	13	14	15	16	Mean.(day 16)
(B) <u>Triple disc groove</u>														
(i) no cover	1	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	3.75
	3	-	-	-	-	-	-	-	-	-	-	-	-	
	4	-	-	-	-	-	-	10	10	15	15	15	15	
(ii) grooves clean of dirt	1	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	0
	3	-	-	-	-	-	-	-	-	-	-	-	-	
	4	-	-	-	-	-	-	-	-	-	-	-	-	
(iii) grooves clean and seed press-ed at 70 kPa	1	-	-	10	15	15	20	25	25	30	30	30	30	
	2	-	-	-	5	5	10	15	15	20	20	20	20	30
	3	-	-	5	10	10	30	40	50	50	50	50	50	
	4	-	-	10	10	15	20	20	20	20	20	20	20	
(iv) grooves, seed pressed at 70 kPa	1	-	-	5	5	5	10	10	25	25	25	25	25	
	2	-	-	5	5	10	15	15	15	15	20	20	20	32.5
	3	-	-	-	5	15	25	30	45	45	55	55	55	
	4	-	-	-	-	-	10	25	25	30	30	30	30	

Treatments	Reps	5	6	7	8	9	10	11	12	13	14	15	16	Mean (day 16)
(v) grooves covered with loose soil	1	-	-	-	-	-	-	-	-	-	-	-	-	
	2	-	-	-	-	-	-	-	-	-	-	-	-	0
	3	-	-	-	-	-	-	-	-	-	-	-	-	
	4	-	-	-	-	-	-	-	-	-	-	-	-	
(vi) soil block covered with polythene	1	-	-	5	20	30	35	35	35	35	35	35	35	
	2	-	-	5	5	5	5	5	5	5	5	5	5	
	3	-	-	-	5	10	15	15	15	15	15	15	15	
	4	-	5	20	25	25	30	30	30	30	30	30	30	20.6
	5	-	10	20	25	25	25	30	35	35	35	35	35	
	6	-	-	-	5	5	10	10	20	20	20	20	20	
	7	-	-	-	-	-	-	-	-	-	-	-	-	
	8	-	-	-	15	15	15	20	25	25	25	25	25	

APPENDIX 8

(c) Seed fate percent

Treatments	Reps	Emergence	"Germinated but unemerged" Dead	Alive	Ungerminated
(A) **Knife cut-groove**					
No cover	1	5	36	0	59.0
	2	2.5	21	23.7	52.8
	3	0	10.3	7.7	82
Loose soil cover	1	5	38	53.7	3.3
	2	5	41.3	53.7	0
	3	10	34.3	53.0	2.7
Seed pressed at 70 kPa	1	10	56.3	7.5	26.2
	2	50	23.5	14.7	11.8
	3	10	37.7	28.5	23.8
Polythene cover	1	67.5	8.7	20.8	3
	2	30	50	17.5	2.5
	3	10	57.5	32.5	0
(B) **Triple disc coulter**					
No cover	1	0	0	0	100
	2	0	0	6	94.0
	3	0	8	5.5	86.5
Loose soil cover	1	0	74.2	13	17.8
	2	0	70.8	8.7	20.5
Seed pressed at 70 kPa	1	15	32.0	10.7	42.3
	2	20	30.8	3.7	45.5
	3	20	35.0	5.5	39.5
Polythene cover	1	32	50.3	17.7	0
	2	54	35.7	10.3	0
	3	29.3	24	31.5	13.2

APPENDIX 9

Experiment 5: Equilibrium moisture absorption isotherms of Karamu wheat at 20°C in salt solutions (liquid and vapour imbibition)

Specifications of experiment 5

Experiment date	17.7.78
Species	"Karamu" wheat
Germination potential	96% (Massey University, Seed Tech. Centre).
Type of experiment	Seed germination and seedling emergence potential, under various liquid and vapour moisture potentials
Weight of seeds used	8 g/treatment
NaCl concentrations	(6) 0 M, 0.25 M, 0.5 M, 1 M, 2 M, saturated solution.

APPENDIX 9a

Calibration of dew point hygrometer

Ambient conditions

r.h. = 60%

temp. = 20°C

Flow Rate Cm^3/sec	Ambient Relative humidity (%) measurement in climate room	Relative humidity (%) measured in open type soil coulter grooves	Relative humidity (%) measured in grooves covered with soil
1.573 (minimum)	60	63	72
3.932	58	63	74
7.865	57	62	78
15.73	56	61	80
23.59	56	60	82
31.46 (maximum)	55	58	84
Mean	57	61.1	78.3
S.D.±%	1.79	1.94	4.63

APPENDIX 9

(b) Specification of experiment 6a.

Experiment date	28.6.78
Type of experiment	Tillage bins in controlled climatic laboratory
Soil type	"Manawatu fine sandy loam"
Coulter types used	(i) Chisel coulter, no pressure (ii) Hoe coulter, no pressure (iii) Hoe coulter, pressure over seed (iv) Triple disc coulter, no cover or pressure (v) Triple disc coulter, pressure directly over seed, no cover (vi) Triple disc coulter, pressure over covered seeds
Experimental design	"completely randomised blocks" with three replicates
Herbicides application and rate	5.6 l/ha paraquat + 1.4 l/ha dicamba in single spray 3 days before drilling
Fertilizer application	Nil
Climatic condition	Controlled relative humidity at 60% constant and 20^{o}C temp. constant until day 17 after forming the grooves
Initial soil moisture conditions	15.5% (d.b.)

APPENDIX 9c

Experiment 6a. Soil in-groove relative humidity measurement (%) at controlled ambient relative humidity of 60%

Treatments	Reps	Days from sowing 1	2	3	4	5	6	7	8	9	10	11	12	13*	14*	15*	16	17
1 Chisel	1	95	95	95	92	94	90	92	89	80	80	81	80	80	82	84	81	81
coulter	2	93	93	93	94	92	94	90	85	81	81	80	81	81	83	85	82	82
	3	95	95	91	86	89	86	84	84	82	81	80	80	82	82	86	84	82
	4	94	92	90	89	86	88	87	84	84	82	81	81	83	84	85	85	81
	5	92	92	92	89	89	89	88	85	84	82	81	81	83	84	86	83	80
	6	94	93	93	88	89	89	89	86	83	81	81	81	83	84	86	84	81
Mean		93.8	93.3	92.3	89.6	89.8	89.3	88.3	85.5	82.0	81.1	80.6	80.6	82.0	83.6	85.5	83.1	81.1
2 Hoe coulter	1	94	94	94	89	92	92	92	85	75	73	75	72	85	85	85	70	70
no pressure	2	96	95	95	92	89	89	88	84	73	75	72	71	84	84	86	71	71
	3	92	91	89	88	82	80	77	75	72	72	72	72	84	84	85	71	71
	4	93	92	90	88	86	82	77	76	73	71	70	70	85	85	86	71	71
	5	90	90	90	82	77	77	77	77	77	76	76	75	84	84	85	70	70
	6	89	90	89	80	80	80	78	77	77	75	75	75	85	84	85	69	68
Mean		92.3	92	91.1	86.5	84.3	83.3	81.5	78.6	74.5	73.6	73.3	72.5	84.5	84.5	85.3	70.6	70.1
3 Hoe coulter	1	88	86	85	86	83	83	78	75	73	73	74	73	84	84	85	72	70
70 kPa	2	96	84	84	84	83	78	81	78	74	74	73	73	85	85	84	71	70
pressure	3	91	89	89	88	88	88	84	78	75	75	74	73	84	84	86	70	69
over seeds	4	90	89	89	89	89	89	80	77	74	74	73	74	84	84	86	69	69

Appendix 9c contd.

Treatments	Reps	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	5	95	90	90	86	86	86	84	80	75	75	75	75	84	84	87	69	69
	6	89	85	86	84	85	85	80	78	77	75	73	73	83	83	85	70	70
Mean		91.5	87.1	87.1	86.1	85.6	84.8	81.5	77.6	74.6	74.3	73.6	73.5	84	84	85.3	70.1	69.5
4 Triple disc	1	95	94	90	84	79	82	82	78	64	63	62	62	87	86	86	70	67
coulter	2	94	94	90	85	85	78	78	75	64	62	62	61	81	87	86	71	66
no pressure	3	86	86	90	80	78	79	75	72	65	63	62	62	85	86	88	67	64
	5	95	85	85	79	73	74	74	70	70	68	64	63	88	87	87	68	65
	6	89	79	79	77	74	74	74	72	71	65	63	63	88	87	86	68	63
Mean		91.6	88.3	86.6	0.8	78	77	76.5	72.8	66.3	63.6	62.1	61.8	86.6	86.5	87	68	64.9
5 Triple disc	1	95	85	85	88	82	79	77	75	69	67	65	65	88	87	84	70	67
coulter 70	2	92	92	92	84	82	77	78	74	69	67	64	64	88	87	85	69	68
kPa pressures	3	93	91	90	84	84	80	78	74	68	65	65	64	89	88	85	67	68
over seeds	4	95	89	84	84	80	82	79	72	70	68	67	67	86	85	85	68	67
	5	94	92	92	80	74	80	77	73	70	66	67	66	87	86	86	68	66
	6	93	90	90	82	80	73	73	72	68	68	66	66	87	87	85	68	65
Mean		93.5	89.8	88.8	83.6	80.3	78.5	77	73.3	69	67	65.6	65.3	87.5	86.6	85	68.3	66.5
6 Triple disc	1	95	94	95	95	94	88	90	85	80	80	80	80	80	82	85	82	80
coulter	2	95	94	94	94	91	90	89	84	80	80	80	80	80	84	86	83	82
loose soil	3	94	94	94	86	86	88	88	85	79	79	78	78	81	3	84	83	81
cover + 70	4	95	95	94	88	88	90	86	83	81	80	80	80	81	84	85	83	81
kPa pressure	5	94	94	92	86	88	88	84	82	80	80	80	80	81	84	85	83	81
over grooves	6	94	94	91	89	89	89	83	81	82	81	80	80	82	85	85	83	80
Mean		94.5	94.4	93.3	88.6	89.3	88	86.6	83.3	80.3	80	79.6	79.6	81	84	85	83	81

* controlled ambient r.h. on days 13 to 15 was at 90%

APPENDIX 9

(d) Specification of experiment 6(b)

Experiment date	30.11.78
Species sown	"Karamu" wheat
Seed germination potential	96% (Massey University, Seed Tech. Centre)
Type of experiment	Tillage bins in controlled climate
Soil type	"Manawatu fine sandy loam"
Coulter types used	(i) Chisel coulter, no pressure (ii) Hoe coulter, no pressure (iii) Hoe coulter, 70 kPa directly over seeds (iv) Triple disc coulter, no pressure or cover (v) Triple disc coulter, 70 kPa pressure directly over seeds (vi) Triple disc coulter, 70 kPa over covered seeds.
Experimental design	"Completely randomised blocks with 4 replicates
Pre-drilling herbicides used, their rate of application	Paraquat 5.6 l/ha + dicamba 1.4 l/ha 3 days before drilling in single blanket spray
Fertilizer application	Nil
Climatic condition	Controlled relative humidity & temp. at 60% and 20°C constant respectively
Initial soil moisture condition	14% (d.b.) at 0-45 mm depth
Seedling emergence & seed fate count	Daily seedling emergence counts until the termination of experiment on day 17 and at that seed fate was determined
In-groove relative humidity measurement	Daily r.h. measurements using a dew point hygrometer until the termination of experiment on day 17.

APPENDIX 9(e)

Experiment 6b. The rate of seedling emergence (%) as a function of coulter types and covering techniques

		Days from sowing												
Treatments	Reps	5	6	7	8	9	10	11	12	13	14	15	16	17
Chisel coulter	1	-	-	3.3	17.7	25.5	27.7	35.5	38.8	38.8	40	41.1	42.2	42.2
	2	-	-	1.1	11.1	28.8	31.1	32.2	35.5	35.5	38.8	38.8	38.8	38.8
	3	-	-	5.5	16.6	28.8	30.0	30.0	31.1	31.1	31.1	30.0	27.7	27.7
	Mean			3.3	15.1	27.7	29.6	32.5	35.1	35.1	36.6	36.6	36.2	36.2
Hoe coulter no pressure	1	-	-	-	4.4	5.5	13.3	18.8	22.2	24.4	27.7	30	30	30
	2	-	-	-	1.1	10	13.3	19.9	22.2	23.3	23.3	23.3	23.3	23.3
	3	-	-	-	3.3	11.1	32.2	33.3	36.6	36.6	37.7	40.0	40	40
	Mean				2.9	8.8	19.6	24.0	27.0	28.1	29.5	31.1	31.1	31.1
Hoe coulter 70 kPa over seed	1	-	7.7	16.6	25.5	34.4	35.5	35.5	37.7	37.7	37.7	37.7	37.7	37.7
	2	-	3.3	7.7	24.4	27.7	28.8	33.3	34.4	34.4	33.3	33.3	31.1	31.1
	3	-	2.2	7.7	21.1	46.6	46.6	46.6	45.5	44.4	42.2	42.2	42.2	42.2
	Mean		4.4	10.6	23.6	36.2	36.9	38.4	39.2	38.8	37.7	37.7	37	37
Triple disc coulter no pressure	1	-	-	-	-	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	2	-	-	-	-	-	-	-	-	-	-	-	-	-
	3	-	-	-	-	2.2	3.3	3.3	3.3	3.3	4.4	6.6	6.6	6.6
	Mean					1.1	1.4	1.4	1.4	1.4	1.8	2.5	2.5	2.5

Appendix 9e contd.

Treatments	Reps	5	6	7	8	9	10	11	12	13	14	15	16	17
Triple disc	1	-	-	-	-	1.1	2.2	2.2	3.3	3.3	3.3	2.2	2.2	2.2
coulter 70 kPa	2	-	-	-	2.2	2.2	2.2	4.4	11.1	14.4	17.7	16.6	15.5	15.5
over seed	3	-	-	-	1.1	4.4	6.6	6.6	6.6	6.6	4.4	4.4	4.4	4.4
	Mean				1.1	2.5	3.6	4.4	7	8.1	8.4	7.7	7.3	7.3
Triple disc	1	-	-	-	-	1.1	1.1	2.2	3.3	3.3	2.2	2.2	2.2	2.2
coulter 70 kPa	2	-	-	-	-	5.5	6.6	6.6	7.7	8.8	16.6	16.6	17.7	17.7
over groove	3	-	-	-	-	-	-	-	-	1.1	3.3	5.5	5.5	5.5
after covering with loose soil	Mean					2.2	2.5	2.9	3.6	4.4	7.3	8.1	8.4	8.4

APPENDIX 9(f)

Soil in-groove relative humidity measurements (%)

Treatments	Days from sowing 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Chisel coulter	94	89	84	84	83	81	80	80	80	78	75	75	75	75
no cover or pressure	95	90	85	85	83	82	80	78	78	77	77	77	77	77
	93	89	83	83	82	80	79	78	78	78	78	78	77	77
	92	88	84	83	81	79	78	79	79	78	78	78	77	77
	92	88	85	84	83	81	79	78	78	78	79	79	79	78
	95	89	86	85	84	83	81	81	80	79	79	79	79	79
Mean	93.5	88.8	84.5	84	82.6	81	79.5	79	78.8	78	77.6	77.6	77.3	77.1
Hoe coulter	91	89	78	78	78	78	78	70	70	70	70	70	70	70
no cover or pressure	92	80	79	79	79	79	75	71	70	70	69	69	68	68
	92	86	78	77	77	76	70	66	64	64	64	64	63	63
	94	83	80	79	79	77	72	76	72	72	72	70	70	70
	94	87	79	79	79	79	76	72	70	70	70	70	70	70
	93	88	79	78	78	77	74	72	72	72	72	72	72	70
Mean	92.6	85.5	79	78.3	78.3	77.6	74.1	71.1	69.6	69.6	69.5	69.1	68.8	68.5
Hoe coulter 70 kPa	92	87	82	82	81	80	78	78	78	78	77	77	77	77
pressure over seed	93	86	83	83	81	80	79	81	79	79	79	79	78	78
	92	87	82	82	82	81	78	72	72	72	72	72	72	72
	90	86	84	83	82	82	79	70	70	70	70	70	70	70
	90	83	80	80	80	79	77	69	69	69	69	69	69	69
	89	85	82	81	81	80	76	72	72	72	72	72	72	72
Mean	91	85.6	82.1	81.8	81.1	80.5	77.8	73.6	73.5	73.5	73.1	73.1	73	73

Appendix 96 contd

Treatments		Days from sowing 1	2	3	4	5	6	7	8	9	10	11	12	13	14
Triple disc coulter		90	80	82	82	82	80	82	80	80	80	68	62	62	62
no pressure		92	82	68	69	69	68	68	68	68	65	65	64	63	61
		93	83	72	71	71	70	70	75	72	70	68	68	65	64
		93	84	73	73	73	72	69	68	65	65	63	62	62	60
		94	85	70	70	70	69	69	64	64	64	62	62	62	62
		92	82	70	70	70	70	67	67	62	62	62	62	61	61
	Mean	92.3	82.6	70.8	70.8	70.8	69.8	69.1	68.6	66.8	66	64.6	63.3	62.5	61.6
Triple disc coulter		91	87	74	73	70	79	78	79	79	79	78	78	77	77
70 kPa pressure over		92	88	84	84	81	78	78	80	79	79	78	78	78	78
seeds		93	85	84	83	82	81	79	75	75	75	74	74	74	74
		94	86	83	82	82	80	80	75	72	73	73	73	73	73
		93	87	83	82	82	80	77	66	66	68	65	65	64	64
		95	88	85	83	83	82	79	72	70	70	69	69	69	68
	Mean	93	86.8	83.8	83.8	82.8	81.6	80	74.5	73.5	74	72.8	72.8	72.5	72.4
Triple disc coulter		92	88	82	80	79	78	75	80	80	79	78	78	78	78
70 kPa pressure over		94	89	83	82	80	76	72	70	70	70	70	70	70	70
grooves after covering		92	88	83	83	82	81	78	75	75	75	74	74	74	74
the seed with loose		93	87	84	84	83	82	80	65	65	66	65	65	65	65
soil		93	87	84	84	83	82	80	65	65	66	65	65	65	65
		93	86	82	81	81	80	78	77	78	77	75	75	75	75
		92	87	84	83	82	81	79	73	74	73	72	72	72	72
	Mean	92.6	87.5	83	82.1	81.1	79.6	77	73	73.6	73.4	72.4	72.4	72.4	72.4

APPENDIX 10

(a) Specification of Experiment 7

Starting date of experiment	21.11.1977
Frequency of sowing	Fortnightly
Total no. of drillings	12 until 24.4.1978
Species	'Karamu' wheat
Seed germination potential	96% (Certified by seed technology centre, Massey University)
Type of experiment	Field studies
Location	Agronomy Department plots, Massey University
Direct drill-coulter assemblies	Duncan drill adjusted with 3 effective rows of three coulter types viz. an experimental chisel coulter, hoe coulter and triple disc coulter along with two guard rows one on each side. All coulters included a pre-disc.
Sowing depth	Nominally 38 mm
Row spacing	150 mm
Drilling speed	5 km/h
Condition of parent vegetation	Ryegrass pasture, sheep grazed before drilling
Soil type	"Tokomaru silt loam"
Environmental conditions	Variable ambient conditions
Herbicides used, their rates of application	Single application 3 days before each drilling in a blanket spray at 5.6 l/ha paraquat + 1.4 l/ha dicamba
Seed covering technique	Each drilling was followed by bar harrow
Seeding rate	Nominally intra-row spacing 20 mm
Plot size	4 m x 2.6 m
Experimental design	Completely randomized blocks
Replicates	4
Fertilizer used	Nil
Insecticide application	Slug pellets were used in all the experiments. Thimat was

	applied in drilling no. 2 to 5 to control unidentified insects and pests. Thimat was found to be ineffective. In latter experiments, a bran based diazinon was applied a week after drilling. Formula for bran based insecticide (Bran = 10kg; Molases = 4 kg; water = 12 litres; Diazinon (80%) = 300 ml.)
Seedling emergence counts	A weekly seedling emergence count was taken after each drilling until 3rd week when emergence was assumed to be complete.
Seedling damage measurement	At the end of week 3 after drilling, a metre length of each coulter row was dug and damaged seedlings counted.

APPENDIX 10(b)

The effect of coulter types, ambient conditions and soil moisture on the seedling emergence

(a) 1st drilling 21.11.77		Triple Disc coulter			Hoe coulter			Chisel coulter		
	Reps	week 1	week 2	week 3	week 1	week 2	week 3	week 1	week 2	week 3
	I	53.1	62	83.6	64.8	62.7	79.8	64.1	82.9	92.2
	II	43.6	64.1	66.9	44.3	59.8	67.4	41.0	60.6	58.5
	III	41.7	68.0	80.1	50.3	45.6	56.8	31.1	44.9	59.3
	IV	29.0	57.4	56.0	32.2	58.1	61.7	34.3	52.7	59.3
	Mean	45.8	62.9	71.6	47.9	56.6	66.6	42.6	60.3	67.3
(b) 2nd Drilling										
5.12.77	I	2.7	43.5	55.6	2.8	51	67.6	1.7	40.3	54.9
	II	1.1	29.3	35.4	5.3	33.6	52.7	3.1	10.9	44.6
	III	7.7	43.9	55.7	4.8	31.8	52.1	1.0	25.8	54.2
	IV	2.4	38.9	50.4	10.7	35.7	49.6	3.6	22.3	41.4
	Mean	3.5	38.9	49.3	5.9	38.0	55.5	2.35	24.8	48.7

OBS. = Snail and slug infestation

(c) 3rd drilling

(19.12.77)

Reps	Triple disc coulter Wk 1	Wk2	Wk3	Hoe coulter Wk 1	Wk2	Wk3	Chisel coulter Wk1	Wk2	Wk3
I	20.8	38.2	51.8	15.2	29.3	45.9	21.9	32.9	53.1
II	22.3	38.6	49.7	21.9	34.3	48.0	18.0	33.6	49.2
III	12,2	19.8	27	23.3	34.3	46.9	15.5	31.8	47.1
IV	25.1	51.8	51.8	17.7	38.6	51.5	13.4	33.3	47.8
Mean	20.1	37.1	45	19.5	34.1	48.1	17.2	32.9	49.3

(d) 4th drilling

(2.1.78)

Reps	Triple disc coulter Wk 1	Wk2	Wk3	Hoe coulter Wk 1	Wk2	Wk3	Chisel coulter Wk1	Wk2	Wk3
I	35.0	53.1	54.7	34.3	42.5	56.8	25.1	35.7	48.3
II	47.4	45.3	52.9	17.6	30.1	41.2	24	25.1	61.4
III	54.9	59.8	65.7	45.3	51.0	66	55	56.7	70.6
IV	46.4	54.5	63.3	7.7	30.1	41.5	53.1	62.3	76.3
Mean	45.9	53.2	59.1	26.2	38.4	51.3	39.3	44.9	64.1

(e) 5th drilling

(16.1.78)

All coulter types

Wk 1. No germination field soil moisture below wilting point 8 mm rain on 20.1.78

Wk2. Seed germinated but did not emerge.

Wk 3. Seed fate on Wk 3 show 100% germination

Germinted but unemerged seeds %

	Viable	dead
Chisel coulter	100	-
Hoe coulter	60.6	39.4
Triple disc coulter	42.4	57.6

OBS: Thimat application - not effective cricket and snail attack.

	Triple disc coulter			Hoe coulter			Chisel coulter		
	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
(f) 6th drilling 30.1.78	No seed germination	No germination	100% germination no emergence	No germination	No germination	100% germination but no emergence	No germination	No germination	100% germination but no seedling emergence

OBS: Some cut worms found in hoe coulter grooves. apparently this type of groove have more loose soil and dead sod and hence hiding place for cut worms at day time. Application of bran based diazinon - effective.

	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
(g) 7th drilling 13.2.78	100% seed germination	No seedling emergence	No seedling emerge	100% seed germination	No seedling emergence	No seedling emergence	100% seed germination	No seedling emergence	No seedling emergence

Drilling	Reps	Triple disc coulter Week 1	Triple disc coulter Week 2	Triple disc coulter Week 3	Hoe coulter Week 1	Hoe coulter Week 2	Hoe coulter Week 3	Chisel coulter Week 1	Chisel coulter Week 2	Chisel coulter Week 3
(h) 8th drilling 27.2.78		No seed germination	"	"	No seed germination	"	"	No seed germination	"	"
			"	"		"	"		"	"
(i) 9th drilling 13.3.78	I	No germ-	Seeds	12.7	No	Seeds	12.7	No seed	Seeds	19.9
	II	ination	germinated	16.6	germin-	germin-	25.8	germin-	germin-	44.6
	III		but no	22.3	ation	ated but	23.3	ation	ated	43.2
	IV		emergence	30.5		no emer-	22.6		but no	30.8
	Mean			20.5		gence	21.1		emerg-	34.6
									ence	
(j) 10th drilling 28.3.78	I	Some germination, no emergence	30.8	36.8	Some germination No seedling emergence	45.7	59.1	Some germination but no seedling emergence	19	44.2
	II		16.6	30.5		41.4	63.0		33.6	53.5
	III		57.7	65.9		43.3	65.5		59.8	74.7
	IV		18.0	28.3		26.5	41.4		18.7	43.9
	Mean		30.8	40.3		39.2	57.3		32.8	54.1

OBS (9th drilling): No insect damage. Application of bran based diazinon

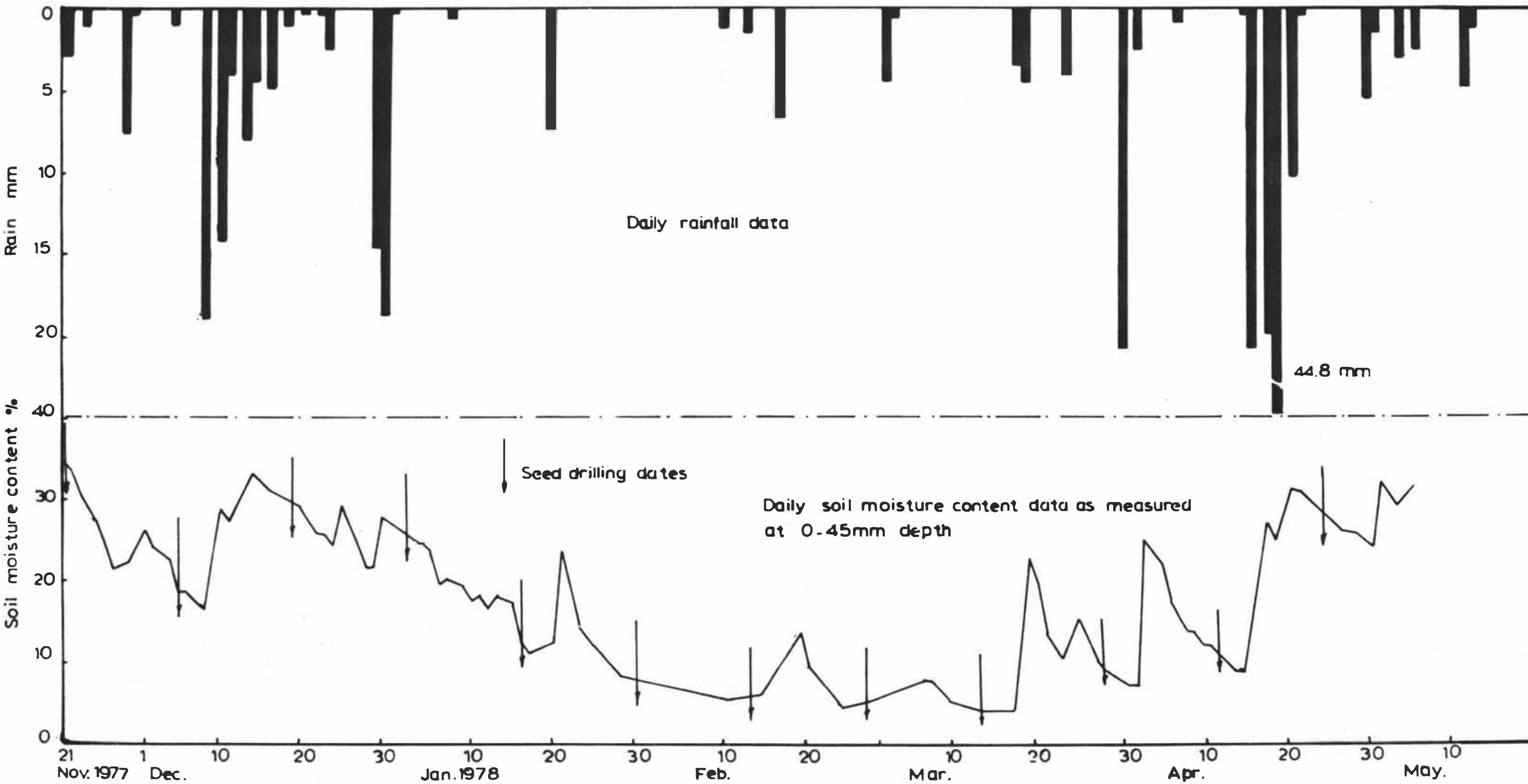
(k) 11th drilling (10.4.78)	Reps	Triple Disc coulter			Hoe coulter			Chisel coulter		
		Week 1	Week 2	Week 3	Week 1	Week 2	Week 3	Week 1	Week 2	Week 3
	I	Seed germ-	33.2	51	Seed	27.2	44.9	Seed	25.5	51.3
	II	ination	56.3	67.6	germin-	27.9	55.2	germin-	36.8	56.7
	III	but no	50.6	55.3	ation but	21.6	55.3	ation but	31.5	64.5
	IV	emerg-	54.5	59.5	no emerg-	42.5	51.7	no emerg-	43.5	66.9
		ence			ence			ence		
	Mean		48.7	58.3		29.8	51.8		34.3	59.8
(1) 12th drilling (24.4.78)	I	29	69.8	69.8	33.6	73.3	73.3	32.9	74.8	74.8
	II	38.2	76.9	76.9	26.5	77.6	77.6	26.5	77.9	77.9
	III	38.3	70.5	70.5	45.7	85.1	85.1	32.9	85.7	85.7
	IV	43.9	64.8	64.8	51.4	87.8	87.8	29.7	82.6	82.6
	Mean	37.3	70.5	70.5	39.3	80.9	80.9	30.5	80.3	80.3

OBS:

Application of bran based diazinon, no insect damage.

Appendix (10c)

Daily soil moisture data, seed drilling dates and daily rainfall data



APPENDIX 10d

Weekly soil moisture and ambient measurements

Weeks Nov. 21, 1977	Av. temperature(^{o}C)	Relative humidity (%)	Rain fall mm	Soil moisture content % (0-45 mm depth)
1	14.3	72	4.1	28.7
2	15.3	79	9.2	23.6
3	15.9	80	37.1	22.1
4	14.3	74	19.7	32.2
5	14.4	72	3.1	27.2
6	14.2	66	33.7	23.5
7	14.8	74	0.5	21.8
8	17.1	72	0	17.7
9	17.2	82	7.3	14.7
10	20.0	78	0	11.5
11	19.8	75	0	7.3
12	19.2	76	2.4	5.5
13	19.7	74	6.6	9.7
14	19.2	74	0	7.1
15	20.1	80	4.7	5.2
16	17.3	67	0	6.6
17	18.1	69	7.7	10.2
18	15.2	69	3.9	14.5
19	17.4	69	23.1	11.7
20	-	81	0.7	15.4
21	-	76	21.5	9.7

22	15.6	88	77.8	28.1
23	15.9	79	6.6	25.2
24	11.1	85	5.3	30.2
25	11.5	86	5.6	-
26	-	-	-	-

May 10, 1978

APPENDIX 10e

	1978	Individual monthly rain (mm) fall 1968-77 68	69	70	71	72	73	74	75	76	77	Mean 68-77	Level of significance
November	81.7	49	36	53	58.3	29.6	59.4	53.1	54.2	69.2	76.7	53.8	**
December	100.6	145	92	74	54.4	39.8	26.6	77.9	101.7	82.3	94.0	78.7	*
January	7.9	59	81	27	131.6	60.1	51.3	30.7	37.7	90.2	65.9	63.4	**
February	9.0	50	70	6	89.9	46.8	15.0	55.5	29.6	60.4	43.8	46.7	**
March	16.3	-	27	89	37.3	135.1	100.4	20.6	53.2	85.4	45.9	65.9	**
April	128.5	121	63	25	23.4	70.2	57.4	111.0	71.4	51.6	88.5	68.2	**
May	42.3	136	107	103	138.7	110.9	117.2	120.8	129.5	104.4	113.3	118.0	**
Mean	55.19											70.67	**
s.e.	18.38											8.79	

Monthly average rainfall (Nov-May 1968-77) is significantly higher at (P = 0.01) compared with (Nov - May 1978) period.

APPENDIX 11

(a) Specification of experiment 8

Experiment date	2.5.1978
Species	"Karamu" wheat
Seed germination potential	96% (Massey University, Seed Tech. Centre)
Type of experiment	Field studies
Location	Research & Development Unit, Massey University
Direct drill-coulter assemblies used	Duncan drill adjusted with 3 effective rows of three coulter types viz. an experimental chisel coulter, hoe coulter, and triple disc coulter along with two guard rows one on each side. All coulters included a pre-disc.
Sowing depth	Nominally 38 mm
Row spacing	150 mm
Drilling speed	5 km/h
Condition of parent vegetation	Ryegrass pasture, sheep grazed before drilling
Soil type	"Tokomaru silt loam"
Environmental conditions	Variable ambient conditions
Herbicides used, their rate of application	Single application 3 days before each drilling in a blanket spray at 5.6 l/ha paraquat + 2 l/ha dicamba
Seed covering technique	Bar harrow
Seeding rate	Nominally intra-row spacing 20 mm
Plot size	4 m x 4 m
Experimental design	Split-plot randomized blocks with 4 replicates
Insecticide application	Bran based diazinon
Seedling emergence counts	A weekly seedling emergence count until day 21 after drilling.
Herbage dry matter yield measurement	On day 70 after drilling

APPENDIX 11(b)

Seedling Emergence % (day 21)

Herbicide Treatments	Reps	Triple disc coulter	Hoe coulter	Chisel coulter
1. Paraquat	1	74.4	77.3	70.2
sprayed 4 days	2	66.6	71.6	86.5
before	3	71.6	76.6	74.4
drilling	4	88.0	70.9	74.4
	Mean	75.1	74.1	76.3
2. Paraquat +	1	53.2	68.1	67.3
dicamba sprayed	2	41.8	49.6	58.8
4 days before	3	60.3	75.1	63.8
drilling	4	69.5	88.0	71.6
	Mean	56.2	70.2	65.3
3. Paraquat	1	64.5	76.6	65.9
sprayed 4 hours	2	78.7	75.1	80.8
before drilling	3	81.5	80.1	79.4
	4	70.2	63.1	76.6
	Mean	73.7	73.7	75.6
4. Paraquat +	1	49.6	55.3	87.2
dicamba 4 hours	2	80.1	82.2	76.2
before drill-	3	65.2	88.	73.7
ing	4	56.7	62.4	74.4
	Mean	62.9	71.9	77.9
5. No spray	1	65.9	66.6	72.3
grass grazed	2	65.2	68.1	73.0
to ≃50 mm	3	55.3	60.3	71.6
height	4	60.3	56.7	63.1
	Mean	61.6	62.9	70

APPENDIX 11c

Analysis of Variance Table

Treatments	DF	F	P
Herbicide spray type and time of application	4	3.81	0.009 **
Coulter types	2	3.02	0.059 *
Herbicides x coulter types	8	0.74	0.650
Replicates	3	0.51	0.674
Error	42		
Total	59		